PRÁCE A ŠTÚDIE

STUDIES

KATEDRA LETECKEJ DOPRAVY

AIR TRANSPORT DEPARTMENT

FAKULTA PREVÁDZKY A EKONOMIKY DOPRAVY A SPOJOV

FACULTY OF OPERATION AND ECONOMICS OF TRANSPORT AND COMMUNICATIONS

ŽILINSKÁ UNIVERZITA V ŽILINE

UNIVERSITY OF ŽILINA

VYDANIE 12

VOLUME 12

Žilina, 2022

TLAČ / PRINTED BY

EDIS – vydavateľstvo Žilinskej univerzity / EDIS – University of Žilina publisher

TECHNICKÝ REDAKTOR / TEXT DESIGNER

Ing. Matúš Materna, PhD.

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vedúci Katedry leteckej dopravy

PRÁCE A ŠTÚDIE sú publikované v nadväznosti na projekt ***KEGA 040ŽU-4/2022*** *Transfer progresívnych metód vzdelávania do študijného programu "Technológia údržby lietadiel" a "Letecká doprava".*

OBSAH

https://doi.org/10.26552/ pas.Z.2022.2.01

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DANGER OF ICING WHEN OPERATING UNMANNED AERIAL VEHICLES

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Abstract

The paper examines icing on Unmanned Aerial Vehicles (UAV) during the flight. We chose the Mavic Pro and Mavic 2 Pro UAV by company DJI to carry out the research. Research flights are performed during the early morning hours with meteorological conditions suitable for icing. We use the AirData application to analyse flight data. The aim of the work is to find out how dangerous icing is, what meteorological conditions are suitable for icing, how fast icing is formed during the operation of an unmanned aircraft and how it is possible to suppress or eliminate icing.
In introduction of this work elaborated theoretical knowledge about the formation of icing and its types. Subsequently, the negative effects of icing on the flight are described, such as changes in lift, drag, controllability of the aircraft and others. The following section describes the accidents of UAV due to the impact of icing. After analysing the data from the mentioned application, we proposed recommendations for pilots of UAV. Before the flight, we recommend checking the meteorological forecast, focusing on the temperature and humidity at the flight area, usually up to 120 meters above the Earth surface. In-flight recommendations include monitoring rotation speed of propellers and frequent inspection of propellers in meteorological conditions suitable for icing and others.

Keywords

Icing, Lift, Drag, UAV

1. INTRODUCTION

Icing is a significant danger to air transport. It is known from the aviation incidents which happen in the last century that the de-icing and anti-icing systems were not sufficiently researched and developed at that time. This meteorological phenomenon has not been given due importance and attention. Icing on an aircraft can reduce flight performance to a minimum when the aircraft is no longer capable of flight. A very similar phenomenon can occur on unmanned aerial vehicles.

Unmanned aerial vehicles are becoming a more popular tool to use thanks to the built-in camera. Often many laic drone pilots do not look out to icing conditions and in the winter months they like to shoot the snowy landscape or exemplary cold mornings.

In this diploma thesis we focus on this meteorological phenomenon, which is quite common in commercial air transport. In the first chapter, we discuss in detail icing, icing conditions, types of icing, describe how icing is predicted and how it is separated according to intensity. In the second chapter we will describe how much icing affects the aircraft during the flight, it means how negative icing affects the lift, aircraft drag, stability of the aircraft and others. Subsequently, we will describe documented examples of air incidents at the UAV due to icing.

In the practical part of this thesis, we describe the technical parameters of the selected DJI technology - Mavic Pro and Mavic 2 Pro. Next, we will closely describe the methodology of work, it means how we will conduct research flights and analyze the necessary data about these flights from the AirData application. In the end, we will present the results of work from research flights and our recommendations, especially to laic UAV pilots, to know in the future how to prevent icing on the drone and its possible damage.

2. ICING

In general, water on the earth's surface begins to freeze at 0°C, but in the atmosphere the air density is lower, and temperatures are significantly lower, so the freezing point in the atmosphere is not precisely defined and we can find the term "subcooled" water in expert documents. The proportion of this subcooled water decreases together with the static pressure temperature to approximately -40°C and changes to a solid state, in a Cumulonimbus cloud the subcooled water temperatures may be even lower.

2.1. Conditions of icing

Icing usually forms in the frontal area. Atmospheric fronts form when two different air masses collide and cause a weather change in the given area. Many fronts are caused weather events such as rain, storms, gusts of wind or tornadoes. During the cold front, massive and dramatic storms can occur, during the warm front, low stratified clouds such as Stratus, Altostratus, Nimbostratus and similarly. The sky usually clears up after the frontal activity. [1]

2.2. Frost formation

The size of the subcooled water droplets and the nature of the air flow around the surface of the aircraft determine the extent to which these subcooled droplets fall on its surface. Large droplets often break up into smaller ones, which freeze faster. Undivided large subcooled droplets freeze more slowly due to the greater release of latent heat and can form a surface layer of liquid water before the change of state occurs. Factors influencing icing include: [2]

- droplet size

- concentration of drops
- shape of aircraft surfaces
- aircraft speed
- ambient temperature
- aircraft surface temperature (must be below 0°C for icing)

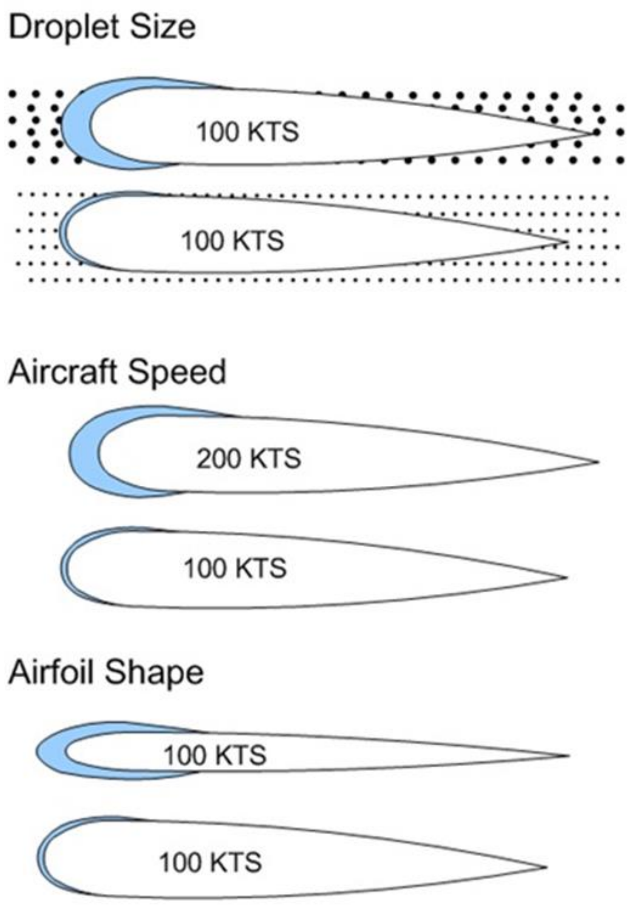

Figure 1: Ice formation analysis [3]

2.3. Types of icing

Frost on the aircraft in the atmosphere can be formed in two ways: directly from water vapor – desublimation, or freezing of liquid water droplets. In aeronautical meteorology, we recognize icing according to the conditions of origin, structure and according to the surface and distribution on the aircraft. The type of icing is mainly affected by the air temperature and the size of the subcooled water droplets in the air. According to the structure, we distinguish the following types of icing: [4]

1. Rime ice
2. Glaze ice
3. Hoarfrost

2.4. Frost forecast

The amount of icing on the aircraft depends on the air temperature, the amount of liquid water, the size of the droplets and the vertical movement of the air mass. In order to predict these parameters, it is necessary to evaluate the current and probable vertical profile of the atmosphere, the rain of radar images, satellite images and knowledge of the various clouds and their characteristics. [5]

3. NEGATIVE EFFECT OF ICING ON FLIGHT

Icing in aviation has a major impact on the aerodynamic configuration of the aircraft, affects airflow and gets worse the aerodynamic characteristics of the aircraft, which causes deterioration in controllability and stability.

Icing on the surface of the aircraft changes its aerodynamic properties, reduces lift and increases drag for a given angle of attack. Icing on the propeller blade reduces the thrust and efficiency of the propeller. The total icing contributes to a significant increase in the weight of the entire aircraft, which needs increased lift. Therefore, for a given flight speed, it is necessary to increase the angle of approach to achieve the required lift and the critical angle of approach can be reached at a higher speed. This means that icing on the plane increases the fall's speed. [6]

4. OPTIONS FOR ELIMINATION AND PREDICTION OF ICING

The subject of research is the effect of icing on unmanned aerial vehicles and how icing affects the efficiency of UAV propellers. First, we characterize the selected technologies that are used for the implementation of research, then we describe the research methodology, it means how we proceeded during the research flights and subsequently in the results of the work we will determine our recommendations for the elimination and prediction of icing on the UAV.

4.1. Technology used

In the practical part of this thesis, we use DJI technology - Mavic Pro and Mavic 2 Pro, due to their good flight characteristics and compactness. We analyze the flight data using the AirData application.

Mavic Pro is one of the smallest drones manufactured by DJI since 2017. Its dimensions are 83mm x 83mm x 198mm and the weight with the gimbal case is 743g. The weight shows that the DJI Mavic Pro belongs to category C1. The Mavic Pro is easily portable, as the entire drone can be easily folded. It is equipped with a fully stabilized camera thanks to the integrated gimbal on the bottom of the drone. Safe flying is ensured by an intelligent flying mode and an obstacle avoidance system. [7]

The Mavic 2 Pro drone is a newer and larger model from DJI. The dimensions of the drone are 214mm x 91mm x 84mm and the weight is 907g, which means that it belongs to category C2. The Mavic 2 Pro is also easily portable, as the entire drone can also be folded. It is equipped with a fully stabilized camera thanks to the integrated gimbal on the bottom of the drone. Safe flying is ensured by DJI technology - intelligent flying mode and obstacle avoidance system. [8]

4.2. Work methodology

The research part of the work was carried out in the morning hours in the winter month - February, when the air temperatures were below 0°C and the humidity was higher than 80%. The measurements took place over three days at an elevated place near the campus of the University of Zilina in Zilina.

The first recorded research flight took place using the above-mentioned DJI Mavic Pro technology. It was only a brief verification of icing and its impact on the flight characteristics of the UAV. Icing was formed using a sprayed aerosol on UAV propellers.

The second test day took place with using DJI Mavic Pro technology, similar as previous test day. During the test period, we performed several flights, during which we kept adding an aerosol to the drone propellers, which froze due to low temperatures (higher drag, lower lift of the propellers). We gradually increased the state of icing on individual flights. Subsequently, we discontinued research flights due to improving meteorological conditions (increasing air temperature). We named the four most significant flights, which rightly illustrate the evolution of icing.

The third test day took place in the early morning hours with DJI Mavic 2 Pro technology. We performed ten research flights, closely monitoring how flight characteristics changed during the flight. During these flights, icing formed naturally, without the application of an aerosol, due to moderate ground clouds. We listed the three most significant flights, during which we noticed significant icing and deteriorating aerodynamic characteristics. Due to the very intensive formation of icing, we thoroughly removed icing from the previous flight from the propellers before each flight.

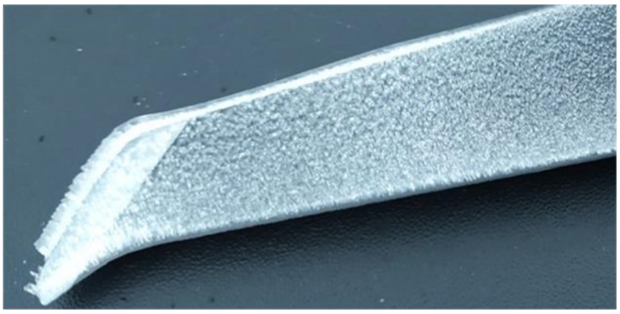

Figure 2: Icing on the propeller during [Source: Author]

4.3. Work results

We deduce from the research flights that icing is formed mainly at temperatures below freezing, it means 0°C and at elevated humidity of 80% and more. Icing does not require low clouds or fog, but its occurrence at the flight area helps to create icing faster. The graphs on the change in current consumption during the flights show that the icing generated increased the drag of the UAV propellers and decreased the lift. Therefore, to maintain sufficient propeller power, the drone needed to draw more electricity from the battery. As a result, the battery overheated and discharged faster during the research flights. It can be seen in the figures describing the changes in battery temperature. During the second day, when Mavic Pro did not manage the icing on its propellers, the UAV fell from a minimum height due to insufficient lift and increased drag. Last day measurements showed that if the pilot is informed of the consequences of flying in icing conditions, maneuvering the UAV carefully and slowly, the icing may not have the catastrophic consequences as the previous day. We also noticed very fast natural icing and significantly warmed UAV engines during the last day. During the first flight on this day, the UAV started automatic landing after only 3 minutes and 28 seconds to prevent a fall, which means that icing formed extremely quickly. During the research flights, we also monitored the speed of propellers rotations. The speed of propellers rotations on the Mavic Pro drone (used on the first and second test days) without icing was 5270 per second, with icing the speed increased by almost 22%. Mavic 2 Pro (used on the third test day) without icing had 5010 rotations per second, with icing the speed increased by almost 8%.

4.3.1. <u>Recommendations For Pilots:</u>

Pre-flight preparation is an important part of every flight. Thanks to it, the pilot knows what to expect during the flight and can prepare for certain situations. We recommend UAV pilots to check the meteorological forecast at the place of flight before the flight. It is necessary to focus mainly on the air temperature and relative humidity, or the height of the cloud base.

It is also necessary to have several fully charged batteries in good condition. They should be charged the earliest day before flight to ensure that they do not discharge over time. We recommend warming the batteries to 20°C or more before the flight, because at temperature below 15°C there may to increase resistance inside the battery, which results in a reduction in battery capacity and a voltage drop during discharge, it means during flight.

The UAV itself and its accessories should be stored in a dry place with an air temperature of approximately 20°C to 25°C away from direct sunlight. Before the flight, we recommend removing any dirt, water drops, moisture or snow from the UAV so that it does not increase the drag and weight of the entire UAV during the flight and to prevent icing.

For the first minute after take-off, we recommend that pilots let the UAV to hover so that the battery warms up to operating temperature, while monitoring the speed of propellers rotations. If the speed increases rapidly, we recommend landing and checking the propellers, there is most likely icing on them. We do not recommend long flights at maximum speeds and sudden ascents and descents. We recommend not to let the battery completely discharge, the battery should be in condition to allow the UAV to return home called Home Point or change the battery after each flight.

During the flight in icing conditions (temperature below 0°C and humidity above 80%), we recommend constantly monitoring the meteorological situation, due to possible deteriorating weather changes - in a mountain environment, the weather tends to change faster. The pilot should avoid places with strong winds, rain, storms, snow, fog and significant clouds. Snow may not have fatal consequences for UAVs in the first moments, but it can obscure the UAV's sensors, which guide the UAVs and therefore, together with the icing created, would most likely make an automatic landing at best, at worst, the UAV would fall.

We do not recommend adding additional components (cameras and others) to the UAVs due to their excess weight, which could cause UAV overload, insufficient performance and shortened flight time.

According to Slovak regulations, the UAV should not fly higher than 120 meters above the earth's surface. In cold weather, we recommend lower altitudes, because the UAV must break through a smaller vertical distance and the battery will keep longer. In cold weather, we also recommend having a fully charged phone or tablet with which the pilot controls the UAV or have an external charger.

After the flight, we recommend checking the UAV for accidental damage or wear to some parts. It is also necessary to remove water from the surface of the UAV, as possible moisture can damage the electronic parts of the UAV.

To protect the propellers, we recommend using liquids like those used in transport aircraft, such as ethylene glycol or propylene glycol, which prevent the deposition of snow, water, dirt and others. The pilot should spray similar liquid from a safe distance on the propellers, shoulders and body of the UAV, wait a few minutes and start the first test flight. We recommend further research in anti-icing fluids for UAVs, in search of suitable effective and available medium that would prevent the deposition of water droplets throughout the UAV.

5. CONCLUSION

The work deals with the effect of icing on drones during the flight. The purpose of the work was to find out how dangerous icing is, in what meteorological conditions and how fast icing is formed, how it can be suppressed or completely eliminated. In the first part, we analyzed the basic theory of icing, it means in which clouds we can expect icing, what are the factors influencing formation of icing, how intense icing can be, what are the three basic types of icing and how we can predict icing. We also described the negative impact of icing on the aerodynamic characteristics of the aircraft, such as a reduction in lift, a significant increase in drag regarding the angle of attack, deterioration of controllability and stability, and an overall decrease in aerodynamic performance. Subsequently, we looked at examples of documented drone incidents caused by icing. The practical part presents the used drones from the company DJI - Mavic Pro and Mavic 2 Pro. Subsequently, the methodology of research flights is described, during which we looked at how fast and in what meteorological conditions icing will form. The methodology of the work contains data from flights, which we obtained using the AirData application, which recorded this data in real time. This application also offers a record of approximate meteorological conditions during the flight time, which we have included in the methodology of work.

Analysis of data from the mentioned application AirData showed that during the research flights the meteorological conditions at the flight aera were suitable for icing, it means low air temperature, high relative humidity and low clouds, which was confirmed by a record from the meteorological station in Zilina, available on the internet SHMU website. The analysis also confirmed icing on the UAV by changing the current consumption during the research flights, it means if there was no icing on the UAV, the current consumption was in reasonable values (in green). With more icing, the current consumption sometimes increased up to three times the normal values (in the pictures, the change in current consumption is shown by the change in colors from orange through red to purple). During the flights, the battery temperature also changed depending on the difficulty of maneuvering and the amount of icing on the arms and propellers of the UAV. The more frost, the more the battery warmed up, the speed of propellers rotations increased, and the engines overheated. During a long and demanding flight in icing conditions, we expect that UAV engines could be permanently damaged by icing. We also observed that icing affects battery life and flight efficiency, as data analysis showed that the combination of icing and maneuvering with UAVs (even a small number of gentle maneuvers) reduces battery capacity, it means time that can still be used for full-fledged flying with UAV.

From dataS of research flights, we evaluate that icing is formed fast enough to mean a significant hazard to drones. Icing began to form after take-off, usually after about three minutes it was obvious from the speed of propellers rotations on the controller that the icing formed to such range that the UAV had difficulty maintaining the specified altitude and the system itself recommended to us that the UAVs should land carefully and check propellers, because system cannot detect icing on the drone. In one case, the UAV did not even manage to land automatically and lost the required power from a minimum height and subsequently fell.

From the results of the work, we have compiled recommendations that can be very beneficial for beginners and professional UAV pilots. The work also serves to support the teaching of subjects included in the study plan at the Department of Air Transport of the University of Zilina in Zilina, Operation of Unmanned Aerial Vehicles and Flight Training of Unmanned Aircraft.

ACKWNOLEDGEMENT

This work was supported under the project of Operational Programme Integrated Infrastructure: "Research and development of contactless methods for obtaining geospatial data for forest monitoring to improve forest management and enhance forest protection", ITMS code 313011V465. The project is co-funding by European Regional Development Fund.

REFERENCES

[1] UCAR: Weather fronts. [online]. Available on the Internet: https://scied.ucar.edu/learning-zone/how-weather-works/weather-fronts [cited 2022-02-28]

[2] Skybrary: In-Flight Icing. [online]. Available on the Internet: https://www.skybrary.aero/index.php/In-Flight_Icing [cited 2021-12-22]

[3] Langley flying school: Meteorology (Part II). [online]. Available on the Internet: http://www.langleyflyingschool.com/Pages/CPGS%20Meteorology,%20Part%202.html [cited2021-12-22]

[4] National Weather Service: Icing Hazards. [online]. Available on the Internet: https://www.weather.gov/source/zhu/ZHU_Training_Page/icing_stuff/icing/icing.htm [cited 2021-12-22]

[5] World Meteorological Organization. 2007. AVIATION HAZARDS: Education and training programe ETR-20. WMO/TD-No. 1390. Geneva: Secretariat of the World Meteorological Organization, 2007. 59 s. [online] Available on the Internet: https://library.wmo.int/doc_num.php?explnum_id=9359 [cited 2022-03-13]

[6] European General Aviation Safety Team. In flight icing. In Safety promotion leaflet. 2015. [online] Available on the Internet: https://www.easa.europa.eu/sites/default/files/dfu/198961_EASA_EGAST_GA10.pdf [cited 2021-12-30]

[7] DJI Support. 2017. Mavic PRO User Manual. [online]. Available on the Internet: https://dl.djicdn.com/downloads/mavic/Mavic%20Pro%20User%20Manual%20V2.0-.pdf [cited 2022-02-04]

[8] DJI Support. 2020. Mavic 2 PRO/ZOOM User Manual. [online]. Available on the Internet https://dl.djicdn.com/downloads/Mavic_2/Mavic_2_Pro_Zoom_User_Manual_v2.2_en.pdf [cited 2022-02-07]

[9] BUGAJ, M. 2020. Aeromechanics 1: fundamentals of aerodynamics. 1st ed. - Žilina : University of Žilina, 2020. 193 s. ISBN 978-80-554-1675-5.

[10] PECHO, P., HRUZ, M., SKVAREKOVA, I., AZALTOVIC, V. 2020. Optimization of Persons Localization Using a Thermal Imaging Scanner Attached to UAV. NTinAD 2020 - New Trends in Aviation Development 2020 - 15th International Scientific Conference, Proceedings, 2020, pp. 192–196, 9379095. ISBN 978-172817325-2.

[11] Ažaltovic, V., Škvareková, I., Pecho, P., Kandera, B. 2020. The correctness and reaction time of piloting the unmanned aerial vehicle. Transportation Research Procedia, 2020, 51, pp. 342–348. ISNN 23521457.

[12] Hrúz, M., Bugaj, M., Novák, A., Kandera, B., Badánik, B. 2021. The use of UAV with infrared camera and RFID for airframe condition monitoring. Applied Sciences 11 (9), 3737

https://doi.org/10.26552/ pas.Z.2022.2.02

USE OF TRANSPARENT DISPLAYS IN AVIATION

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Abstract

The introductory part deals with the design and technologies used in HUD systems and their history of introduction into the aviation industry. Furthermore, the work deals with the implementation of transparent displays in civil transport aircraft and the benefits of their use with respect to the human factor of the crew in low visibility operations. After the part devoted to airliners, there is a chapter describing the possibilities and technical solutions for the installation and use of HUD technology in general aviation aircraft. The final points then point out the advantages and disadvantages of installing this technology in aircraft.

Keywords

Transparent display, display symbols, combinator, human performance, efficiency and safety of flight with HUD

1. INTRODUCTION

This article deals with the use of instrumentation of modern aircraft called Head-up Display. These displays are intended to assist pilots in all phases of flight, from taxiing to landing. The main use occurs when the LVO conditions are announced at the airport. The main task of the Head-up display is to increase situational awareness during critical phases of flight or taxiing on taxiways. Not only the Head-up Display itself helps the pilots, but this display can be equipped with additional systems such as EFVS, SVS or CVS. My motivation for writing this diploma thesis was that this device is not commonly known, it is not taught in schools and also because in the future this device will be widely used by all air operators.

2. HISTORY

The history of Head-up Displays begins with the French test pilot Gilbert Klopfstein. This test pilot invented the first Head-up display, which he introduced in the Nord aircraft. He paid for the production of this equipment from his own finances. At the exhibition, he demonstrated to other test pilots all the possibilities of his device. This device had only a limited number of functions such as an angle of attack indicator, artificial horizontal and speed and altitude indicators. Thanks to this advanced technology, he was able to approach and land on any runway without the use of navigation aids such as PAR or ILS. However, this system was not successful at that time. A few years later, however, Klopfstein was asked to install his display on a Mirage aircraft. During the test flights, he was monitored by ground personnel, who found that the flight trajectory was much more accurate than on the same aircraft without Head-up display technology.

Klopfstein was introducing HUD technology in the USA. There, the Head-up Display found great success. The US Air Force installed this technology in the A-7 aircraft, where it helped pilots with controling the aircraft, but also with the use of weapon systems.

3. HEAD-UP DISPLAY DESIGN

The head-up display is actually any transparent display on which information can be projected. Nowadays, we no longer have to meet them only in airplanes, but they are also installed in cars or even tractors. However, in my diploma thesis I deal only with aviation HUDs.

We recognize the basic types of HUD. The first, the most used, is the HUD, which is permanently installed to the airframe. The display is completely linked to the direction of the aircraft and also the position of the pilot. [1]

The second group of view displays are the so-called HMD or Helmet Mounted Displays, which are installed on the pilot's helmet, and therefore rotate with his head / view and are not firmly attached to the aircraft airframe. Most modern combat aircraft and helicopters use both applications, the classic HUD and HMD. We are talking about aircraft such as F / A-18, F-22, Eurofighter, SU-35, MiG-29 and others. The exception is the latest F-35 Lightning II aircraft, which uses only HMD technology. [1]

A typical HUD consists of three components: a projector, a combiner, and a computer that generates video information. For further simplification, we will refer to the visualization parts of the HUD, ie the projector and the combiner, by one name – the pilot display unit (PDU). All transparent displays require an image source, a generally high brightness cathode ray tube, and an optical system for projecting the information contained in the image at an optical infinity. The pilot views the image after reflection from a semi-transparent element called a HUD combiner. The combiner is located between the pilot's eyes and the aircraft's windshield and is tilted to reflect the light from the image source to the pilot for viewing. The special surface treatment of the combiner simultaneously displays the HUD system information and allows a view of the real environment through the collimator glass so that the pilot perceives both information at the same time.

4. OPTICAL CONFIGURATIONS OF THE HUD SYSTEM

The optical system in the HUD system is designed to collimate the image generated by the HUD computer, ie basic flight parameters, navigation information and command data, while maintaining the background image of the outside world. We distinguish four basic field of view (FOV) characteristics, which will help us describe the nature of the angular range in which the HUD image is still visible to the pilot. [2]

Total field of view (TFOV) - the maximum perimeter in which the symbols from the image source are seen through both eyes of the pilot, which allows vertical and horizontal movement of the head inside the eye box of the HUD. [2]

Instantaneous Field of View (IFOV) - contains what both the left and right eyes see fixed in position inside the HUD's eye box. [2]

Binocular overlapping field of view - is formed by the intersection of two instantaneous fields of view with the standard "eyebox" setting. It defines the maximum range from which the HUD is visible to both eyes at the same time.

Monocular field of view - a perimeter reached by one eye when viewed through the optics of the HUD. Its size and shape vary depending on the position of the eye inside the eyebox.

The field of view characteristics are designed and optimized for the specific geometric configuration of the cockpit based on the intended HUD function. In some cases, the cockpit geometry can affect the maximum achievable field of view.

A significant advance in the design of the optical parts of the HUD is the transition from refractive collimation optical systems to reflection or, in some cases, diffraction collimating systems. The move to more complex (and more expensive) reflex collimation systems led to the implementation of larger display units, which could thus become the primary flight display, thanks to the much lower workload of the pilot in terms of human performance.

5. LIMIT RANGE OF THE PILOT'S HEAD

The limit range of the pilot's head for a given view or "eyebox" is a three-dimensional space surrounding the DEP, from which the HUD display is visible to at least one eye. The location of the eye reference point (DEP) depends on a number of ergonomic parameters of the cockpit, such as visibility of displays in head down mode, angle between the extended axis of the aircraft with a line intersecting the pilot's eyes and nose, steering column or chassis controls. [2]

The HUD's eyebox should be as large as possible to allow maximum head movement without losing the information displayed. The output aperture of the transfer lenses, the distances between the transfer lenses and the combiner, or the distances between the combiner and the DEP or the focal length of the combiner - all these parameters affect the size of the eyebox. The eyebox of modern transparent displays is most often characterized by the following dimensions: 13.2 cm laterally, 7.6 cm vertically and 15.2 cm longitudinally. [2]

In all HUDs, the monocular instantaneous field of view decreases as the head moves, especially at the eyebox boundaries. By defining a minimum monocular field of view at the eyebox boundary, it ensures that even when the pilot's head is moved from the ideal center position, the usable field of view for at least one eye will be maintained. In general, the eyebox limit values for the monocular field of view reach 10 degrees horizontally and vertically. [2]

6. SYMBOLOGY OF HUD

The symbols that are displayed on the HUD must be known and understood by each trained pilot using this technology. Only a limited amount of information was displayed on the first displays, such as the A-7, and pilots were confused if they had to switch between the Head-up display and the Head-down display, as the information displayed was interpreted by different symbols on each. Nowadays, designers strive to display the same symbols on both the HUD and the HDD. Today, HUDs also have many more functions than in the past. Examples are the various modes for taxiing, take-off, surface flight and landing, or the display of a symbol that protects the aircraft from possible tail strike during take-off.

7. HUD SYSTEM IN CIVIL AIRCRAFT

The main purpose of the HUD concept in civil aviation is to offer airlines a cost-effective solution for achieving a high percentage of take-offs, approaches and landings in bad weather conditions. The implementation of transparent displays significantly increases the pilot's situational awareness when reducing or completely missing real visual stimuli. Another advantage is the easier selection of unusual positions, increased accuracy in manual flight and the actual "involvement" of the pilot in the control of the aircraft, ie the elimination of the unfortunate phenomenon, which is a pilot focusing exclusively on monitoring systems. The ability to extend the access of airlines to less well-equipped airports even in bad weather conditions is another factor that motivates the installation of the HUD system.

Alaska Airlines pioneered the commercial concept of HUD. With its 24 Boeing 727-200s equipped with transparent displays, in 1986 it became the first commercial user of this technology in the world. By 1995, it had made 225 landings and 35 takeoffs that could not have taken place without the HUD. During this period, 138 captains qualified for the CAT III approach. Only one of all CAT III approaches was interrupted due to insufficient visual reference at decision height, which means a success rate of 99.6 percent. [3], [4]

Southwest Airlines also has experience with HUD systems. This company also tried to follow its flight schedule very precisely and had two options to achieve this. The first option was to activate the Autoland automatic landing system, which involved high costs for the aircraft manufacturer, but also for the maintenance and monitoring of these systems. The second option seemed to be the installation of a pioneering view display system, which represented a much lower cost. Subsequently, the management of Southwest decided to install the HUD system in the entire fleet of 236 Boeing 737-300, -500 and also -700. [3], [4]

Because HUD has fewer items to certify and retest compared to Autoland, it provides a cost-effective low visibility approach solution.

8. ADDITIONAL SYSTEMS OF HUD

8.1. EFVS - Improved Flight Vision System

EFVS is an electronic means of displaying the external environment using imaging sensors such as an infrared sensor (FLIR), millimeter wave radar or low light image intensification, etc. EFVS must also provide additional flight information / symbology on the HUD (or equivalent display) required to favor lower landing minima. It must also be integrated with the flight guidance system. The elements of the EFVS include: [5], [6]

- EFVS sensor system
- Sensor display processor
- EFVS display
- Pilot controls / interfaces

8.2. SVS-Synthetic vision system

Synthetic vision is a computer-generated image of the external environment from the perspective of the flight deck, derived from the position of the aircraft, highly accurate positioning and terrain database, obstacles created by human activity or nature. Synthetic vision creates an image with respect to the terrain and the airport within the possibilities of the navigation source (position, altitude, course, route and database restrictions). The SVS can provide situational awareness, but no operational credit due to meteorological minima. The components of the SVS include: [5], [6]

- Display
- Terrain and obstacle database
- Location, altitude, course and route

8.3. CVS-Combined vision system

CVS can include database-driven synthetic vision images combined with real-time sensor images that are superimposed and correlated on the same display (eg, HUD, HDD). This involves the selective blending of two technologies based on the intended function of the system. CVS can provide situational awareness, but whether CVS qualifies for operating credit depends on how it is configured and whether it meets the legal requirements for EFVS operating credit. [5], [6]

Each of these systems can be an additional equipment of the HUD system. However, they can also be used in cockpits without a HUD system, as they can also be displayed on HDD displays.

9. APPLICATION OF TRANSPARENT DISPLAY IN GENERAL AVIATION

The first commercially successful design for a general aviation aircraft display application is a product of the American company SkyDisplay, which was approved by the STA in June 2021 by the US Air Force for the use of this technology. Specifically, it is the STC for SkyDisplay AID (Aircraft Interface Device), which is the basic unit for the HUD itself. This avionics kit has been approved for Part 23 aircraft operating under Part 91 rules. In just a few months, more than 20 aircraft owners have begun working with SkyDisplay, who have shown interest in the technology and are also involved in the certification process. These were aircraft such as Cirrus, Cessna, Beechcraft, Phenom, TBM, Piper, AirTractor / Fire Boss, ie aircraft equipped with both piston, turboprop and jet propulsion units. In these cases, the entire SkyDisplay system has been integrated with the onboard avionics of several manufacturers: Aspen Avionics, Garmin and Honeywell, and this is not their final list. Development for the SkyDisplay HUD took place with the direct support of Duncan Aviation of Denver, Colorado. Technically, the HUD SkyDisplay has two main components: a HUD projector with a collimator and an interface unit (AID), ie a computer providing an interface with aircraft systems via the Arinc 429 bus. ground or flying pilot or non-pilot vehicles. [15] To date, SkyDisplay offers the option of installing a classic flight information HUD or an enhanced version that already includes the EFVS enhanced vision system, which comes from Astronics under the trade name Max Viz and is based on an infrared sensor. to install in a wide range of aircraft types, here is a partial list: Air Tractor, Beechcraft Bonanza, Beechcraft Baron, Cessna 421, Cessna Conquest, Cessna Mustang, Cessna Citation CJ2 +, Cessna Citation CJ4, Cirrus SR22, Cirrus Vision Jet, Embraer Phenom 100, King Air 300, Mooney M20, Pilatus PC12, Piper Twin Commanche, Piper Cheyenne, Piper Malibu Matrix, TBM 700a, TBM 850. [7]

10. A PRACTICAL EXAMPLE OF USING HUD AT AIR VANUATU

In my diploma thesis I presented the practical use of the HUD system at the company Air Vanuatu. This company leased two Boeing 737-800 aircraft in 2018, which were not equipped with the HUD system, and in 2019 the company had the same aircraft, but equipped with the HUD system. In my diploma thesis I presented the practical use of the HUD system at the company Air Vanuatu. This company leased two Boeing 737-800 aircraft in 2018, which were not equipped with the HUD system, and in 2019 the company had the same aircraft, but equipped with the HUD system. First of all, however, it is important to say that this company operates in remote areas, where it is very expensive if the aircraft fails to land at its home airport and has to fly to an alternate airport.

Several types of instrument approaches can be used for runway 11/29, unfortunately the airport is not equipped with the ILS system. Due to the terrain in front of the runway threshold and in the direction of the missed approach, most instrument approaches are characterized by a relatively high minimum descent height MDH / DH. Of course, this high altitude relative to the runway threshold then corresponds to the minimum visibility for which this procedure is certified. Contrary to European standards, where we talk about visibility in hundreds of meters, we work with thousands here. During the rainy season, the density of precipitation reaches such an intensity that even with the reported visibility of 2500 meters, it is very difficult for the aircraft crew to establish at a minimum the visual reference necessary for the successful completion of the approach and landing. And this is exactly the reason that leads the new technologies used by the operator to acquire the aircraft with HUD equipment or to its additional installation.

Air Vanuatu's Flight Ops very cleverly chose the B737-800 HUD-equipped fleet as the backbone. In collaboration with the New Zealand State Agency for Procedures for IFR Flights (APP, SID, STAR, etc.), it developed spatial navigation approaches for both runway 11 and runway 29. HUD equipment and dual FMS assembly played a key role here, which made it possible, thanks to the accuracy of flight guidance, to design RNP approaches, which have much lower meteorological limits than the two used so far.

Operational experience with these approaches showed an approximately 97% success rate for Air Vanuatu's B737-800 landing in bad weather, while only 88% of the approach without a HUD system. The implementation of these RNP approaches has led to a very significant increase in the economics of operation on the international routes of Air Vanuatu, where the company has avoided frequent losses due to waiting or departing to a very remote backup airport, as well as reducing the amount of additional fuel.

After completing all the calculations, we found that in 2019, when the company had HUD aircraft, all costs for alternate departures, HUD acquisition and maintenance included $ 566,416. In 2018, when the company did not operate aircraft with the HUD system, the additional costs for departures to the alternate airport and holding company amounted to 1,283,500 USD. This difference is due to the already mentioned large distance between the destination and the alternate airport, which in some cases was up to 4.6 hours of flight.

11. EVALUATION OF THE HUD SYSTEM

The HUD system offers a number of advantages, but also a few disadvantages. The main benefits include: better situational awareness of pilots; the possibility of using additional systems to assist pilots in controlling the airplane during all phases of flight; increasing the accuracy of aircraft control; ground error reduction; increase safety; allows pilots to land in worse weather conditions; relatively fast financial return. Disadvantages include: insufficient field of view; poor readability of the display in direct sunlight; when using the EFVS system, it is sometimes difficult to estimate altitude and distance from objects; frequent updating of synthetic maps required.

ACKNOWLEDGMENT

This paper was supported by national grant scheme VEGA 1/0695/21 Air transport and COVID 19: Research of the crises impact with a focus on possibilities to revitalize the industry.

References

[1] Head-up display [online]. En-Academic, 2022 [cit. 2022-04-26]. Dostupné z: https://en-academic.com/dic.nsf/enwiki/257062

[2] Head-Up Displays [online]. 2001 [cit. 2022-04-26]. Dostupné z: https://studylib.net/doc/18848780/chapter-4--head

[3] Proctor, Paul, Aviation Week & Space Technology, New York, 1999, Enhanced Head-Up Symbology Builds Situational Awareness

[4] Sweetman, Bill, Air Transport World, 1995, Out of the Fog

[5] Advisory Circular [online]. USA: U.S. Department of Transportation Federal Aviation Administration, 2016 [cit. 2022-04-26]. Dostupné z: https://www.faa.gov/documentlibrary/media/advisory_circular/ac_20-167a.pdf

[6] SYNTHETIC VISION SYSTEMS [online]. USA: NASA, Research and Technology Directorate, 2016 [cit. 2022-04-26]. Dostupné z: https://www.researchgate.net/publication/279473108_Synthetic_Vision_System

[7] SKYDISPLAY HUD AIRCRAFT MOUNTED. Https://skydisplay.com [online]. SkyDisplay, 2022, 2022 [cit. 2022-04-26]. Dostupné z: https://skydisplay.com/menu/skydisplay-hud-lcd-180/

[8] BUGAJ, M., NOVÁK, A. 2010. Všeobecné znalosti o lietadle : drak a systémy, elektrický systém. - 1. vyd. - Žilina : Žilinská univerzita, 2004. - 247 s. - ISBN 80-8070-210-1.

[9] NOVÁK, A. 2006. Modern telecommunication networks in the aeronautical telecommunication network (ATN). Aviation 10 (4), pp. 14-17.

https://doi.org/10.26552/ pas.Z.2022.2.03

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AIRPORT OPERATION DISRUPTIONS

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Abstract

Disruptive events have a very strong potential to create a problem, spreading onwards to different participants in the chain of air travel. To minimalize the negative effects, this paper focused on how an airport can deal with disruptive operations effectively. The target of this paper was to come up with a step-by-step method, that airports could follow when coming up with a plan on how to manage their operations during these events. In order to reach this goal, it was essential to understand the principles causing disruptions and furthermore, categorizing them respectively. In addition to that, we had to find out what is the contribution of each category to the overall state of delays. Thanks to interviews with professionals at different international airports, we were able to come up with plans of trainings and exercises as a part of the suggested strategy. At the same time, in the proposed plan, several factors were mentioned, which were considered as an important part of the operations during interruptions that airports should not forget about.

Keywords

disruptive operations, delays, impact, proactive and reactive approach, contribution of disruptions to interruptions, disruptive events, management of disruptive operations.

1. INTRODUCTION

The topic of disruptions can be viewed from many perspectives. These depend on who plays the main character in the whole situation. Disrupting situations represent serious problems that affect many people and organizations. They create significant financial losses and have the potential to spread further down the chain. These are a couple of reasons why they need appropriate attention. There are many papers that discuss the topic of airport disruptions, their origins, and impact. Unfortunately, none of them provide a complex method of solutions, that an airport could use to prepare itself better for these types of situations. Therefore, the purpose of this paper was to develop a better understanding of airport disruptions, in order to create a method an airport could follow to handle these situations better and minimize their negative impact.

2. CURRENT STATE OF THE PROBLEM

Disruptions in general, are very complex situations, just like aviation itself [1]. They interlace a variety of people and events that result in an interruption in the smooth flow of air traffic at an airport. When talking about these situations, we have to consider what is our point of view. This varies, because for example, airlines would deal with disruptions differently than airports or passengers. Since airports play a crucially important role in the air transport process, it is important to focus on them too. If airports manage to handle disruptions better, the impact of such events would decrease [2]. Management of these situations heavily depends on cooperation of all the departments and people that are involved in the process. In addition to that, it incorporates many different aspects, such as the predictability of events, the training of staff or the management of the airport [3]. In order to develop a step-by-step method, which could be used by airports, a deeper understanding of these events is required. Only after consideration of potential situations that cause disruptions and events that affect them, we were able to create a proper picture of this problematics [4].

3. METHODOLOGY PROPOSALS

As it has been mentioned before, disruptions cover a variety of aspects, that had to be considered. To understand this problem better, we had to use different methods and approaches. These mainly consisted of qualitative, statistical, and typological methods [5].

The method that was used the most was qualitative and through it we were able to gather theoretical information about the topic. This meant going through other papers, that discussed the topic of disruptions, their causes and effects [5]. Furthermore, this also included interviews with professionals from different airports, that provided us with valuable insight on the topic. This meant that we were not only able to gather theoretical data, but real-life information as well. The interviews were on a semi-structured level, which means that we had questions prepared, but we were opened for wider talk outside of the scope of our questions.

Another method that was used was the historical point of view on these situations. This was a valuable step, through which we were able to gather information about disruptive events at airports that already happened. This method had to be taken into account since our imagination is limited and we cannot make up scenarios of every possible disrupting event that may happen. Besides that, from this method, we can learn the mistakes that were made and therefore improve our way of approach to these situations. From all of the information assembled, through typological method, we were able to create different categories of disruptions that gather situations that are similar in their nature [5].

Furthermore, statistical research had to be done as well. This mostly focused on the contribution of various categories of disruptions to overall delays in the air transport [5].

Moreover, we used an inductive approach, which means that we first gathered important information, to create something more specific. In our case, that meant the proposed method of solution. In addition to that, it is important to keep the information relevant. This means that we used data from the 21st century, which gave us a wide scale we could work on as well as a high level of precision [5].

4. TYPOLOGY OF DISRUPTIONS

There are many ways how we can look at disruptions. Different papers propose different causes of disruptions as well as their effects on air traffic. In order to understand this problematic better, they all had to be considered. Furthermore, these aspects helped us to reach the goal of this paper.

4.1. Basic categorization

There are different databases that consider disruptions in general. The following table examined American and European databases and therefore was able to create respective categories of disruptions [2].

Table 1 Ten different categories of disruptions Source: [2].

1.	**Cause**	**Weather**						
	Type	Sandstorms	Snow	Wind	Tropical storms	Convective	Fog	Floods
2.	**Cause**	**Other meteorological phenomena**						
	Type	Earthquake	Volcanic ash	Tsunami				
3.	**Cause**	**Accidents and incidents**						
	Type	Crashes	Maneuvering incidents	Disruption of other types of transport	Grounded aircraft	Road blockage		
4.	**Cause**	**Strikes**						
	Type	Airport personnel	Air traffic controllers	Air carrier crew	Transportation			
5.	**Cause**	**Safety and Security**						
	Type	Security warnings	Military conflicts	Terrorism	Cyber attacks			
6.	**Cause**	**Technological failures**						
	Type	System collapse						
7.	**Cause**	**Illness**						
	Type	Pandemic						
8.	**Cause**	**Global occurrences**						
	Type	Sport events	Holidays[2]	Religious events				
9.	**Cause**	**Improvements**						
	Type	Development of airport infrastructure – runways, taxiways, lights, navigational aids, etc.						
10.	**Cause**	**Economic**						
	Type	Air carrier/travel agency economy breakdown						

Table 1 deals with ten categories of disruptions that can arise at an airport. These categories represent a general categorization of disruptions because they may also vary in type.

4.2. Contribution of disruptions to interruuptions

This factor concludes the overall contribution of each category of a disruption to interruption of the normal flow of air traffic. Figure 1 deals with European data that was based on raw data gathered from Eurocontrol. These are disruptions that cause delays of at least 1 000 minutes, or they affect 100 flights or more. The following categories might differ to the ones mentioned in table one, since their description would not fit their true meaning. Figure 1 shows contribution of these categories to overall delays at European airports from 2015 to 2020 respectively [7][8][9][10][11][12].

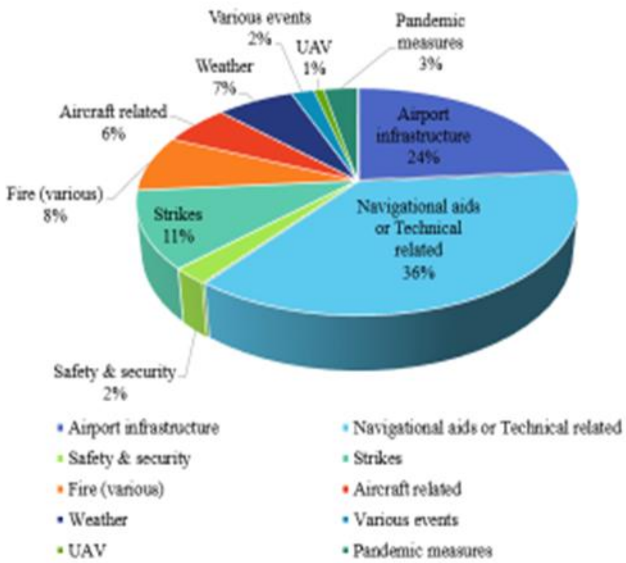

Figure 1 Contribution of various types of disruptions from 2015 to 2020 at European airports. Source: Author

There are different databases that can be used for this step. As it has been mentioned before, figure 1 covers European data. If we were to apply such measure on American airports, we can use database from Bureau of Transportation Statistics. This database uses different categorization of disruptions; therefore, the graph would look different as well [13].

4.3. Parameters affecting disruptions

As it has been mentioned before, in order to fully understand this topic, we had to consider events that affect disruptions as well. These could be narrowed down into seven categories:

- location of an airport
- type of an airport
- predictability
- impact
- duration
- airport's influence
- affecting ground movement

Disruption according to the location of an airport affects this research to a great deal. Certainly, not all airports will have to deal with all types of weather. Airports situated further north will experience different types of weather than airports by the coast of the Mediterranean Sea. This will therefore also affect the equipment the airport is going to possess and their approach on how to deal with different weather situations [14].

Another important factor that needs to be considered is the type of an airport. In this step, we have to conclude if the airport is acting as a primary or secondary. Primary airports serve traditional air carriers, while their capacity is used almost to its full potential. They also handle passengers that continue on their journey, connecting on another flight with different airline [15][16]. This means that impact of a disruption at this airport would be significant [2]. On the other hand, secondary airports serve low-cost carriers, whose passengers usually do not carry on their journey with another airline [15][16]. These airports are therefore more resistant to disruptions and their impact does not transfer further down the chain as significantly as in the case of primary airports [2].

Predictability of disruptions is a very important part of the ability of an airport to react to interrupting situations. If the airport is able to predict a disruption with a timely manner, it is able to prepare itself better. Of course, not all events are easy to predict. The following table shows the minimum time of disruption predictability according to their categories [3].

Table 2 Types of disruptions and their minimum time of predictability. Source: [4].

Type/Predictability	No	Hours	Days	Months	Years
Airport infrastructure					
Maintenance			✓	✓	✓
Upgrades			✓	✓	✓
Blockage on maneuvering area	✓				
Nav Aid/Tech related					
Maintenance			✓	✓	✓
Calibration			✓	✓	
New equip. installation			✓	✓	
System failure	✓				
Safety & Security					
Political conflicts (war)	✓	✓	✓	✓	
Alarms, bombs, threats	✓				
Strikes	✓	✓	✓	✓	
Aircraft related	✓				
Weather & Geology					
Storms		✓			
Local winds			✓	✓	
Icing, precipitation, low visibility, convection, floods		✓	✓		
Volcanic eruptions	✓				
Earthquake	✓	✓			
Events		✓	✓	✓	✓
Pandemic measures	✓	✓	✓		
Economic collapse	✓	✓	✓		

The impact of disruptions does not have to be so severe if the airport handles the situation well. There could be events that only happen at one airport (a bomb) or situations that affect a wider area. Therefore, these affect more airports at once. An example of this could be a storm or pandemics [4].

Duration of disruptions widely depends on the nature of the situation. They can last anything from a couple of hours (navigation aid calibration) to years (disruption caused by war) [4].

Another category that was considered was the influence of airport over the disruptive situations. We can observe three simple groups in this category. Those are events that an airport has no influence over, events an airport has some control over and situations an airport can influence up their full potential. The reason why we have these three groups is the fact that disruptions may vary in their origin [3].

As it has been mentioned before, disruptions are very complex events. The ground movement of aircraft combines many different activities operated by various groups of employees. The interdependence of actions during ground movement of an aircraft makes them vulnerable to disruptions, which can then propagate delays to other areas as well. They gather both the human factor of the process as well as the technical and infrastructural part. If these parts experience any type of malfunction, the delay spreads on. Therefore, looking at disruptions from this point of view, we can observe how different properties of this process are interconnected and have to work reliably [17].

5. AIRPORT DISRUPTION ANALYSIS

5.1. Significant disruptive events

As it has been mentioned before, it is important to focus on disruptions as they have happened. Taking into consideration the location of an airport or its type, an airport can learn from such past events as well. The following events prove just how various these events may be.

• September 11th, 2001 – Hijacking of four commercial aircraft in the United States airspace affected the whole region of North America and have had negative impact on air travel for many years on. This situation required a closure of the US airspace as well as some American airports. On the other hand, Canadian airports were faced with a wave of passengers and flights that had to divert there [18].

• Snowstorm at Heathrow – At the end of 2010, from the 17th to the 23rd of December, the United Kingdom was hit by a severe snowstorm. The cruciality was even multiplied, since this period of the year represents an especially busy time for travel in general. The airport was closed for one full day, while for the following days its operations were limited [19].

• Fire at an air traffic control center – In 2014, a fire at air traffic control center that was responsible for handling the traffic in the area around the city of Chicago, damaged the equipment of the center so much, the traffic had to be diverted. The event caused an emergency situation at Chicago O'Hare, temporarily putting the whole traffic on pause [20].

• Eindhoven luggage drop-off failure – This airport possess a self-drop-off luggage station, where passengers travelling with low-cost carriers can leave their bags, which are automatically handled. In this case, a failure of this mechanism caused that a couple of aircraft had to be delayed [21].

• Power outage in the Netherlands in 2015 – Nationwide power outage affected the whole region around the country's capital.

It not only affected airports, but other types of traffic as well. This event only lasted for about an hour, but it paused operations at Schiphol and the flight were forced to divert [22].

• Change of political system in Afghanistan – This event caused a closure of Kabul International Airport for a couple of days. Its restoration back to normal operations are a complicated topic since it had been severely damaged during the last days of evacuation flights in 2021 [23].

5.2. Solutions to disruptions

While dealing with disruptive situations, airports can take different approaches. Some are more complex than others. The following list describes what an airport can do during these situations.

• Cancel or divert flights

• Traffic holding in the air or on the ground

• Delay of departure

• Switching to other types of traffic

• Command and control – Stating the leading departments that is going to guide the management of operations and responsibilities of others [3].

• Cooperative preparation – Departments involved in operations during disruptive events work closely together. The airport communicates with airlines and other stakeholders [3].

• Passenger well-being – Focusing on the needs of passengers. This includes provision of internet spots, information centers, accommodation arrangements (beds, blankets, sources of power) [3].

• Prepared reserves and facilities – Having third party agreements with organizations that would provide additional help (staff, equipment) when an airport faces a significant disruptive event [3].

• Collaborative decision making – Implementation of overall changes to the culture of an airport. Communication is key and its execution takes time, but it supports general improvement of airport's performance [3].

• Emergency and contingency plans – According to Annex 17, this step is mandatory for certain events. These plans enable to follow particular set of steps, minimizing the risk of an error. It should cover everything from the preparation for such events, trough initial reaction of an airport, to the communication with other involved departments [24].

• Monitoring disruption related indicators – Active approach towards following values indicating an approach of a disruption. This may include meteorological indicators, status of neighboring airports or airlines [25]. Another example of this is monitoring data of terrorist attack probability [26]. An airport needs to have agreements with organizations that would provide these information.

• Airport minimum operating list – Prioritising of certain parts of infrastructure and subsequent recovery of airport's infrastructure [25].

• Exercises and trainings – Airport's prompt response is based on the preparedness of its staff too. Therefore, creating plans, trainings, theoretical materials that would prepare the staff and the management for disruptive situations [25].

6. ACTION PROPOSAL

The goal of this paper was to propose a complex plan considering all the above-mentioned factors. This method would consist of a couple of important steps.

6.1. Selecting key parameters

A Considering all the discussed parameters that affect disruptions, only a couple of them could be used for our research. Therefore, we have considered the type of an airport, location of an airport, predictability, impact, and duration as key parameters. Although we believe that they all represent an equally important fragments of disruptions.

6.2. Development of a disruption calendar and impact matrix

Based on the already selected factors we created a calendar of what types of disruption an airport can expect. With the support of additional information, specific for the location of the airport, we proposed that it would be possible to depict months distinctive for each category of a disruption.

Table 3 Calendar of annual expectation of disruptions. Source: Author

Cause	Type/Month	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Weather	Sandstorm	green	green	green	green	green	green	green	green	green	green	green	green
	Snow	red	red	orange	green	green	green	green	green	green	green	orange	red
	Local winds	green	green	green	green	green	green	green	green	green	green	green	green
	Tropical storms	green	green	green	green	orange	orange	orange	orange	orange	green	green	green
	Convective	green	green	green	green	orange	red	red	red	orange	green	green	green
	Fog	orange	orange	orange	orange	orange	green	green	green	green	orange	orange	orange
	Floods	orange	orange	orange	orange	orange	green	green	green	green	orange	orange	orange
Other meteorological phenomena		green	green	green	green	green	green	green	green	green	green	green	green
Amount of traffic		red	red	green	green	green	orange	red	red	orange	green	green	red
Accidents and incidents		red	red	green	green	green	orange	red	red	orange	green	green	red
Strikes		green	green	green	green	green	green	green	green	green	green	green	green
Safety and security		green	green	green	green	green	green	green	green	green	green	green	green
Technological failures		green	green	green	green	green	green	green	green	green	green	green	green
Illness		green	green	green	green	green	green	green	green	green	green	green	green
Global occurrences	Christmas	red	green	green	green	green	green	green	green	green	green	orange	red
	Religious & sports events	x	x	x	x	x	x	x	x	x	x	x	x
Improvements - maintenance		green	green	green	green	green	green	green	green	green	green	green	green
Economic factors		green	green	green	green	green	green	green	green	green	green	green	green

In this calendar, various categories of disruptions are represented in different colours depending on their month of occurrence. This is because certain disruptions occur more in different seasons. The colours in the table represent severance of the disruption. In this case, a severe disruption (red) represents a situation that is very likely to occur, requiring a considerable preparation of the airport and creates a significant impact on the traffic. The group of disruptions in orange are disruptions that do not happen as often, but usually come after or before the severe ones. An example of this could be the Christmas season. During months such as November or February, we might expect a small increase of passengers, who are travelling due to holidays. This would be represented with colour orange. Although, we know that we can expect a significantly higher number of passengers in December and January. This would be represented with colour red, as it puts the airport's infrastructure under even more pressure. The ones in green do not create significant events and do not happen as often. Further explanation of these events is clarified in the following tables, which also take the parameter of impact into consideration. We recommend this calendar would be prepared before a significant season (winter or summer operations) and should be updated monthly and weekly in order to stay accurate. Although this calendar provides a general proposal, an airport can easily use its database as the input values. The only category that is not coloured is the global occurrence of religious and other events, since they vary from year to year.

The following table considers the impact of disruptions as well and it identifies what the airport should do when respective groups of disruptions arise.

Table 4 Assesment matrix. Source: Author

Possibility of occurrence	Impact		
High			
Medium			
Low			

We can observe that events with high levels of impact and high levels of occurrence are the ones that are going to cause the most difficulties. Therefore, we strongly advise an airport creates specific methods of solutions for these events, that would include ways of how to reduce their significance. After their application, the matrix should look as the following.

Table 5. Assesment matrix after applying specific precautions. Source: Author

Possibility of occurrence	Impact		
High			
Medium			
Low			

Table 5 represents what would be the colour distribution of the same disruptive events after developing specific preparations for them and their consequential application. We can clearly observe that the most hazardous situations, which were colour coded by red, would now represent a lower level of hazard. Level downgradient would be also experienced by category that was in table 4 shown as orange. With application of further preparations, we could lower the level of these situations as well.

6.3. Method of solutions

Methods of solution can be divided into two groups, based on when they take place. There are processes that start way before a disruption occurs (proactive), which have a wider area of impact. The other group is a set of reactive solutions, that implement the previously prepared plans or simple actions as holding of traffic or its cancelation. The following table describes which approaches an airport can take, according to time. It considers the previously mentioned methods of solutions.

Table 6. Potential actions an airport can do prior and during disruptions. Source: Author

Approach	Proactive	Reactive
Action	CDM	Command and control
	Developing a contingency plan	Cooperation of stakeholders
	Third party agreements	Cancellations, diversions, delays, holdings
	-	Following a contingency plan steps

6.4. Testing and exercises

Since disruptions do not happen on daily basis, it is important to provide ways how, not only the management of the airport, but also the ground personnel, can prepare themselves. As stated in Annex 14, Volume I, Aerodromes, these exercises must take place not more than once in two years. We recommend that exercises, including the whole airport and other additional services, should take place at this rate. Although we also propose that a smaller scale training, specifically focused on one type of operations, should take place, depending on climatic conditions of particular airport, before winter operations. Besides maintenance and a winter theoretical training, an airport practical exercise should happen as well. These trainings can take an appearance of tests, workshops, lectures or study materials.

6.5. Correct time management

This step is important to minimize the impact of a closure of a certain part of an airport. Therefore, an airport has to consider the timing of its actions. The more time it has to prepare for disruptions, the better its response is going to be. Moreover, contingency plans and other proactive approaches can be used in this step as well.

6.6. Communication

Proper communication on all levels affects how the whole situation is handled. One might think that this aspect only affects the staff and management of an airport, when in reality, it represents a lot more. It could be divided into internal communication, that includes direct employees of an airport, to external, which covers all the outsiders. The group of externals could be represented by the government, media, or families.

6.7. Proposal for further action

It is almost impossible to create a specific step by step method that would be suitable for more than one airport. This is due to the fact, that each airport is unique. Although we believe our proposal could serve as a template airports in general could follow.

CONCLUSION

The topic of disruptions covers a variety of areas. They affect many stakeholders, airlines and passengers. Therefore, they require adequate amount of our attention. In order to master this topic, we had to dig deeper into the topic and understand what are the causes of these events and what are the factors that affect them. After this process, we were able to propose a method that would deal with these situations and provide a guidance for airports to minimize the impact of disruptions.

ACKNOWLEDGMENT

We would like to thank the professional personnel from different airports that were kind enough to provide real life insight on the topic of disruptions. These information provided us with accurate data to create an authentic picture on the topic.

REFERENCES

[1] TRAPOTE-BARREIRA, C. et al. 2016. Managing Airlines: The Cost of Complexity. In Transportation Research Procedia. 2016, Vol. 18, pgs. 297-304. doi:10.1016/j.trpro.2016.12.039.

[2] MARZOULI, A. et al. 2013. Analysis of recent disruptions of the Air Transport System: Project META-CDM. 2013, 105 pgs.

[3] TEGNER, R., CLAYTON, E., 2013. Managing Airport Disruption: Achieving Resilience through Collaboration: Report. Booz&Co, 2013. 16 pgs.

[4] SERRANO, F., KAZDA, A., 2017. Airline disruption management: yesterday, today and tomorrow. In Transportation Research Procedia. 2017, Vol. 28, pgs. 3-10. doi: 10.1016/j.trpro.2017.12.162.

[5] KAZDA, A., 1985. Obchodná prevádzková činnosť: vybrané state. Bratislava: Alfa, 1985, p. 22

[6] ABUDIYAH, A. K., 2020. Framework Development for Improving Arrival Processing of Pilgrims at Hajj and Umrah Airport Terminals: doctoral thesis. Cranfield University, 2020. 592 pgs.

[7] EUROCONTROL. 2016. Eurocontrol. Eurocontrol - website. [Online]. May 18, 2016. [Cited:2022.05.01.] Available online: https://www.eurocontrol.int/sites/default/files/publication/performance/2015_annual/final-edition/annual_network_operations_report_2015_main_report_final.pdf.

[8] EUROCONTROL. 2017. Eurocontrol. Eurocontrol - website. [Online]. May 8, 2017. [Cited:2022.05.01.] Available online: https://www.eurocontrol.int/sites/default/files/publication/files/nm-annual-network-operations-report-2016-main-report.pdf.

[9] EUROCONTROL. 2018. Eurocontrol. Eurocontrol - website. [Online]. April 24, 2018. [Cited:2022.05.01.] Available online: https://www.eurocontrol.int/sites/default/files/publication/files/nm-annual-network-operations-report-2017-main-report-final.pdf.

[10] EUROCONTROL. 2019. Eurocontrol. Eurocontrol - website. [Online]. April 24, 2019. [Cited:2022.05.01.] Available online: https://www.eurocontrol.int/sites/default/files/2019-11/nm-annual-network-operations-report-2018-main-report.pdf.

[11] EUROCONTROL. 2020. Eurocontrol. Eurocontrol - website. [Online]. April 24, 2020. [Cited:2022.05.01.] Available online: https://www.eurocontrol.int/sites/default/files/2020-04/nm-annual-network-operations-report-2019-main-report.pdf.

[12] EUROCONTROL. 2021. Eurocontrol. Eurocontrol - website. [Online]. April 15, 2021. [Cited:2022.05.01.] Available online: https://www.eurocontrol.int/sites/default/files/2021-04/eurocontrol-annual-nor-2020-main-report.pdf.

[13] Statistics, Bureau of Transportation. 2020. Bureau of Transportation Statistics. Bureau of Transportation Statistics - website. [Online]. 2020. [Cited:2022.01.08.] Available online: https://www.bts.gov/content/delay-cause-year-percent-total-delay-minutes.

[14] LEVIÄKANGAS, P., et al. 2014. Extreme weather impacts on transport systems: technical report. 102 pgs.

[15] KAZDA, A., 1995. Letiská: design a prevádzka. Žilina: Vysoká škola dopravy a spojov, 1995. - 377 s. ISBN 80-7100-240-2

[16] TOMOVÁ, A. et al. 2017. Ekonomika leteckých spoločností: pravidelná osobná doprava. Žilina: Žilinská univerzita, 2017. 274 s. ISBN 978-80-554-1359-4.

[17] WILKE, S. et al. 2014. Airport surface operations: A holistic framework for operations modeling and risk management. In Safety Science. 2014, Vol. 63, pgs. 18-33. doi:10.1016/j.ssci.2013.10.015.

[18] CHANG, S. E. et al. 2003. Airport Closures in Natural and Human-Induced Disasters: Business Vulnerability and Planning. [Online]. Ottawa: Her Majesty the Queen In Right Of Canada, 2003. 58 pgs. [Cited 2022.01.19.] Available online: <https://publications.gc.ca/collections/Collection/PS4-8-2004E.pdf>. ISBN 0-662-37716-8

[19] BAA. 2011. Report of the Heathrow Winter Resilience Enquiry. [Online]. 81 pgs. [Cited 2022.01.20.] Available online: <https://im.ft-static.com/content/images/89937494-55ed-11e0-8de9-00144feab49a.pdf>

[20] SUNSHINE. B., 2015. The Chicago Air Traffic Control Fire: Radio Silence. Flyingmag – website. [Online]. [Cited: 2022.02.09.] Available online: https://www.flyingmag.com/technique-proficiency-radio-silence-chicago-air-traffic-control-fire

[21] Share luggage travelers left behind at Eindhoven Airport after malfunction. [Online]. [Cited: 2022.02.10.] Available online: https://www.nu.nl/eindhoven/5977943/deel-bagage-reizigers-achtergebleven-op-eindhoven-airport-na-storing.html

[22] Power cuts cause flight interruptions in Amsterdam. [Online]. [Cited: 2022.01.30.] Available online: https://www.rte.ie/news/2015/0327/690148-amsterdam/

[23] RAINS, T., 2021. Taliban promising 'full cooperation' as it asks airlines to resume international flights to Afghanistan. [Online]. [Cited 2022.02.21.] Available online: https://www.businessinsider.com/taliban-ask-international-airlines-to-return-to-afghanistan-2021-9?r=US&IR=T

[24] [24] ACI. 2014. Emergency Preparedness and Contingency Planning HANDBOOK First Edition. [Online]. Montreal: ACI World, 2014. 110 pgs. [2022.03.07.] Available online: < https://applications.icao.int/tools/RSP_ikit/story_content/external_files/Emergency_Preparedness_Handbook_First_Edition2014_FinalLR_NoPswd.pdf>

[25] NASH, M. J. et al. 2012. Guidebook for Airport Irregular Operations (IROPS) Contingency Planning. Washington D.C.: The National Academies Press, 2012. 261 pgs. ISBN 978-0-309-21385-1

[26] SERRANO, F. 2021. Business Continuity in Aviation: dissertation thesis. Žilina: Žilinská univerzita, 2021. 183 pgs.

[27] SEDLÁCKOVÁ, A.N., REMENCOVÁ, T. 2021. Adoption of Digital Technologies at Regional Airports in the Slovak Republic. Transport Means - Proceedings of the International Conference, 2021, 2021-October, pp. 616–621. ISSN 1822296X.

https://doi.org/10.26552/ pas.Z.2022.2.04

INFLUENCE OF STRESS ON THE PERFORMANCE OF PILOTS IN TRAINING

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Abstract

This paper deals with the influence of stress that affects pilots in training, how stress affects their daily lives, but especially how it affects their concentration and performance during pilot training. It describes what risks, whether mental or physical, can occur to pilots in training. It also discusses about the factors that affect pilots. One of the factors is the kinetosis, to which more attention is paid and which had also become the subject of the research in this diploma thesis. The aim was to use a questionnaire to find out whether the pilots in the training encountered signs of motion sickness during the training, how it affected their concentration and how they dealt with these situations. In conclusion, based on these responses, we suggested possible preventive solutions for other future novice pilots on how to avoid motion sickness and if it had already occured, how it should be eliminated as much as possible not to affect performance and concentration of pilots.

Keywords

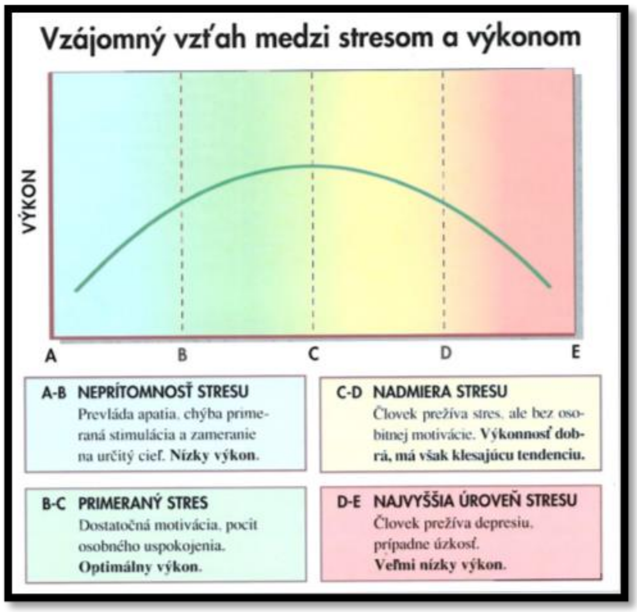
stress, kinetosis, mental stress, physical stress, psychosomatics

1. INTRODUCTION

Pilot work is considered to be one of the most challenging in terms of concentration and stress that pilots experience quite often. High demands are placed on pilots because they are responsible for the aircraft, passengers and all crew members. Pilots in training are inexperienced and, unlike older and more experienced pilots, often do not know how to react correctly to different situations, which can cause stress for them. The research is focused on reducing and eliminating stress and motion sickness, which is one of the stressors with which pilots who start flying can have problems.

2. DEFINITION OF STRESS

When we talk about stress, we are talking about a state in which the level of stress exceeds the tolerable limit in terms of the adaptive capacity of the human body under certain conditions. Stress is associated with situations that are demanding and significantly upset the balance of the body and cause changes and fluctuations in the hormonal and immune system. Stress occurs when the safety of an organism, the so-called integrity, is threatened and the organism must use as many abilities as possible to protect itself. When people were in danger, their bodies mobilized, their muscle tension increased, their breathing quickened, and their adrenaline levels also increased. Their senses sharpened and they watched their surroundings carefully so that they could react as soon as possible. The stress that affects a person can be considered as the body's response to the influences of the environment during his life. The stress that affects a person can be considered as the body's response to the influences of the environment during his life. Stress is divided into eustress, which is positive stress, and distress, which is negative. Although stress is harmful, it can also help a person to some extent. Every person is affected by stressful stimuli, but these stimuli do not have the same effect on every person, because every person is different.



2.1. Eustress

A certain amount of tension is healthy and necessary for the body. Even in dangerous situations, it is important that the body responds quickly to certain situations and that a sufficient amount of adrenaline is secreted into the blood and provides the reactivity that the body needs in these situations. Even in less dangerous situations, it is good to have a little tension and vigilance that people can use, for example, in tests, during important interviews or even in piloting. This type of stress is important when piloting, as the pilot needs to be constantly vigilant, paying attention to the operation and also to unexpected situations that may occur during the flight. This so-called good stress helps to increase performance, improve concentration and sharpen the senses. The impact of stress has also a major impact on learning new things that pilots can better remember. At low levels of stress, fatigue and boredom can occur, so it can negatively influence pilots´ ability to remember something. That is why there is no need to worry about this type of stress. This type of stress is commonly experienced by people during promotions, weddings or other pleasant situations that they experience throughout their lives.

2.2. Distress

Distress is a negative form of stress that occurs when people find themselves in a situation where they feel uncomfortable, time constrained and do not catch up, or when they find themselves in an embarrassing situation. Just as eustress occurs under certain conditions, distress also occurs under certain conditions, which are uncomfortable in this case, and this occurs, for example, when people have to solve a problem that they do not want to solve. Another unpleasant situation is when the pilots have little control over a certain situation, or they have no control over the situation at all. This can happen, for example, if a pilot gets into an unexpected situation that he is not prepared for or has never encountered. If distress persists, it can turn into chronic stress, which has a negative impact on the immune system.

3. STRESS FACTORS THAT INFLUENCE PILOT

Pilots are affected by many factors, which we call stressors. These factors affect pilots, whether it is training, work or even private life. They cause stress but also affect how long the stress will last for the pilot. These factors can be either different stimuli or situations. What matters is not only how much the stimulus or situation affects the pilot, but also how the pilot can deal with it. Each of us is different and each of us can deal with stress differently. For some, the given stressful situation or stimulus has a great impact and for others only minimal. During the performance of their work, but also in private life, pilots are constantly exposed to burdens (psychological and physiological) or to factors that affect pilots in the form of external influences.

3.1. Determinants of mental stress

One of the determinants that affects pilots but also ordinary people who are not affected by aviation is the psychological burden. In addition to being stressed by the human body as perceived as dangerous or threatening, people create this type of burden in their minds by thinking about stressful situations that have occurred to them in the past. They think about different situations, which may or may not occur, create different scenarios in their heads and sometimes put unnecessary psychological burdens on themselves. This type of load is difficult to defend because it is only in the head. These types of burdens that affect pilots include, for example, family problems, the loss of a loved one, interpersonal relationships between pilots and instructors, between pilots but also in private life, the financial situation that may be related to training, various dependencies that may have a great influence on the psyche and also the medical examinations, which are a condition for the pilot to be able to perform training and later also his work as a pilot. Into this group belong for example loss of a loved ones, interpersonal relationships, financial situation, addictions, medical examinations and many others.

3.2. Determinants of physiological stress

Kinetosis, lack of sleep, unhealthy lifestyle or even hypoglycemia are considered to be determinants of physiological load. These determinants act in such a way that they affect the functions of the human body and also the physical condition, which is important for pilots. However, most of these factors can be influenced by positive lifestyle changes. Into this group belong for example kinetosis, lack of sleep, unhealthy lifestyle and hypoglycaemia.

3.3. Impact of the external environment

The pilot is also stressed by the effects of the external environment, which can be threatening and dangerous for the body. The pilot may not even be aware of this, but his body is under stress. These factors can be, for example, take-offs and landings, meteorological conditions such as wind, turbulence, fog and many others. In this group belong for example take - offs and landings, meteorological conditions, hypoxia, and gravitational overload.

4. MANAGEMENT OF STRESS

The human body works in such a way that when something unusual happens to it, a so-called alarm is triggered, which can sometimes save lives. However, the signals that the body sends must be taken seriously and acted upon. The body triggers defense mechanisms to warn of danger, while activating muscles, organs and glands that are on standby. However, if this so-called alarm system of the body is abused and ignored for a long time, serious disorders of the immune system can occur.

5. THE IMPACT OF STRESS AND THE RISKS OF THE IMPACT OF STRESSORS

In addition to the psychological effects of stress, there can be physical effects that vary from individual to individual. Stress is perceived by the brain as a form of response to danger. As already mentioned, the body prepares for threat and all the senses are activated more intensely. The body is therefore ready to fight or escape, as has happened in the past with our ancestors who fought against their opponents or beasts. Nowadays, however, it is in this situation that it is crucial to calm down and deal with things prudently and with a cool head. When working as pilots, it is important not to panic in a stressful situation, because they are responsible for the lives of passengers, crew and even their own, which must be safely transported to the place. Under the influence of stress, there can be various risks that can endanger the life of the pilot, but also the lives for which the pilots are responsible.

5.1. Psychosomatics

Psychosomatics examines the interaction between a person's body and soul. It deals with the question of how physical illnesses affect the human psyche and also how psychological stimuli affect the body. It has been scientifically confirmed that these interactions between the psyche and the body interact. If a person is exposed to stress that is not addressed in any way, it can affect their health in the form of various diseases. It also works the other way around. If a person develops a more serious illness, such as cancer or other diseases, it can have an impact on mental health. Genetic influences, the job the individual performs, the environment where he or she lives or works, and social problems also contribute to the human psyche and thus to the development of psychosomatic diseases. In the 80's of the last century, a department called psychoneuroimmunology was created, which deals with the connection between the psyche, the body and also the immune system. The brain has been found to affect the body's defense mechanisms through the secretion of hormones such as cortisol. When stressed or depressed, cortisol can block the immune system. This makes stress-prone people more likely to develop infections. Usually, reducing stress or depression also improves a person's immunity, and conversely, reducing a person's immunity also reduces the level of depression and stress.

5.2. The effect of long-term stress on the individual systems of the human body and on the immune system

The effect of stress on the pilot may not be immediate. They may not even be aware of it, but over time, its effects on the body may manifest themselves. Stress has a negative effect on both the psyche and the body and its systems. It negatively affects individual systems, the digestive system and negatively affects the immune system.

5.3. Hyperventilation

The word hyperventilation consists of the word hyper, which means excess or more than usual, and the word ventilation. The word ventilation in the respiratory system means the exchange of air between the lungs and the outside environment. Hyperventilation changes the state of the respiratory system, which is not natural for the body, as the body does not need as much oxygen as is delivered to the lungs during hyperventilation. For a pilot, this can also manifest as difficulty breathing. In addition to deep breathing, shallow breathing may occur. In an individual, who experiences hyperventilation, breathing from the outside is highly audible. With persistent hyperventilation, there are problems and difficulties associated with the biochemical changes that occur in the blood. Due to the excessive excretion of carbon dioxide from the body and thus from the blood, the arteries narrow. As a result, the oxygenation and blood supply to the whole body and thus to the brain and heart is reduced. There is a higher heart rate in the body and also a higher irritability of the nervous system. The causes of hyperventilation can be various, but it is usually caused by anxiety, nervousness, panic, or stress. In pilots, it can be caused by either increased stress in dangerous or unpredictable situations, or hyperventilation can be accompanied by motion sickness. Hyperventilation can result in disorientation and eventually complete loss of consciousness. In this condition, it is necessary to calm the individual, talk to him and it is also recommended to breathe in a paper bag. Various breathing exercises and relaxation techniques are also recommended to calm the individual.

D. Decreased performance

Everyone who is exposed to stressful situations should control the balance between tension and rest. When one of these things deviates, the individual becomes stressed. In order for the pilot to expect the best possible performance from each other, the tension and rest must be in imaginary balance. When deviating, there is a state of alertness, when the body defends itself, causing muscle tension and nervousness. There is a loss of motivation, a decrease in concentration and fatigue on the body. Performance is declining and the body is not achieving the same results as before. If there are any side effects or health problems associated with this imbalance, there is tremendous pressure on the body. Stress also occurs in monotonous work and in work for which a person is too qualified or bored during this work. This is the other side of the imbalance. With these two aspects of imbalance, an individual experiences frustration or even a loss of appetite. At the same time, one does not want to do anything and his attention fluctuates. These symptoms are manifested mainly in one-sided and repetitive work activities. The most optimal thing for an individual would be a job that would be a challenge for him, but not so demanding as to cause him stress. However, everyone is different and some are adapted to give the best performance under high stress, while others give low or even no performance under high stress.

6. STRESSOR ELIMINATION OPTIONS

The pilot's work is considered prestigious as well as exciting. Young pilots who want to pursue flying throughout their lives and want to build a career see mainly the positives of this job, but are not aware of the psychological problems that this profession entails. Pilots in training are under constant stress, whether due to training in which they experience stressful situations such as weather conditions, kinetosis, instrument flights, night flights, but also interpersonal relationships involving pilots and instructors, but also pilots' relationships in training each other. In addition to training, young pilots can experience stressful situations due to family conflicts, health status, lack of funds and, if the pilot is a student in training, also due to school. Long-term stress has a negative effect on mental as well as physical health and can cause serious problems if it persists. In order to reduce stress for pilots, pilots should either avoid stress and thus prevent stressful situations, or if stress persists, they must learn how to reduce or eliminate stress.

6.1. Stress prevention

One of the ways in which a person can prevent stress is to build and develop psychological resilience to stressful situations. Strengthening resilience can also be seen as increased adaptability, including the use of all resources that have a positive effect. This means limiting or eliminating the impact of risk factors that affect a person. How the body will strengthen against and resist stressful situations can be divided into several points. Preventing the creation of an unreasonable burden, dealing with an already existing burden and choosing the right decisions to deal with it. Strengthening rapid, effective regeneration and recovery. The last point is to look for other solutions to stress relief to some extent. When developing resilience to stress, it is essential to prevent existing potential stressors from becoming real. It is essential that everyone who wants to prevent stress finds out for themselves what causes stress in them. The individual should develop self-knowledge and also how he can use the help of other people and various technologies to manage stress. Another thing to focus on is the evaluation of the stressful situation, how important the situation is, the way in which the situation can be evaluated and whether it is possible for the individual to deal with the situation with their abilities. It is important to reconsider the question of whether it is necessary to be popular, to satisfy everyone at all costs and to solve other people's problems. These things lead to hasty and distorted conclusions that adversely affect and bother individuals. This can cause frustration and stress. It is necessary to focus on oneself and on things that are solvable, not on things that cannot be influenced. The cognitive aspect of work memory management can be used to build resilience to stressful situations. To prevent stress and strain, a technique can be used to stop negative thoughts by trying to think of positive things that make people happy. If an individual finds out which stimuli have a negative effect on him, he should learn from the situations he has experienced in the past. Another principle that is used to build resistance to stress is called psychological immunization. There are several ways to improve mental immunity. One solution is to avoid the disruptive and dangerous effects that the pilot encounters. However, this is just a theory, which is quite challenging in everyday life, because the pilot is exposed to various situations on a daily basis, which he often cannot even predict or influence. Different forms of training are a better option to adapt the individual to stressful situations. At the beginning, the pilot should be subjected to appropriate loads, but these should increase over time.

6.2. Time management

When working as a pilot, proper time management and preparation are important to prevent stressful situations. Pilots who start training and go to school have a lot of responsibilities and do not always manage to schedule their time. To make the most of your time, you need to clarify your priorities regarding how time is spent. In other words, it is necessary for people to realize what they want to achieve in their lives, set goals and find time in addition to all their responsibilities for things that make them happy. This should serve as a brief guide to how they should organize their time for each activity. Pilots in training should not neglect their training responsibilities so that they can prepare for the flight well in advance and devote sufficient time to pre-flight preparation. When planning time, in addition to training, they should take into account important things such as school, various other responsibilities and the family. People waste a lot of time in their lives especially with searching of various things, such as documents, clothes or other objects that they have founded or lost somewhere. Because of this, it is better to divide individual things into different categories and keep things in order. The advantage of the organization is systematic, better organization and a sense of control over certain things and situations. In practice, it is worthwhile to plan the individual things or tasks that need to be done only for a shorter period of time, for example what needs to be done on a given day, week or month, and also to divide these things according to importance. It is necessary to focus first on tasks that are demanding and that take a lot of time. People tend to put things aside until they end up with a lot of tasks that they can't cope with and thus come under psychological pressure. Then it can help to make a list of things and tasks that need to be done and gradually tick them off after they have been completed.

6.3. Elimination and stress reduction

How pilots cope with stress depends on whether they have ever experienced the situation, their experience of experiencing stress, and the nature of the individuals. However, if they want to deal with stressful situations and manage it, they should first get to know their body and find out how it reacts to individual situations or stressors. People are stressed especially when they place high demands on each other, they try to do their best and not to make any mistakes, they add extra work, they feel responsible for everything, they want everyone to like them and they also ignore all the symptoms that their body warns. It is desirable to eliminate the stress or at least reduce it as much as possible. There are several ways to try this and it might be for example practicing breathing methods, better time management, having good nutrition, having physical activity, taking medication and so on.

7. RESEARCH

In the research, we discuss issues related to stress and its impact on pilots in training, as well as the impact of kinetosis on pilots during flying. We used questionnaire, which was distributed among pilots who are recently in training, but also among those pilots who have already finished training. Data were subsequently collected and evaluated. The research in the next part of the diploma thesis is focused on the evaluation of individual questions. Before the questionnaire for pilots was compiled, a theoretical part had been first created in which the information was obtained by studying various literature and sources related to the issue, such as stress factors that affect pilots, how they are distributed and how stress manifests itself on pilots. The questionnaire consists of 16 questions, which were compiled on the basis of the chosen topic, where the pilots were asked questions about stress and motion sickness. The questionnaire was made in electronic form and was anonymous, which allowed respondents to answer truthfully and share their experiences. Subsequently, this questionnaire was sent to the pilots. During the period when the questionnaire was among the pilots until the time when the data were processed, the questionnaire was filled in by 72 respondents, from which 57 were men and 15 women. One of the respondents did not state his gender, but on the basis of verbal answer in the respondent's questionnaire, it was found that he was a man. At the beginning of the questionnaire, the sex of the respondents was ascertained and also at what age they started the training. These statistics were not included in 16 questions related to kinetosis and stress. They are in the questionnaire only to inform us. The questions in the questionnaire were mostly of the choice type and 2 of the questions were open, where the respondents were given space to give their own verbal answers. The questions were evaluated in the order in which they were included in the questionnaire. The questionnaire was created by Google forms software, which is used to collect and then evaluate data, based on which it creates graphs with individual answers.

7.1. Questionnaire

7.1.1. <u>Stages of training when the kinetosis appeared to pilot</u>

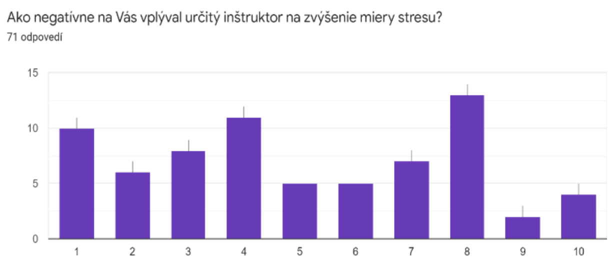
The first question evaluated in the survey was at what stage of training the pilots felt kinetosis. In 21 respondents, kinetosis during the flights did not occur at all, in another 21 it occurred mainly during the training phase of falls, slides and spirals. Other stages in which several pilots experienced kinetosis were picking out unusual positions, flying during strong turbulence that could be caused by thermals or strong winds, reconnaissance flights, but also when practicing emergency procedures such as engine shutdown or engine fire. During the other phases of training, the pilots showed kinetosis only to a lower extent.

7.1.2. Reduction of kinetosis symptoms

This question was asked in the questionnaire so that individual respondents could comment on how they tried to reduce or eliminate the symptoms of motion sickness. The question was answered by 55 respondents, 4 of whom said that they did not show kinetosis and therefore did not have to address how to reduce or eliminate the symptoms. According to the answers, the largest number of pilots tried to breathe deeply during the manifestations of kinetosis, to reduce the temperature in the aircraft and to let cold air into the cabin. The other numerous answers given in the questionnaire were of the type of looking out of the plane, either at the horizon or some fixed point, such as a hill or other fixed point that was on the ground and visible from the plane. Some of the respondents said that during the practice of the phases that caused them kinetosis, they took a break for a while, flew in horizontal flight and the symptoms of kinetosis eased after a while. Among the answers there was also mentioned that the manifestations of kinetosis in the respondents stopped after several years. Less common answers were, for example, chewing menthol chewing gum and using ginger.

7.1.3. Influence of the instructor

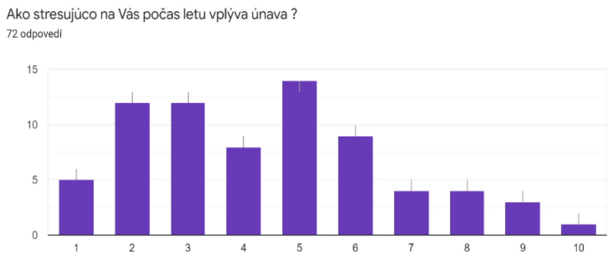
By asking the respondents, we wanted to find out if there is a negative effect that could affect pilots on the plane or on the simulator when there is a certain instructor that the respondents do not have good relationship with. In the questionnaire, respondents had the opportunity to choose a number from 1 to 10 on a scale, where 1 represents the lowest level of stress and 10 the highest. In this question, the largest number of respondents chose the number 8 on the scale, which represents a high level of stress. The second most numerous answer on the scale was number 4 and then number 1. The results of this question shows that the most numerous main groups of respondents were influenced by a certain instructor either to a high degree or to a low degree. The other answers in between were of about the same value.



The graph shows that the influence of the instructor on the increase of the pilot's stress in the training is not negligible, therefore the instructors should pay close attention to the pilot and create a friendly environment during the flight in the aircraft. They should communicate with each other and, if the pilot fails, find a solution to the problem. How the instructor treats the pilot greatly affects the pilot's level of stress, which can be reflected in the pilot's concentration, self-confidence, but also his performance.

7.1.4. Effect of fatigue

The answers of individual respondents to the question of the extent to, whether fatigue has a stressful effect on pilots, show that fatigue affects respondents in a medium degree of stress, which is shown in the graph, where most respondents voted on a scale from 1 to 10, where 1 represents the lowest stress level and 10 the highest, number 5. The second and the third most chosen option, which represents about 33%, were low to almost no fatigue stress. For less than 20% of the total number of respondents, the fatigue factor represents a high level of stress.



Based on the results, the number of respondents with fatigue which represents high level of stress is not entirely negligible. In order for these respondents to perform well during the flight, it is important that they take a break and gain strength before the flight. If the pilot is tired and unable to concentrate properly, it is at his discretion whether to fly or prefer to postpone the flight. Inattention while piloting can cause serious complications that can lead to fatal consequences.

7.1.5. How stressful do the phases and tasks of training work?

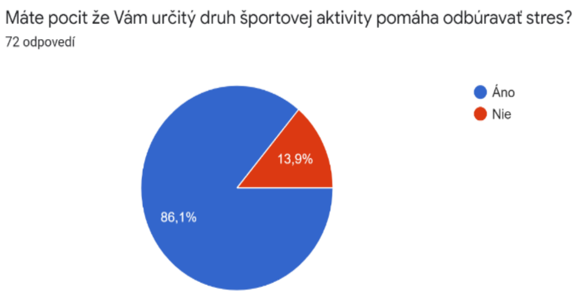
The question included the individual phases and tasks in the training, which were evaluated by the respondents by a number on a scale from 1 to 5, where the number 1 represents the lowest stress level and 5 the highest stress level. The lowest level of stress, according to chart number 13, was mainly affected by line flights, low-altitude circuits, comparative navigation, but also the basics of piloting and piloting techniques. Instrument flights and night flights, in which pilots have to rely mainly on instruments during the flight, affected the pilots' level of stress during training. According to the results shown in the graph, the slightly increased stress load was represented by emergency procedures and the selection of unusual positions. The phase in which the largest number of respondents chose the option of the highest level of stress was the phase in which falls, slips, spirals and high levels of stress were practiced in training.

7.1.6. Flying frequency and stress

The question was whether the pilot was affected by the increased frequency of flying to reduce the impact of stress. The question was asked because the increased frequency of flying, with pilots gaining more and more new experience and skills, should have a positive effect on reducing stress, as shown by the answers recorded in the graph. As many as 87.3% of respondents confirmed that the increased frequency of flying has a positive effect on the reduction of the stress rate, and only in 12.7% of the respondents the increased frequency of flying did not affect the stress rate.

7.1.7. The impact of sports activities

The graph shows how individual respondents voted on the question of whether a certain type of sports activity has an effect on reducing stress. Most of the respondents, which represents up to 62 of the total number of 72 respondents, confirmed the assumption that any type of sports activity has a beneficial effect on relaxation and reducing stress.



7.2. Research results and solutions

From the results of the questionnaire, we found that pilots who had symptoms of kinetosis during the flight, were caused mainly by more demanding elements, such as falls, slips, spirals, picking unusual positions, fall prevention, performing emergency procedures, flying during severe turbulence, but in some cases, manifestations of kinetosis also occurred during the reconnaissance flight. In the questionnaire, we also analyzed what causes increased stress for pilots. We found that a certain instructor, fatigue, but also the phases and training tasks that caused kinetosis, had also stressful effect on the pilots. On the contrary, the pilots are not affected by stressful factors, which we assumed would represent an increased level of stress, and these are, flights on the new track, hunger and hypoglycemia, noise and radio communication. Instructors should get into situation of young pilots who are starting training and from beginning of the training only take short flights with them, so pilots could used to the new environment which air space is. It is beneficial for novice pilots if there is good communication with the instructor and the right motivation from the instructor. During the manifestations of kinetosis during the demanding elements, the pilots said that it helps to interrupt the demanding flight tasks for a while, to put the plane into horizontal flight and to continue the exercise only when the symptoms subside. We assumed that cold air helped to alleviate the symptoms of kinetosis and that the pilot decreased symptoms by looking out of the plane. Our assumptions were met because several pilots raised these options in an open-ended question. If novice pilots have problems with kinetosis, an individual and patient instructor approach is needed. With the correct procedure of the instructor, the kinetosis will gradually disappear.

8. HEART RATE MEASUREMENT

In addition to the questionnaire, which was sent out to the pilots and which was subsequently evaluated, measurements were also made to verify what was stressful to the pilots during the flight. The purpose of this measurement was to determine which phases and tasks cause the highest level of stress for the novice pilot, and the aim of these measurements is to help pilots as well as instructors to choose the right approach to training tasks so that the stress is as low as possible for the pilot. After discussing with the tutor, who is also a flight instructor, testing was performed on one of the beginning pilots in the training, who was willing to cooperate.

The increase in stress is measurable in several ways and in several parts of the body. Under the influence of stress on the pilot, many changes take place in the body, which are affected by the secretion of stress hormones. The changes that take place in the body are both physically manifested, which can be observed and measured. These include rapid breathing, decreased body temperature, rapid eye movement, enlarged pupils, increased muscle tension and increased heart rate. From these measurable physiological signals, we chose heart rate measurement

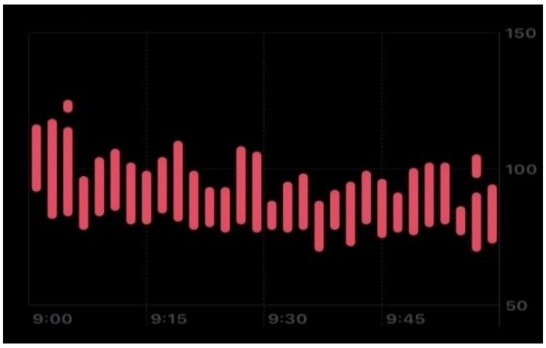
8.1. The course of measurement

The choice of heart rate measurement was chosen based on the easy availability of measuring devices. Heart rate can be measured at multiple parts of the body, such as the wrist or chest. For heart rate measurements, there are simple devices such as a watch or chest strap that send the recorded values to an application installed on the mobile device. With regard to the pilot's comfort, we chose to measure the heart rate on the wrist using an Apple Watch, which, after recording the heart rate, transmits the individual recorded data to the Health application, which was installed in iPhone devices. The pilot on whom the measurements were performed, flew on Zlín 242L aircraft and all these measurements took place at the public international airport Žilina with the designation LZZI, which is located at an altitude of 311 meters above sea level and has a concrete-asphalt runway with a length of 1150 meters. The pilot performed 10 measurements, which started with the circuit phases and ended with solo flight and relaxation in quiet mode.

8.2. Measurement

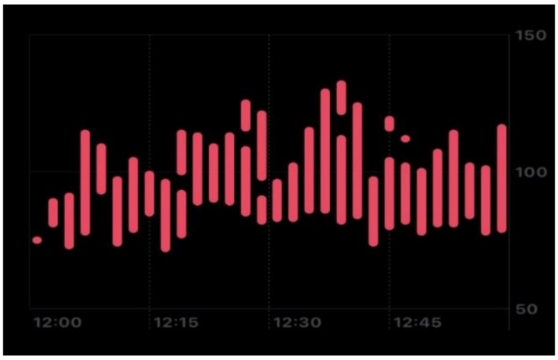
8.2.1. Measurement n.1

The first measurement involved 45° turn and practice of preventing a fall from a straight flight, a climb, a descent and a turn. During the measurement, a heart rate in the range of 71 - 124 beats per minute was recorded. The pilot's highest heart rate prevailed at the beginning of the flight and later decreased. The increased heart rate during the flight was measured at times when the pilot and instructor performed the individual elements, which followed in the order in which they were mentioned.



8.2.2. <u>Measurement n.2</u>

Measurements in the phase during which the pilot practiced the avoidance of unusual positions, the avoidance of the spiral showed that these individual tasks seem relatively stressful. The pilot's heart rate ranged from 72 to 132 beats per minute, with an increased heart rate prevailing during the measurement. It can be seen that at the time of 12:37, when the pilot was practicing the prevention of falling from the spiral, his heart rate was the highest and therefore this task caused the greatest degree of stress to the pilot.



8.2.3. <u>Measurement n.3</u>

This measurement was recorded on the day when the pilot completed his first solo flight - circuits. Before that, however, he completed this phase, which was the circuits - the activity of stopping the engine. The flight took place between 10:20 - 11:00 and the pilot's heart rate in training was in the range of 83 - 131 beats per minute. The lowest level of the heart frequency was higher than usual, which could be caused by increased stress because of the solo flight during the day. The graph shows how the heart rate was risen and fallen down during fall prevention during engine shutdown training as well as during landings.

8.2.4. <u>Measurement n.4</u>

This graph shows how the first solo flight affected the pilot's degree of stress, which was reflected in an increased heart rate in the range of 77 - 134 beats per minute. The solo flight took place immediately after the end of the previous measurement, which was the progress test before the first solo flight. At this stage, the pilot recorded the highest heart rate compared to the measurements taken since the beginning of the research. The graph shows that the solo flight had a greater impact on this particular pilot than the other phases and tasks in the training.

8.3. Analysis and results of measurement

The measured values, which resulted from the individual graphs of heart rate measurement, confirmed the expected assumptions, which approached the results from the questionnaire, except for the training phase of engine shutdown. At this stage, the pilot was expected to have a higher degree of stress. This could be due to the fact that the pilot was well prepared for this phase. This phase is first rehearsed on the ground and the pilot must apply the engine shutdown procedures by heart. At the same time, the pilot expected the engine to stop and knew when it would happen. Graph 26 shows the phases of training during which the highest heart rate was measured. The graph shows that the following phases have the highest stress on a pilot during basic training:

- first solo flight - circuits;
- selection of unusual positions of falls, slips, spirals;
- first circuits;
- bends with an inclination of 45 °, fall prevention;
- emergency procedures training;
- engine shutdown.

ACKWOLEDGEMENT

This paper is an output of the project of the Ministry of Education, Science, Research and Sport of the Slovak Republic KEGA 040ŽU-4/2022 Transfer of progressive methods of education to the study program "Aircraft Maintenance Technology" and "Air Transport".

REFERENCES

[1] KRASKA-LÜDECKE, K. 2007. Najlepší techniky proti stresu. Vydanie 1. Praha: Grada Publishing, 2007. 116s. ISBN 978-80-247-1833-0.

[2] MELGOSA, J. 1994. Zvládni svoj stres! Preklad 1998. Vrútky: Advent-Orion, 1998, 190s. ISBN 80-88719-81-X

[3] GEISSELHART, R. – HOFMANN-BURKART, CH. 2006. Zvítězte nad stresem. Vydanie 1. Praha: Grada Publishing. 2006. 112s. ISBN 80-247-1518-X.

[4] SELADI-SCHULMAN, J. Hypothalamus Overview. [online] Dostupné na internete: https://www.healthline.com/human-body-maps/hypothalamus?fbclid=IwAR1Sf6UwpqJTe_PRm7e9J

1G6UCQNVaH1zp2DeMfZXCuDgeScmu8OTvvCTss -hormones

[5] PAULÍK, K. 2017. Psychologie lidské odolnosti. Vydanie 2., prepracované a doplnené vydanie. Praha: Grada, 2017. 368 s. ISBN 978-80-247-5646-2

[6] ĎURÍKOVÁ, K. Trochu stresu neuškodí ale pozor, ak je ho príliš. [online] Dostupné na internete: https://eduworld.sk/cd/kornelia-durikova/6546/trochu-stresu-neuskodi-ale-pozor-ak-je-ho-prilis (cit. 2022-01-15)

[7] ŠARAFÍN, M. Fajčenie a stres [online] Dostupné na internete: https://stromzdravia.sk/zdrave-dychanie/fajcenie-a-stres/ (cit. 2022-01-23)

[8] VITAMINYPREZDRAVIE. 2021. Prečo je spánok dôležitý? [online] Dostupné na internete:https://www.vitaminyprezdravie.sk/aktuality/preco-je-spanok-dolezity/ (cit. 2022-02-05)

[9] NZIP. 2022. Psychosomatika: co to je? [online] Dostupné na internete: https://www.nzip.cz/clanek/712-psychosomatika-zakladni-informace (cit.2022-03-10)

[10] TÓTH, L. 2018 Čo je hyperventilácia? Dýchavičnosť, tŕpnutie tváre, rúk, kŕče svalov vetrom [online] Dostupné na internete: https://zdravoteka.sk/magazin/hyperventilacia-nie-len-stazene-dychanie-a-trpnutie-tvare-ruk-noh-az-svalove-krce/

[11] VILÍMOVSKÝ, M. 2021. Hyperventilácia: všetko čo potrebujete vedieť. [online] Dostupné na internete: https://sk.medlicker.com/1903-hyperventilacia-nadmerne-dychanie (cit.2022-04-07)

[12] BARTOŠOVÁ. Z. 2021. Ako premôcť stres? [online] Dostupné na internete: https://www.drmax.sk/poradna/ako-premoct-stres (cit.2022-04-09)

[13] SME PRIMÁR. 2021. Otužovanie priaznivo vplýva na psychiku. Odbúrava stres a zlepšuje spánok [online] Dostupné na internete: https://primar.sme.sk/c/22628396/otuzovanie-priaznivo-vplyva-na-psychiku-odburava-stres-a-zlepsuje-spanok.html (cit.2022-04-09

[14] MELGOSA, 1994, s. 28

[15] NOVÁK SEDLÁČKOVÁ, A., PITOR, J., MRÁZOVÁ, M. 2015. Crisis management in aviation. 1. vyd. - Bratislava : DOLIS, 2015. - 152 s., ilustr. - ISBN 978-80-8181-000-8.

[16] PECHO, P., HRUZ, M., SKVAREKOVA, I., AZALTOVIC, V. 2020. Optimization of Persons Localization Using a Thermal Imaging Scanner Attached to UAV. NTinAD 2020 - New Trends in Aviation Development 2020 - 15th International Scientific Conference, Proceedings, 2020, pp. 192–196, 9379095. ISBN 978-172817325-2.

[17] Ažaltovic, V., Škvareková, I., Pecho, P., Kandera, B. 2020. The correctness and reaction time of piloting the unmanned aerial vehicle. Transportation Research Procedia, 2020, 51, pp. 342–348. ISNN 23521457.

https://doi.org/10.26552/ pas.Z.2022.2.05

BAGGAGE POLICY OF EUROPEAN AIRLINES

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Abstract

The purpose of this article is to research the baggage policy of European airlines. Its main objective is to identify groups of European airlines based on the used baggage policy and to compare the baggage policies of selected European air carriers in terms of cost-effectiveness for a passenger. The current state of baggage policy research, focusing mainly on the United States, has highlighted the lack of comprehensive research on European air carriers' baggage policies. Therefore, the actual research in this paper examines European airlines' carry-on and checked baggage policies and their charging. It then uses two model cases to compare the baggage policies of selected airlines in terms of cost-effectiveness for the passenger and examines the pricing applied to baggage fees. The research results in the determination of the most advantageous booking method with respect to baggage fees. Simultaneously, three groups of European airlines were identified according to the baggage policy used.

Keywords

airline, baggage, baggage policy, checked baggage, hand baggage, baggage fees, Europe

1. INTRODUCTION

Baggage fees were largely introduced as a response to rising jet fuel prices. Despite subsequent reductions in fuel prices, the baggage fees have not been reduced or abolished, but have become a fixed part of airline baggage policy. Since 2010, baggage fees have even been supplemented by cabin baggage fees. Although at first sight it might appear to be a sort of ancillary service, it is in fact a powerful tool that contributes significantly to airlines' profit generation, not only directly, but this revenue also allows them to generate interesting offers in other areas, such as low base tickets fares. Baggage policy can therefore be considered as an important part of airlines' revenue management that can improve their bottom line. Proper management of this area is thus becoming a necessity for airlines, through which an airline can significantly differentiate itself from competitors, build a positive image and, last but not least, attract new customers. The literature available to date on the topic of baggage policy often refers to older sources from 2008-2012 and focuses primarily on US air transport markets and US airlines. There is no more comprehensive body of research on European air carriers' baggage policies. If these carriers are mentioned in academic or technical articles, this is only sporadic and based on anecdotal evidence. For this reason, research is necessary and justified in the European context.

2. AIRLINES' BAGGAGE POLICY FROM A THEORETICAL PERSPECTIVE

Most airlines allow customers to bring some luggage on board for free - included in the ticket price. This is the so-called cabin baggage (or hand baggage/luggage or carry-on baggage), the size or weight of which is limited, and each airline sets these parameters according to itself [1]. Some airlines even allow only personal items to be carried on the cheapest fare. This is an item with a relatively small dimensions, which does not allow the carriage of other than truly essential items. Carry-on baggage is placed on board in the overhead compartment and the personal item under the seat in front of the passenger. Another restriction is that many items are prohibited from being carried in hand luggage. For security reasons, their presence on board an aircraft is prohibited [2].

If a passenger needs to carry a larger volume of luggage or needs to transfer items that cannot be carried on board, there is the option of using checked baggage. Checked baggage (also hold luggage) is transported in the baggage/cargo compartment of the aircraft. On arrival at the airport, it is handed over to the airline at the check-in counter.

Airlines' baggage policies are strongly linked to their business model. While a more generous baggage policy can be expected in the traditional business model, where in some cases baggage is carried without additional charges, low-cost airlines can be expected to charge fees. However, scholarly articles have produced a surprising result in that in the USA. Most airlines with a traditional business model charge a fee for checked baggage and, conversely, the low-cost airline Southwest does not charge a fee [3].

Using unbundling of airlines’ services, baggage transportation has essentially become a separate service that can be sold separately from the ticket.

2.1. Unbundling

Tomová et al. define an unbundled product, offered by airlines, as the air transport itself without additional on-board services or with services in a lower range [4].

"Unbundling" of air carriers' services reflects the process of separating ancillary services from the core service - the actual carriage of the passenger. At the same time, "unbundling" can mean charging additional fees for the provision of ancillary services. Garrow et al. argue that many US airlines have implemented measures to reduce costs and generate ancillary revenue in the first decade of the 21st century [5].

Jason Holland, divides airline ancillary revenues into several categories and compares them to each other. The highest proportion, up to 27% of ancillary revenue, is baggage fee revenue [6]. For low-cost airlines, this ratio is expected to be even higher [6]. According to cartrawler.com, the share of ancillary revenues in total revenues has been increasing year on year [7]. This data illustrates the importance of ancillary revenues, including their most important component, baggage fee revenues.

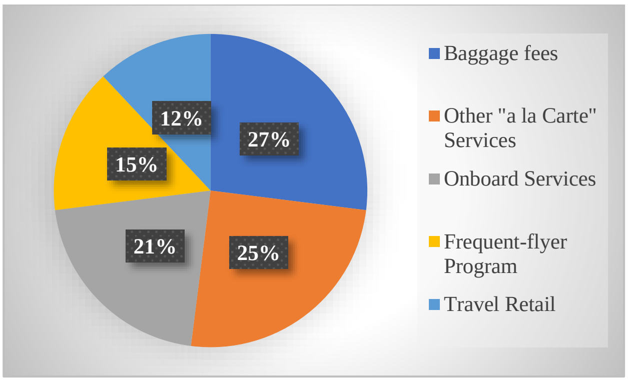

CHART 1 ANCILLARY REVENUES OF AIRLINES WITH TRADITIONAL BUSINESS MODEL, 2017, SOURCE: COMPILED BY THE AUTHOR FROM [6]

3. THE CURRENT STATE OF BAGGAGE POLICY RESEARCH

The current research is largely focused on the airlines operating in the USA. The focus of research can be divided as follows. The collective of authors Barone et al [8] and Scotti et al. [3] focuses on the impacts of baggage policy on the airlines. Wong et al. [9] and Allon et al. [10], in turn focus on the shape of ideal baggage policies. Jiang et al. [11] investigate the impacts of baggage policy on airport infrastructure. The authors' collectives of Scotti et al. [12], Hamilton et al. [13] and Cho et al. [15] investigate the impacts on passengers. Garrow et al. [5], Henrickson et al. [14] and Schrager [16] look at the actual "unbundling" of airline services. All the aforementioned research focuses on US airlines and largely omits European airlines and their baggage policies.

Recent research has shown the positive impact of baggage fees on airlines' operational performance [8][3], on the other hand it shows passengers' dissatisfaction with the introduction of fees for services that used to be free [12]. However, a negative impact of baggage fees on passenger demand has not been demonstrated, as passengers have a higher elasticity for basic fares, but a lower elasticity has been demonstrated for ancillary services, such as baggage fees [12]. It was the introduction of baggage fees that many times the price for the base fare could be reduced. A major problem associated with the introduction of checked baggage fees is the increased number of carry-on bags as a response of passengers to such fees [11]. The increased number of carry-on bags creates an unreasonable congestion on security control [11]. Elimination of this unfavourable associated phenomenon can be achieved by introducing fees also for cabin bags, which has already been used by some, especially low-cost airlines.

The research on baggage policy is interesting from the point of view of several aspects, such as the introduction of checked and cabin baggage fees, the pricing of these fees, the impact of the fees on the economic performance of airlines, on operational characteristics, the impact of the fees on passengers, airports and so on. However, there is no more comprehensive body of research on the baggage policies of European air carriers. If these carriers are mentioned in scientific or technical articles, it is only sporadically and based on anecdotal evidence. The research to date refers many times to older sources from 2008-2012, which is also why the research needs to be updated.

4. RESEARCH ON THE BAGGAGE POLICIES OF SELECTED EUROPEAN AIRLINES

4.1. Research objectives

The aim of the research is to compare the baggage policies of selected European air carriers in terms of cost-effectiveness for the passenger based on two model situations and to identify groups of European air carriers according to the baggage policies used. The first situation is a flight of one passenger with cabin baggage and the second situation is a flight of a family of four with one cabin baggage and two checked bags. At the same time, the aim is to identify and research the differences between the approaches of traditional and low-cost airlines to baggage policy.

4.2. Selection of airlines

The airlines were selected according to their size, as determined by the number of passengers carried, combined with the airline's revenue and their business model. Five airlines with a low-cost and five with a traditional business model were selected. However, it should be emphasized that airline business models are undergoing hybridisation and may exhibit attributes that are typical of an oppositional business model. In the case of groups composed of several airlines, such as the Lufthansa Group, only one airline, namely the largest airline, has always been selected. Russian airlines were not included in the research as it would not have been possible to make comparisons on the selected flights from Milan and Mallorca, due to the sanctions imposed and the ban on flights in the airspace of EU countries [16].

4.3. Description of model cases

Two model cases were created to examine air carriers' baggage policies using specific examples:

1. Flights from Milan to city destinations and back
2. Flights to and from the holiday destinations of Palma de Mallorca and Barcelona respectively

From the analysed airlines, pairs were created that were identical in both model examples. Each pair was formed from one low-cost and one traditional/network airline as shown in table 1.

TABLE 1: SELECTED GROUPS OF AIRLINES AND ROUTES, SOURCE: OWN RESEARCH

No.	Airline	1. model flight	2. model flight
1.	Ryanair	Milan - Frankfurt	Frankfurt - Palma de Mallorca
	Lufthansa		
2.	Easyjet	Milan - Paris	Paris - Palma de Mallorca
	Air France		
3.	Wizz Air	Milan - London	London - Palma de Mallorca
	British		
4.	Pegaus	Milan - Istanbul	Istanbul - Barcelona
	Turkish		
5.	Norwegian	Milan - Oslo	Oslo - Palma de Mallorca
	SAS		

In the first model situation, airfare costs for one adult passenger from the business traveller segment on a route from one of the Milan airports to a selected destination of a given airline pair was calculated. To the total price was added the price for one large cabin baggage, in cases where such baggage is charged by the airline. Departure from Milan was set for Tuesday 3.5.2022 and arrival in Milan for Thursday 5.5.2022. The booking date was 14.4.2022, approximately three weeks in advance.

In the second model situation, airfare costs for two adults, one child and one infant were calculated. The purpose of the journey was a family vacation from the selected departure airport to the holiday destination of Palma de Mallorca. The selected departure city was the same for both airlines forming the pair, but the airport in the city/region could be different. Pegasus and Turkish airlines were assigned the destination Barcelona in the model example. The price for the carriage of a large cabin baggage and two 20 kg checked bags if charged by the airline, was added to the total base price. Arrival in Palma de Mallorca or Barcelona was set for Saturday 26.6.2022 and departure from Palma de Mallorca/Barcelona for Saturday 3.7.2022. The booking date for all flights was 15.4.2022, approximately ten weeks in advance.

The following tables contain information on the fares/packages offered by selected European air carriers, together with the conditions for baggage transport. The airlines have been divided into tables according to their business model. Table 2 illustrates that the low-cost airlines studied offer between three and four service packages from which the passenger chooses when booking. The low-cost airlines analysed, apart from Pegasus Airlines, offer a completely basic package. The package price includes the air transport itself, with the option to take only a small cabin bag. Pegasus Airlines, on the other hand, does not carry more than one cabin bag under any circumstances and passengers must choose whether to take one small cabin bag or one large cabin bag on board.

TABLE 2: FARES AND BAGGAGE CONDITIONS – LOW-COST AIRLINES, SOURCE: OWN RESEARCH

	Fare	Small cabin bag	Large cabin bag	Checked baggage
Ryanair	Value	☑ 40x20x25 cm	✕	✕
	Regular a Flexi Plus	☑ 40x20x25 cm	☑ 55x40x20 cm, 10kg	✕
	Plus	☑ 40x20x25 cm	☑ 55x40x20 cm, 10kg	☑ 1x 20kg
Wizz Air	Travel Light	☑ 40x30x20 cm	✕	✕
	Pack and Save	☑ 40x30x20 cm	☑ 55x40x23 cm, 10kg	☑ 1x 20kg
	All in and Full Flex	☑ 40x30x20 cm	☑ 55x40x23 cm, 10kg	☑ 1x 32kg
Easyjet	Standard	☑ 45x36x20 cm, 15kg	✕	✕
	Flexi	☑ 45x36x20 cm, 15kg	☑ 56x45x25 cm	☑ 1x 23kg
Norwegian	Low Fare	☑ 30x20x38 cm, 10kg	✕	✕
	Low Fare +	☑ 30x20x38 cm	☑ 55x40x23cm, 10kg	☑ 1x 23kg
	Flex	☑ 30x20x38 cm	☑ 55x40x23cm, 15kg	☑ 2x 23kg
Pegasus	Basic	✕	☑ 55x40x20 cm	✕
	Essentials, Advantage, Comfort Flex	✕	☑ 55x40x20 cm	☑ 20kg

Table 3 presents the baggage rules of airlines with a traditional business model, of which only SAS offers a package that does not include the transportation of a large cabin bag. All other airlines allow the carriage of one small and one large cabin bag even in the cheapest package. Turkish Airlines, unlike other traditional airlines, carries one checked bag even in the cheapest package. It is thus the only airline in the analysis that does not charge at all for the first bag and only starts charging for the second checked bag on some fares. A major difference is in the way the airlines approach the checked baggage limits. While Turkish Airlines and Pegasus Airlines limit only the total weight of checked-in baggage but not the number of bags, the other airlines apply the 'piece concept'. This means that in addition to the maximum weight allowed, they also limit the quantity of checked baggage. However, for Turkish airlines, a passenger can bring any number of bags, but the total weight cannot exceed a set weight, e.g., 20 kg [48], [51].

TABLE 3: FARES AND BAGGAGE CONDITIONS – TRADITIONAL AIRLINES, SOURCE: OWN RESEARCH

	Fare	Small cabin bag	Large cabin bag	Checked baggage
Lufthansa	Economy Light	✓ 30x40x10 cm	✓ 55x40x23 cm, 8 kg	✗
Lufthansa	Economy Classic, Economy Flex	✓ 30x40x10 cm	✓ 55x40x23 cm, 8 kg	✓ 23kg
Lufthansa	Premium Economy	✓ 30x40x10 cm	✓ 55x40x23 cm, 8 kg	✓ 2x 23kg
Lufthansa	Business	✓ 30x40x10 cm	✓ 2ks 55x40x23 cm, 8 kg	✓ 2x 32kg
Lufthansa	First	✓ 30x40x10 cm	✓ 2ks 55x40x23 cm, 8 kg	✓ 3x 32kg
Air France	Economy Light	✓ 40x30x15 cm	✓ 55x35x25 cm, 12kg	✗
Air France	Economy (Standard, Standard Plus, Flex)	✓ 40x30x15 cm	✓ 55x35x25 cm, 12kg	✓ 1x 23kg
Air France	Premium Economy	✓ 40x30x15 cm	✓ 2ks 55x35x25 cm, 18kg	✓ 2x 23kg
Air France	Business (Standard, Flex)	✓ 40x30x15 cm	✓ 2ks 55x35x25 cm, 18kg	✓ 2x 32kg
	La Première	✓ 40x30x15 cm	✓ 2ks 55x35x25 cm, 18kg	✓ 3x 32kg
Turkish	Economy	✓ 40x30x15 cm	✓ 55x40x23 cm, 8kg	✓ 20kg
Turkish	Business	✓ 40x30x15 cm	✓ 2ks 55x40x23 cm, 8kg	✓ 30kg
British	Economy Basic	✓ 40x30x15 cm	✓ 56x45x25cm	✗
British	Economy Plus	✓ 40x30x15 cm	✓ 56x45x25cm	✓ 1x 23kg
British	Business	✓ 40x30x15 cm	✓ 56x45x25cm	✓ 2x 32kg
SAS	Go Light	✓ 40x30x15 cm	✗	✗
SAS	Go Smart, Plus Smart, Go Bonus, Plus Bonus	✓ 40x30x15 cm	✓ 55x40x23 cm, 8 kg	✓ 1x 23kg
SAS	Plus Pro	✓ 40x30x15 cm	✓ 55x40x23 cm, 8 kg	✓ 2x 23kg
SAS	Business a Business Bonus	✓ 40x30x15 cm	✓ 55x40x23 cm, 8 kg	✓ 2x 32kg

4.4. First model case - Milano case

In the first model case, the resulting prices for the transportation of one passenger with large cabin baggage on flights from Milan with departure date 3.5. and arrival date 5.5. are compared.

When booking, the passenger can proceed in two ways. The first, and on routes from Milan the cheapest, is to choose the basic - the cheapest package, or to choose only the air transport itself, without additional services. In this case, the carriage of large cabin baggage must be purchased with some airlines. The second option would be to choose a package with higher package, which includes the carriage of large cabin baggage. However, such a package may also include services that the passenger will not use and, ultimately, such a choice may disproportionately increase the final amount paid by the customer.

For all airlines, the basic product is the cheapest option for flights from Milan and for one person with large cabin bag. Ryanair, Wizz Air, Easyjet, Norwegian and SAS charge a fee for carrying the required cabin baggage, which is added to the base fare. Lufthansa, British, Air France, Pegasus, and Turkish carry the required hand baggage free of charge, already included in the basic fare. In all the pairs created by the airlines, the airline with the low-cost business model offers the lowest final fare, sometimes with a smaller price difference compared to a traditional airline and sometimes with a larger one.

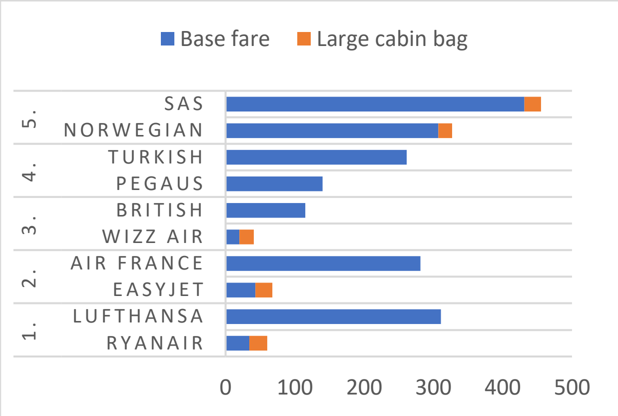

CHART 2: COMPOSITION OF THE FINAL PRICE OF THE BASE FARE WITH BAGGAGE FEE ON FLIGHTS TO/FROM MILAN, SOURCE: OWN RESEARCH

4.5. Second model case - Palma de Mallorca case

In the second model case, the resulting prices for the transportation of four passengers with one large cabin bag, two 20 kg checked bags and one pushchair on flights from Palma de Mallorca with departure date 26.6. and arrival date 3.7. are compared. The lowest amount of all the packages offered by the airline is, for most airlines, the price for the basic product.

For British Airways, the family in the model example will find it is more cost effective to book a flight on the higher Economy Plus fare. This is because the Economy Plus package includes the carriage of 20 kg of luggage and cabin baggage in addition to the air travel itself, as requested by the family. The Economy Basic package includes only the air transport with cabin bag, whereas the family would have to pay a fee for the required checked baggage. This would make the package more expensive by 49,46€. The same situation is the case when using SAS services. In this case, it is worthwhile for passengers to book a flight with the Go Smart fare, the resulting amount of which is slightly lower than the basic product, and even passengers receive extra services. This is again due to the high baggage fees, which, on the other hand, are already included in the Go Smart package.

While only Ryanair, Wizz Air, Easyjet, Norwegian and SAS charge a fee for large cabin baggage in combination with the basic fare, all analysed airlines except Turkish charge a fee for checked baggage in combination with the basic fare. An interesting finding is that when a given family travels, the differences between the resulting amount of the compared low-cost and traditional airlines are significantly reduced. In some of the airline pairs compared, a family would even travel cheaper with a traditional airline than with a low-cost airline. Specifically, these are flights from London with British Airways and from Istanbul with Turkish Airlines. In the other pairs, the low-cost airline still offers the lowest final fare.

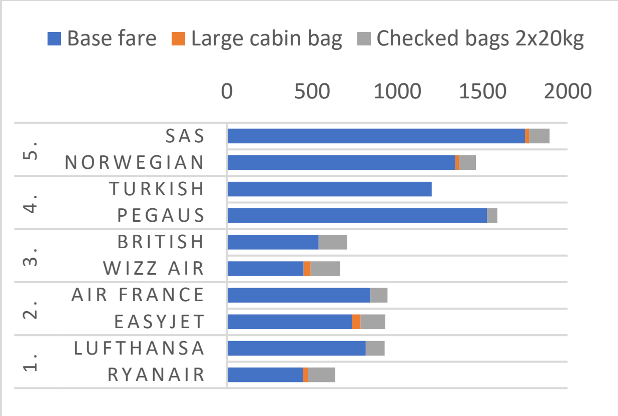

CHART 3: COMPOSITION OF THE FINAL PRICE OF THE BASE FARE WITH BAGGAGE FEE ON FLIGHTS TO/FROM PALMA DE MALLORCA, SOURCE: OWN RESEARCH

The following chart 4, shows the differences in average prices for large cabin bag. While Norwegian and SAS apply fixed prices on all flights, Ryanair, Wizz Air and Easyjet demonstrate dynamic pricing applied to baggage fees. Dynamic pricing and differences in pricing can be seen between different routes as well as on the same route on different days.

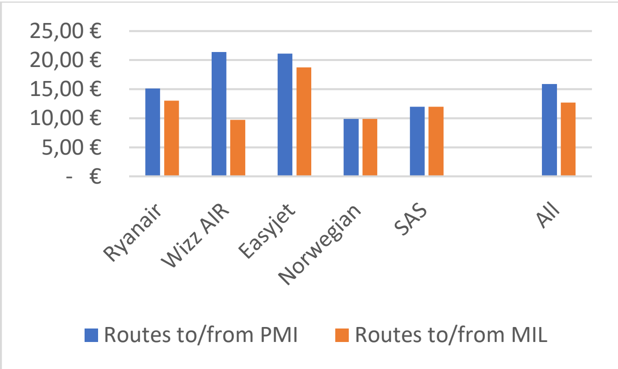

CHART 4: COMPARISON OF AVERAGE FEES FOR LARGE CABIN BAGGAGE, SOURCE: OWN RESEARCH

The following chart shows the differences in average prices for the carriage of checked baggage. While only Lufthansa applies on average the same level of baggage fees on all flights, the other airlines show evidence of dynamic pricing applied to baggage fees. Dynamic pricing and variations in prices can be seen between different routes as well as on the same route. All airlines that apply dynamic pricing have higher baggage fees in place on routes to and from Palma de Mallorca compared to fees on routes from Milan

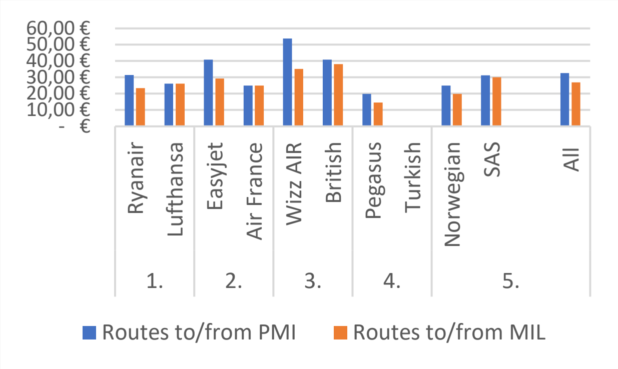

CHART 5: COMPARISON OF AVERAGE CHECKED BAGGAGE FEES, SOURCE: OWN RESEARCH

4.6. Airline revenues

U.S. airlines are required to disclose their revenues divided into five separate accounts [17]. The revenue categorisation is as follows: passenger revenue, other transport-related revenue, baggage fee revenue, revenue from cancellation fees, and miscellaneous revenue. Unlike US airlines, European airlines do not disclose revenue from baggage fees but from a whole group of ancillary services, including baggage fees. According to research, baggage fees account for the largest part of ancillary revenues [6] and can therefore be used to derive an approximate level of baggage fee revenues. The revenue data refer to fiscal years 2019 and 2020, with Ryanair and Wizz Air having fiscal years from 1 April to 31 March, Easyjet from 1 October to 30 September, SAS from 1 November to 31 October and the other airlines in the analysis from 1 January to 31 December.

Table 4 shows, for most low-cost airlines, the level of core revenues, which represent, for example, revenues from passenger traffic itself. It also shows ancillary revenues, which represent revenues from the sale of ancillary services. Ancillary services may include baggage fees. For Easyjet, Ryanair and Wizzair, total revenue is the sum of core and ancillary revenue. Norwegian also reports 'other revenues' in its annual reports, which together with core and ancillary revenues make up total revenues. Highlighted in green are the percentages of ancillary revenues in total revenues, which account for 16-56% for the airlines analysed.

All airlines analysed that report ancillary revenues also report a year-on-year increase in their share of total revenues. In the case of Wizz Air, these revenues even account for more than half of the total revenues. Thus, it can be argued that in the fiscal year 2020, Wizz Air will generate €0.56 of ancillary revenues out of €1 of total revenues. Airlines with a traditional business model and Pegasus Airlines do not report ancillary revenues in their annual reports. Air France only reports total revenues together with KLM in its annual reports, so they are much higher than for other airlines. All revenues are in millions of euros and those of British Airways, Easyjet, Norwegian Air Shuttle, Pegasus Airlines, SAS, and Turkish Airlines have been converted at the current exchange rate set by the European Central Bank as at 23.4.2022 [18].

TABLE 4: REVENUES OF SELECTED EUROPEAN AIRLINES, SOURCE: COMPILED BY THE AUTHOR FROM AIRLINE ANNUAL REPORTS

(millions €)	**2020**			**2019**		
Airline	**Core rev.**	**Ancillary rev.**	**Total rev. 2020**	**Core rev.**	**Ancillary rev.**	**Total rev. 2019**
Wizz Air	325,7	413,3	739	1508,50	1252,80	2761,30
% Of ancillary revenues		55,90%			45,40%	
Ryanair	1036,00	600	1636,00	5566,00	2929,00	8495,00
% of ancillary revenues		36,70%			34,50%	
Easyjet	2744,12	841,23	3585,34	5968,42	1639,56	7607,98
% of ancillary revenues		23,50%			21,60%	
Norwegian Air Shuttle	670,65	159,48	944,96	3658,65	691,03	4521,52
% of ancillary revenues		16,90%			15,30%	
Airline	**Total revenues 2020**			**Total revenues 2019**		
Air France - KLM	8 571,00			22 251,00		
Lufthansa	4 104,00			16 634,00		
British Airways	4 767,35			15 835,57		
Turkish Airlines	3 505,59			10 323,56		
SAS	1 995,82			4 547,19		
Pegasus Airlines	301,27			691,47		

Table 5 shows in the third and fourth columns the difference in the resulting prices paid by customers on the traditional airlines when compared with a selected competing low-cost airline. The third column refers to the first model case. The amount is for the carriage of one passenger and one large cabin bag on a return flight from Milan. The cheapest airline offers are compared. The table shows that in all five cases such a journey with a low-cost airline is cheaper. For example, Lufthansa offers a return flight on the same route and date at a price that is up to 416.1% higher than the compared airline Ryanair.

4.7. Evaluation of research results

TABLE 5: COMPARISON OF THE FINAL FARE WITH A TRADITIONAL AIRLINE VERSUS A LOW-COST AIRLINE, SOURCE: OWN RESEARCH

No.	Airline	1. case	2. case
1.	Ryanair		
	Lufthansa	+416,1%	+45,3%
2.	Easyjet		
	Air France	+317,0%	+1,3%
3.	Wizz Air		
	British	+182,0%	-1,2%
4.	Pegaus		
	Turkish	+86,8%	-24,3%
5.	Norwegian		
	SAS	+39,3%	+28,7%

On the other hand, in the fourth column, where the second model case of return flights to Palma de Mallorca is compared, the differences between the cheapest offers of the compared airlines are significantly smaller. In two cases, such a journey is even cheaper with a traditional airline. Such a situation is mainly due to the large amount of luggage that the family requires to be transported. Especially in the case of low-cost airlines, the family pays high baggage fees. Also, the minimal price difference on flights to Palma de Mallorca can be justified by the fact that it is a holiday destination and the summer tourist season.

The airlines studied can be divided into three groups according to the baggage policy applied. Of the selected airlines, only Turkish Airlines belongs to the first group, which carries both cabin baggage and first checked baggage in the basic package price. The second group, which charges for first checked baggage but carries cabin baggage as part of the basic package, includes the traditional airlines Air France, British Airways and Lufthansa and the low-cost airline Pegaus Airlines. The third group with both first checked and large cabin baggage fees includes low-cost airlines Easyjet, Norwegian, Ryanair, Wizz Air, and the traditional airline SAS.

TABLE 6: IDENTIFICATION OF AIR CARRIER GROUPS ACCORDING TO THEIR BAGGAGE POLICY, SOURCE: OWN RESEARCH

Cabin & 1. checked baggage for free	Cabin baggage for free	Charched all types of baggage
Turkish	Air France	Easyjet
	British	Norwegian
	Lufthansa	Ryanair
	Pegaus	SAS
		Wizz Air

In some cases, charges increase as the departure date approaches, in other cases depending on whether the flight is scheduled to take place in the high or low season. In the case of both checked and cabin baggage, the average price of luggage on airlines to and from Palma de Mallorca is higher. Such increased charges compared to flights from Milan could be observed both during the high season and in the low season. For this reason, it is important to emphasise that the price differentiation of baggage charges also depends on the destination.

CONCLUSION

The article studied the baggage policy of European airlines. The literature available so far on the topic of baggage policy often refers to older sources from 2008-2012 and focuses primarily on the US airline service markets and US airlines. These research were mentioned in the introductory chapters of the paper and predetermined its future direction.

The article conducts the actual research on European airlines' baggage policies in the form of model cases. In these model cases, the differences in the conditions of transport of checked and cabin baggage by the selected airlines were investigated. While in the first case with a single passenger the convenience of travelling with low-cost airlines was confirmed, this was not the case in the second case. In the second model case, a family of four was travelling for a summer holiday and such travel was cheaper with a traditional airline in some cases and in all cases the price differences between low-cost and traditional airlines were reduced. One of the reasons for this is the baggage fees, which were higher on low-cost airlines.

The paper identified three groups of airlines according to baggage policy. The first are airlines that carry both carry-on and first checked baggage in the basic package price. The second group is airlines that charge for first checked baggage but carry cabin baggage in the basic package price. The third group consists of airlines with both first checked and large carry-on baggage.

There is a lack of information or data for a more comprehensive study of European air carriers' baggage policies. In particular, this concerns the revenue side of baggage policy, which can only be estimated from the airlines' published ancillary revenues. Information on European airlines' baggage fee revenues would allow to examine baggage policy as part of the customer value proposition and more broadly as part of European airlines' business models. A still uncovered part of the research is how customers perceive baggage fees and baggage conditions of European air carriers in their decision making and how this affects the competitiveness of European air carriers. The unavailability of some data and information limited the research carried out.

We see scope for further research in examining baggage policy from the perspective of more than one checked bag per passenger, oversized baggage, and the impact of baggage policy on flight economics.

REFERENCES

[1] IATA. Passenger Baggage Rules. [online]. URL: https://www.iata.org/en/programs/ops-infra/baggage/check-bag/ (accessed 2022.01.13).

[2] COMMISSION IMPLEMENTING REGULATION (EU) 2015/ 1998 - of 5 November 2015 - laying down detailed measures for the implementation of the common basic standards on aviation security, n.d. 142.

[3] SCOTTI, D. et al. 2016. Baggage fees, operational performance and customer satisfaction in the US air transport industry. Journal of Air Transport Management 55, 139–146. https://doi.org/10.1016/j.jairtraman.2016.05.006

[4] TOMOVÁ, A. et al. 2017. Ekonomika leteckých spoločností. Žilina: EDIS - vydavateľské centrum ŽU, 2017. 274 s. ISBN 978-80-554-1359-4.

[5] GARROW, L.A. et al. 2012. Assessment of product debundling trends in the US airline industry: Customer service and public policy implications. Transportation Research Part A: Policy and Practice. 255–268. https://doi.org/10.1016/j.tra.2011.09.009.

[6] Airline ancillary revenue expected to surge by +22% in 2017 : The Moodie Davitt Report. [online]. URL: https://www.moodiedavittreport.com/airline-ancillary-revenue-expected-to-surge-by-22-in-2017/ (accessed 2022.02.18).

[7] Airline Ancillary Revenue Plummets to $58.2 billion in 2020. CarTrawler. [online]. URL: https://cartrawler.com/ct/en-gb/news-resources/news/ancillary-revenue/airline-ancillary-revenue-plummets-to-58-2-billion-in-2020-erasing-5-years-of-annual-gains/ (accessed 2022.02.19).

[8] BARONE, G. et al. 2012. Baggage Fees and Airline Performance: A Case Study of Initial Investor Misperception Author(s). J. Transp. Res. Forum 51. https://doi.org/10.5399/osu/jtrf.51.1.2796.

[9] WONG, W.H. et al. 2009. Optimal Baggage-Limit Policy: Airline Passenger and Cargo Allocation. Transportation Science 43, 355–369. https://doi.org/10.1287/trsc.1090.0266.

[10] ALLON, G. et al. 2011. Would the Social Planner Let Bags Fly Free? Social Science Research Network, Rochester, NY. https://doi.org/10.2139/ssrn.1919807.

[11] JIANG, C. et al. 2020. Airline baggage fees and airport congestion. Transportation Research Part C: Emerging Technologies 117. https://doi.org/10.1016/j.trc.2020.102686.

[12] SCOTTI, D. et al. 2015. The impact of baggage fees on passenger demand on US air routes. Transport Policy 43, 4–10. https://doi.org/10.1016/j.tranpol.2015.05.017.

[13] HAMILTON, R. et al. 2010. When should you nickel-and-dime your customers? MIT Sloan Manag. Revenue, Fall. [online]. URL: http:// sloanreview.mit.edu/article/when-should-you-nickel-and-dime-your-custo mers/.

[14] HENRICKSON, K. et al. 2011. Baggage fees and changes in airline ticket prices. In: Peoples, James (Ed.), Advances in Airline Economics: Pricing Behavior and None-Price Characteristics in the Airline Industry, vol. 3. Emerald Group Publishing Limited, Bingley, UK, pp. 177–192.

[15] CHO, W. et al. 2018. The impact of a baggage fee waiver on airline choice: Evidence from the Washington-Baltimore region. Transportation Research Part A: Policy and Practice, 2016 ATRS Conference 112, 4–17. https://doi.org/10.1016/j.tra.2018.01.003.

[16] EU sanctions against Russia explained [online]. URL: https://www.consilium.europa.eu/sk/policies/sanctions/restrictive-measures-against-russia-over-ukraine/sanctions-against-russia-explained/ (accessed 2022.03.22).

[17] US GOVERNMENT ACCOUNTABILITY OFFICE. 2017. Information on Airline Fees for Optional Services. GAO-17-756.

[18] NBS. Denný kurzový lístok ECB. [online]. URL: https://www.nbs.sk/sk/statisticke-udaje/kurzovy-listok/denny-kurzovy-listok-ecb (accessed 2022.04.23)

[19] KOŽUŠNÍK J. 2022. Batožinová politika európskych leteckých dopravcov. Diploma Thesis. Žilina: Žilinská Univerzita v Žiline, Fakulta prevádzky a ekonomiky dopravy a spojov, 2020. 69 s.

[20] BADÁNIK, B., ČERVINKA, M. 2015. Marketing leteckých spoločností a letísk. 1. vyd. Bratislava : DOLIS, 2015. 152 s. ISBN 978-80-8181-024-4.

[21] TOMOVÁ, A., MATERNA, M. 2017. The Directions of On-going Air Carriers' Hybridization: Towards Peerless Business Models? Procedia Engineering, 2017, 192, pp. 569–573

[22] NOVÁK SEDLÁCKOVÁ, A., TOMOVÁ, A. The fleet of regional air carriers in Europe commonality analyses in a broader context of business models research. Transportation Research Procedia, 2021, 55, pp. 276–283. ISSN 23521457.

https://doi.org/10.26552/ pas.Z.2022.2.06

STATE AID SCHEMES IN AVIATION SECTOR IN TIMES OF THE CRISIS CAUSED BY COVID-19 AS A TOOL TO REVITALIZE THE SECTOR

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Abstract

This article is focused on state aid schemes as a tool to revitalize the sector in times of crisis COVID-19. The aim of the article is a comprehensive analysis of state aid in air transport and the subsequent proposal of measures to revive the sector and a proposal for changes in the air transport market after the coronacrisis. Article defines the various stages of state aid in air transport in the past as well as during the crisis caused by the spread of COVID-19. There are analyzed approaches to dealing with state aid to airlines and airports before and during the crisis. At the same time, the article also focuses on the impact of the coronacrisis on air navigation service providers. In the end are identified key components to revitalize air transport and the proposal of changes in the air transport sector caused by the coronacrisis

Keywords

Coronacrisis, Airlines, Airports, Air navigation service providers, State aid, COVID-19

1. INTRODUCTION

The COVID-19 pandemic began in late 2019 in China. It gradually spread around the world. The onset of the COVID-19 viral disease is also linked to the crisis that has hit economies around the world. The coronary crisis has also hit the air transport industry hard. The effects of the crisis were felt at the outset. Flights have been phasing out all over the world and strict measures have been put in place to prevent the spread of the disease.

The total volume of transport fell by more than 80%. In air transport, state aid was provided to individual entities even before the crisis, which arose due to the spread of COVID-19. The work deals with the analysis of the rules of state aid before the coronary crisis and its individual stages, which were linked to the development of the air transport market and the entities that operate on it. It focuses on the analysis of specific cases of state aid to selected airlines and airports. The examples illustrate the basic principles and point to the European Commission's response to individual state aid, as well as the argument as to whether state aid complied with the established rules and whether or not it was justified. The onset of the coronary crisis was an unexpected blow to air travel. Even though the industry has already gone through many crises, the coronary crisis is the biggest crisis that has hit the aviation industry and has not been prepared for it. In response, temporary frameworks were adopted to assist Member States of the European Union in providing state aid.

2. STATE AID IN THE AIR TRANSPORT SECTOR

2.1. First stage

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2.2. Second stage

The second stage was subject to the rules based on the 2005 legal framework. In the Community Guidelines on airport financing and start-up aid for airlines departing from regional airports 2005 / C 312/01, it classifies airports into four categories according to passenger numbers. The Guidelines also define the categories of airport activities for which State aid may be granted under certain conditions:

- construction of infrastructure and airport facilities,
- infrastructure operation,
- supply of airport services related to air transport,
- public funding of services of general economic interest [1].

2.3. Third stage

The third is defined by the emergence of new state aid rules in 2014. The EC has issued rules that have simplified access to state aid while allowing for better prioritization of state aid enforcement activities. The rules also supported the improvement of the efficiency of drawing public resources. The rules define:

- investment aid,
- operating aid,
- start-up aid for airlines,
- state aid in the form of public service compensation, social help [2].

2.4. Fourth stage

The 2014 EC Communication set out the legal framework under which state aid was provided to airports and airlines. Air transport has evolved, faced new situations and the EC has gained new experience. Therefore, in 2017, it revised part of the state aid rules. Practical experience has prompted the EC to adjust the rules for providing investment and operating aid so that:

- investment aid to airports with less than 3 million passengers per year does not distort competition (under certain circumstances),
- operating aid to airports with less than 200 000 passengers does not distort competition per year (under certain circumstances).
- To be adequate, investment aid should meet two conditions:
- the aid intensity should not exceed the allowable aid intensity given by category of airport,
- the amount of aid should not exceed the difference between the eligible costs and the operating profit of the investment [3].

2.5. Temporary framework for state aid to support the economy in the context of the Covid-19 pandemic

The EC has adopted a temporary framework that will allow Member States to benefit from the full flexibility provided by state aid rules, they could support the economy during the COVID-19 pandemic (hereinafter referred to as the "temporary framework"). The Temporary Framework, together with many other support measures that Member States may use under existing State aid rules, allows Member States to ensure that all companies have sufficient liquidity and maintain economic continuity during and after the COVID-19 pandemic [4].

3. EXAMPLES OF STATE AID

3.1. Examples of State Aid to Airports before Coronacrisis

State aid rules for airports have evolved gradually. As the rules evolved, states gradually began to notify state aid to airports. The EC gradually published the notified state aid. Between 2014 and 2018, only seven Member States notified investment aid to airports (France, Ireland, Germany, Italy, Lithuania, Estonia and Hungary). The Irish National State Aid Scheme for Airports was the first to be notified to the EC under the 2014 EC Guidelines.

While Ireland has applied the approach of the common bilateral state aid scheme for regional airports, which includes both operating and investment aid, France has notified three separate national state aid schemes for regional airports. State aid was in line with the structure of the guidelines. In addition, France notified investment aid to Tarbes Airport in an individual application in 2016. The airport is one of the smaller airports that carries around half a million passengers a year [5].

3.2. Examples of State Aid to Airlines before Coronacrisis

Alitalia is an Italian airline that provides domestic and international air transport, maintenance, ground handling and cargo services. The company has been at a loss since 2008. At the beginning of 2017, Alitalia needed funds, but due to the deteriorating financial situation, it did not have access to any credit. For Alitalia to continue in operation, Italy provided the company with two loans of EUR 600 million and EUR 300 million in May and October 2017. At the same time, Alitalia was placed in a special insolvency procedure under Italian insolvency law. A year later (2018), the EC launched an investigation to determine whether the two loans complied with EU state aid rules. The EC concluded that two € 900 million state loans granted by Italy to Alitalia in 2017 were illegal under EU state aid rules. Italy must therefore recover unlawful State aid plus interest from Alitalia. The investigation showed that when granting the two loans to the company, Italy did not proceed as it should. The State did not assess in advance the likelihood of repayment of the loans plus their interest. Following the investigation of the case, the EC stated that the State loans to the carrier distorted competition [6].

Another example, Cyprus Airways has received a lot of public money since 2007, but has failed to restructure and become viable without continued state support. Cyprus Airways therefore had to repay all state aid received, which is generally incompatible with the EU, which, according to the EC, amounts to more than € 65 million plus interest. In particular, the EC found that Cyprus Airways did not have a realistic prospect of becoming viable without continued state subsidies [7].

3.3. Impact of the Covid-19 pandemic on air transport

During 2020, Covid-19 developed into a pandemic that posed a global risk to our health and global economies. Across all sectors, the aviation sector is probably one of the sectors most affected by the coronary crisis. The unprecedented drop in passenger demand has led to the suspension of most airlines. Many companies had to close almost all of their activities and ground their entire fleets. Repatriation and cargo flights were performed. This initially had a strong impact on the number of international flights as well as the number of domestic flights. March 2020 can probably be considered the month with the lowest number of flights in modern aviation history [8]. Many airports closed their runways and they were subsequently used to park unused aircraft.

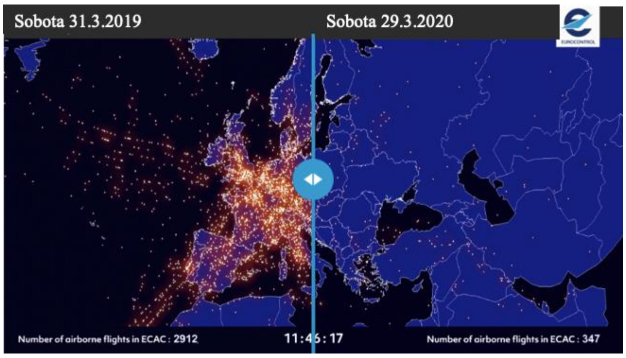


Figure 1 Comparison of airspace utilization in March 2019 and March 2020 [https://www.eurocontrol.int/covid19]

3.4. State Aid to Airports during the Coronacrisis

Saarbrücken Airport is a small regional airport located in the German state of Saarland. It is operated by Flug-Hafen-Saarland. In 2017, the EC approved € 12 million state operating aid for Saarbrücken Airport valid until 2019. Germany announced its intention to provide additional operating aid to the airport by 2024. The EC assessed the case and found that while 2019 the airport saw an increase number of passengers, the airport has seen a drop in passenger numbers since the beginning of the coronary crisis. This was due to the gradual introduction of measures against the spread of the Covid-19 virus in Germany, but also in other countries. It took these exceptional circumstances into account in the assessment. The EC also concluded that the aid would help improve citizens' connectivity and facilitate regional development. At the same time, it will not distort competition in the single market. The EC approved state aid on 12 May 2020 [9].

3.5. State Aid to Airlines during the Coronacrisis

The EC has approved state aid of € 7 billion in line with EU state aid rules. The State aid consisted of a State loan guarantee and shareholder loans to Air France to provide urgent liquidity to the company. The EC explained the approval of the aid by saying that the aviation industry is important in terms of jobs and connectivity. Also, in connection with the spread of the Covid-19 virus in other countries, Air France played an important role in the repatriation of citizens and in the transport of medical supplies. In addition, France has announced so-called "green plans" in relation to Air France.

The aid therefore also covers certain environmental obligations of Air France, such as:

- reducing the number of domestic flights on routes of less than 2 hours 30 minutes if there is an alternative rail service (and limiting such flights to transfers to hub airports),
- 50% reduction in CO_2 emissions from flights over mainland France by the end of 2024,
- 50% reduction in CO_2 emissions per passenger per kilometre by 2030,
- implement 2% of sustainable alternative fuels by incorporating them into fuel tanks by 2025,
- future investments must be directed towards the development of medium and long-distance routes [10].

The EC approved state aid from Germany (June 25, 2020) to contribute € 6 billion to the recapitalization of Deutsche Lufthansa AG (DLH). The company is the parent company of the Lufthansa Group. The recapitalization measure is part of a larger package, which also includes a state guarantee for a loan of EUR 3 billion. Germany plans to grant the loan to DLH as individual aid. Lufthansa has committed to make slots and additional assets available at its main airports in Frankfurt and Munich. This gives competing carriers a chance to take advantage of these slots [11].

3.6. Impact of the Corona Crisis on Air Navigation Service Providers

Airlines lacked the necessary liquidity, and in response, the European ANSPs helped the airlines by agreeing to defer payments for the provision of air navigation services. The 41 Member States of Eurocontrol, which coordinates air traffic control operations across Europe, voted to postpone the payment of February fees to November 2020, with payments for March, April and May postponed to 2021. IATA thanked the Eurocontrol Member States and the European ANSP for solidarity.

In view of the coronary crisis, measures were also taken in the third reference period. Rules have been adopted governing the consequences of the late adoption of performance plans set out in the EU Implementing Regulation of 2020/1627. They have been adjusted to mitigate the adverse financial impact and to avoid high volatility in unit rates for liner and terminal services [12].

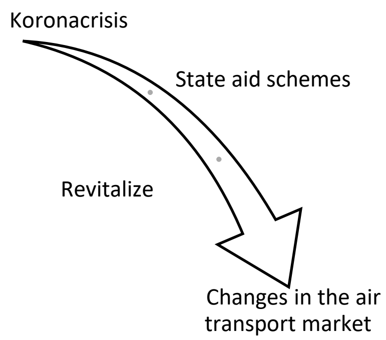
4. RESEARCH METHODOLOGY

Based on the available information provided on the website ec.europa.eu, performed analyzes and interpretation of the conclusions of the comparison of approaches, the aim of the thesis is to suggest possible approaches to the recovery of air transport in times of crisis caused by COVID-19, which may be mainly in the form of state aid.

5. PROPOSAL OF APPROACHES TO THE RECOVERY OF AIR TRANSPORT IN THE TIME OF CRISIS CAUSED BY COVID-19

Based on the complex analyses of the literature review, detailed analyzes of examples of state aid to airlines and airports before crises and during it were defined the results of the research. State aid schemes at the time of the coronary crisis brought:

- revival of air transport,
- changes in the air transport market.



Picture 1 – Influence of coronacrisis [Source:Authors]

5.1. Reviving Air Transport

After complex analyzes were defined the key components that help revitalize air traffic in times of corona crisis:

- time of granting state aid,
- amount of aid provided,
- conditions for providing assistance,

- interest in air transport services.

5.1.1. Time of State aid

Airlines and airports began to experience a sharp drop in demand at the outset of the crisis. At the time of the coronacrisis, the speed of state aid was crucial. The EC also pointed out this fact. Despite the fact that airports and airlines were losing the necessary liquidity at this time, there were cases where EU Member States notified aid late. In the case of airports, state aid was quickly granted in Belgium. In Slovakia, state aid was provided to airports faster than air carriers, but in both cases it can be stated that the aid came late.

A good example of a rapid response is France, which has helped mitigate the effects of the crisis on airlines by allowing French airlines to defer payments in March 2020. About a month later, it notified another state aid scheme. It provided 7 billion euros for Air France. On the other hand, Slovakia notified state aid to airlines only at the end of 2021. That is more than a year and a half later, since the first state aid to airlines was announced. Slovakia addressed the issue of state aid to airlines late. In the meantime (01.09.2020), the Slovak air carrier Go2Sky terminated its activities. The owner saw as the main reasons for the end of the company that since March 2020 the company was financed from its own resources and they could not agree with the owners of the leased aircraft on further cooperation. The company was able to agree only until the end of August 2020, they could no longer agree on the month of September. The same problem was in the Czech Republic. The Smartwings group was ignored by the Czech Republic when it asked for help. Finally, they received state aid [13].

5.1.2. Conditions for granting state aid

Some EU Member States have provided public support to stakeholders in the aviation sector. During the coronacrisis, there were cases where support was provided with well-defined conditional rules that created some form of conditions. State aid conditions increased the chances of the EC scheme being approved. Given the EU's goal of reducing emissions, the conditions that led to the reduction were welcome. France and Germany are examples of such state aid. Germany conditioned its aid on modernizing the fleet. France has embarked on tighter emission reductions. For flights of less than two and a half hours, rail transport will be preferred and the future direction of investment on longer routes will divert Air France from domestic flights over the mainland. This pushes carriers to greener and more efficient transport. Despite the positive shift towards reducing emissions, this leaves room for carriers from countries that are not constrained by similar conditions.

5.1.3. Interest in air transport

Not only airlines but also airports are dealing with the recovery of their activities during the coronacrisis. Airlines and airports need people to trust air traffic again and to be able to travel. According to the International Airports Council (ACI), interest in air travel is a key factor in reviving airports during the coronacrisis. During the crisis, when flights were canceled, some of the connections offered were reassessed.

The overall recovery will be driven mainly by domestic transport and international transport will experience a slower recovery (worldwide, domestic transport accounted for 58% of total passenger transport in 2019).

5.2. Changes in the Aviation Market

Based on the results of research can be declared that the aviation industry will be partially changing. The coronary crisis helped to accelerate some of the trends that had emerged before the crisis. We think that the impact of the coronary crisis will also:

- "greener" transport,
- higher degree of digitization,
- departure from short-haul flights,
- modernization of air transport,
- a partial change in the business model of some airlines.

5.2.1. Airlines

National carriers were the first to receive state aid. Lufthansa and AirFrance are examples of receiving state aid when they need it. The conditions for the provision of aid, which were approved by the EC, were set so that after the aid was granted, the carriers were "greener" and greener. This trend was evident even before the coronacrisis. Airlines have started to make more use of the potential of new trends. They modernized their fleets, went through digitization, and all this led to more efficient and "greener" operations. The coronacrisis will accelerate this trend. In order for airlines to qualify for state aid and in the meantime decommission less efficient aircraft.

Also, we think that the business model of traditional air carriers will partially change under the conditions that existed in the provision of state aid at the time of the coronacrisis. The modernization of the fleets will lead to their unity. This should mean a reduction in maintenance costs, and at the same time new aircraft models are also characterized by more efficient, "greener" operation. Air France's state aid is an example of the abandonment of short-haul flights. The EU is pushing for greener and more sustainable transport. The coronacrisis has helped airlines become greener and partially change their business model. At the time the measures were the toughest, the airlines did not serve food on board. This did not affect them and later they resumed serving food on board.

5.2.2. Airports

In the past, the International Airports Council (ACI) has developed rules for determining the quality coefficient of airports and the services they provide (SQ1-SQ12). The coronacrisis has fundamentally influenced and emphasized the importance of some of the selected rules, which has led to greater emphasis on some of them, namely:

- the number of days in a calendar year that passengers in an open terminal must stand in line for more than 30 minutes before passing the security check (QS1),
- the number of quarters in the calendar year in which the airport violated the ACI rule, which says "terminal cleanliness" (QS6),

- the number of quarters in the calendar year in which the airport violated the ACI rule, which says "toilet cleanliness" (QS7),
- the number of quarters in the calendar year in which the airport violated the ACI rule, which states "airport facilities in the field of communications, electronic communications and business communications support" (QS12).

5.2.3. ANSP

The provision of air navigation services has been liberalized in only a few countries and has not affected the sector as a whole. However, the commercialization of individual ANSPs has become more frequent, especially in the last ten years [14]. This is a radical departure from the old way of thinking of air navigation service providers. The commercialization of ANSP is described as a process that includes new ways of financing and managing organizational and ownership structures. This is one way of modernizing the provision of air navigation services. In general, the EC has often spoken of competition and modernization in the provision of state aid. ANSPs will look for ways to increase revenue. At the same time, however, they will face competitive challenges due to gradually increasing commercial trends. Therefore, we think that the commercialization of ANSP will be one of the tools to revive the market. However, there are many perspectives on the commercialization of ANSP. IATA understands commercialization not only as a change in organizational and ownership structures, but also as the orientation of ANSP services to commercial revenue. However, IATA recommends that commercialization should never lead to a conflict between public and commercial interests.

5.3. Overview of Changes as well as Proposals for Changes

In the following section, is offered an overview of the changes and proposed changes caused by the coronary crisis. The provided proposals will help air transport to be stronger and more resilient during and after the crisis. At the same time, the proposals offer the possibility of further direction of air transport market and defined the changes in the position of individual entities (airlines, airports, ANSP).

TABLE 1: TABLE I. PROPOSALS FOR APPROACHES TO THE REVIVAL OF AIR TRANSPORT DURING THE CORONARY CRISIS [SOURCE:AUTHORS]

	Before coronacrisis	**Change**
A fleet of traditional carriers	Inconsistent	Higher degree of uniformity
Airline Alliance	Uncertain attitude in some companies	Guarantee of higher security from membership, which can be an incentive to join the alliance
Low-cost carriers	Growth in the number of virtual carriers	Transformation to a virtual carrier model
Carrier fleets	Focused on the possibility of transporting a large number of passengers	Airlines' focus on more efficient and environmentally friendly aircraft
Security check	The traditional way	Gradual introduction of "contactless" security control
Digitization	Waiting in line	Greater use of smart technologies such as smartphone
ANSP	Services of general interest	Commercialization of ANSP

The EU's goals of creating a sustainable market economy with high competitiveness and protecting the environment as well as improving its quality are also reflected in the provision of state aid. The state aid provided to individual air carriers during the coronary crisis pushed for air transport to be "greener" and more modern. We think that making state aid conditional on fleet modernization is the right step to revitalize the sector and "start" changes in a certain part of the sector, which will then lead to its partial restructuring. Such modernization will bring new types of aircraft that are more economical and modern. At the same time, it will help to suppress the possible replacement of air transport by another mode of transport that is considered "greener". At the same time, the results of our research have shown that membership in the airline alliance has demonstrably increased a certain degree of certainty for airlines, which could lead to a change in the attitudes that airlines had before the coronary crisis.

Defined as well as proposed changes may also affect the business model of airlines. Based on the above, it is possible to accept a possible assumption of the need to change the business model of airlines, especially towards an even more significant hybridization of the traditional model of the air carrier.

Measures at the time of the coronary crisis pushed for the use of contactless means, which put pressure on the development of devices that would allow contactless security control in several forms. In combination with applications in the smartphone, it is possible to achieve shorter time spent in lines as well as shorten the total time that passengers must spend at the airport before departure.

In the case of ANSP, the approach to their activities does not change in any fundamental way, but precisely the need to reduce costs, resp. increasing revenue at a time when this is not possible by increasing the number of aircraft in the airspace leads to the only possible alternative that could help ANSPs, namely commercialization, which is a way to modernize ANSPs, but it is not easy and the recommendations need to be followed IATA.

CONCLUSION

COVID-19 disease began to spread in China in December 2019. It didn't take long for the virus to cross the border and spread around the world. The COVID-19 pandemic was not only a health crisis but also an economic crisis. It has affected every sector of the economy. Air transport and tourism were the most affected sectors. Strict measures, border closures and cancellations have caused one of the biggest crises in air transport.

The aim of the article is to propose approaches and changes that lead to the revival of air transport during the coronary crisis. It defines the forms of state aid that can be one of the tools to revitalize air transport and affected economies. In order to be able to define the attributes that have a major impact on the recovery of the industry as well as the changes that have occurred in the industry, respectively. To define changes that could be permanent and not only temporary, an analysis of state aid before and during the coronary crisis was needed. The first chapter describes how state aid in air transport has developed. The state aid recorded four stages and gradually responded to the development of air transport. In response to the coronary crisis, the European Commission adopted a temporary framework to assist Member States in providing state aid. Selected state aid before and during the coronary crisis was further analysed. On this basis, can be explained basic principles and point to the European Commission's response to individual state aid. The European Commission's argument has helped us to identify the key attributes in the provision of state aid. A positive example is the state aid granted to Air France. They provided their help quickly and are committed to making the carrier greener. It is an example that has defined the direction of the industry. State aid to Air France was granted more quickly than in other cases and its conditions indicate the future direction of the sector, resp. changes in air transport.

We have come to key components in providing a proposal to revitalize air traffic during the coronation crisis. The key is time, volume, conditions of assistance and interest in air transport services. At the same time, based on the results of the research was concluded that this crisis will accelerate some of the trends that existed before the crisis. We also anticipate the changes that will occur. Hybrid airline business models will emerge more in the market. Aviation will feel the European Union's pressure to reduce emissions. We anticipate a shift away from flights to shorter routes of traditional carriers and the modernization of fleets. The new fleets of air carriers will be more environmentally friendly, and we also expect greater fleet uniformity. Airports felt pressure for cleanliness and were motivated to digitize their services more to ensure the highest possible level of contact lessness. Digitization and the use of smart devices have helped speed up check-in, and this is another positive step forward.

A detailed analysis and comparison of individual cases of state aid helped us to show that state aid as a tool to revive the sector and the coronary crisis led to the acceleration of trends, resp. led to changes.

The provision of state aid is a complex problem. A comparison of cases has shown an imbalance in the provision of state aid by Member States. We therefore propose that the European Union set up a group of experts to address this issue. This could provide more prompt and targeted assistance.

ACKNOWLEDGMENT

This paper was supported by national grant scheme VEGA 1/0695/21 Air transport and COVID-19: Research of the crises impacts with a focus on the possibilities to revitalize the industry.

REFERENCES

[1] Európska komisia. 2005. Usmernenia Spoločenstva týkajúce sa financovania letísk a štátnej pomoci na začatie činnosti pre letecké spoločnosti s odletom z regionálnych letísk (2005/C 312/01). [online] <https://eur-lex.europa.eu/legal-content/SK/ALL/?uri=CELEX:52005XC1209> [cit. 2021-31-10]

[2] Európska komisia. 2014. Nariadenie EU? c?. 651/2014 o vyhlásení urc?itých kategórii? pomoci za zlúc?itel?né s vnu?torny?m trhom podl?a c?la?nkov 107 a 108 zmluvy a Usmernenie s?ta?tnej pomoci pre letiska? a letecke? spoloc?nosti (2014/C 99/03). [online] <https://eur-lex.europa.eu/legal-content/SK/TXT/?uri=celex%3A32014R0651> [cit. 2021-31-10]

[3] Európska komisia. 2017. Nariadenia Komisie EU? 2017/1084. [online].<https://eur-lex.europa.eu/legal-content/SK/TXT/?uri=CELEX%3A32017R1084> [cit.2021-31-10]

[4] Štátna pomoc: Komisia prijala dočasný rámec. 2020. [online]. <https://ec.europa.eu/commission/presscorner/detail/sk/ip_20_496> [cit. 2021-22-12]

[5] Novák-Sedláčková, A. - Tomová, A. 2021. Air transport and regional develpoment policies. Guidelines for airports. London, 2021. 184s. ISBN 978-0-367-53314-4

[6] State aid: €900 million to Alitalia are illegal aid. 2021. [online] <https://ec.europa.eu/commission/presscorner/detail/en/ip_21_4664> [cit. 2021-01-12]

[7] State aid: Commission orders Cyprus to recover incompatible aid from national air carrier Cyprus Airways. 2015. [online]. <https://ec.europa.eu/commission/presscorner/detail/en/ip_15_3121> [cit. 2021-01-12]

[8] ICAO: COVID-19 crisis response and recovery planinng. 2020. [online]. <https://www.icao.int/EURNAT/Pages/news_articles/EURNAT-DG-Algeria-Morocco-Tunisia-join-efforts-on-COVID-19.aspx> [cit. 2021-05-11]

[9] EC: Daily news 15/12/2020. 2020. [online]. <https://ec.europa.eu/commission/presscorner/detail/en/MEX_20_865> [cit. 2021-18-12]

[10] BBC: Coronavirus aid Air France. 2020. [online] <https://www.bbc.co.uk/news/world-europe-52527517> [cit. 2021-18-12]

[11] State aid: Lufthansa. 2020. [online] <https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1179> [cit. 2021-18-12]

[12] Európska Komisia. 2020. Vykonávacie nariadenie komisie EÚ o mimoriadnych opatreniach na tretie referenčné obdobie (2020-2024) systému výkonnosti a spoplatňovania v rámci jednotného európskeho neba

[13] Airliners.sk: Koniec Go2Sky. 2020. [online] <https://www.airliners.sk/slovenska-letecka-spolocnost-go2sky-konci-svoju-cinnost/> [cit. 2022-06-02]

[14] Materna M, Badanik B, et al. Commercialisation of Air Navigation Service Providers - Evidence from Europe. 2021. [online]. <https://hrcak.srce.hr/file/392724> [cit. 2022-08-02]

[15] TOMOVÁ, A., NOVÁK SEDLÁČKOVÁ, A., ČERVINKA M., HAVEL K. 2017, Ekonomika leteckých spoločností, 1. vyd. Žilina: EDIS, 2017. 274 s. ISBN 978-80-554-1359-4.

https://doi.org/10.26552/ pas.Z.2022.2.07

THE IMPACT OF THE COVID-19 PANDEMIC ON THE ECONOMIC PERFORMANCE OF THE EUROPEAN AIR CARRIERS

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Abstract

The outbreak of the COVID-19 pandemic which was officially declared in March 2020 as a whole new global risk, has negatively affected operations in all industries around the world. Air transport was one of the first sectors to be affected the most by this event as the disease has been easily transmittable among people. As a measure to prevent the spread of the disease, governments around the world have severely restricted international commercial air traffic. These travel measures have significantly reduced the market value of airlines operating scheduled passenger air services worldwide, where operations have had to be largely limited or even canceled by air carriers. These facts motivate to research the impact of the COVID-19 pandemic on the performance of air carriers, which is also the main aim of this paper. This paper examines the impact of the COVID-19 outbreak on 15 European airlines using economic analysis of the influence of the determining factors.

Keywords

air carrier, COVID-19 pandemic, Determining Factors, Economic analysis

1. INTRODUCTION

Only four months after the first case of COVID-19 was reported in China, the disease has spread around the world infecting more than two million people. Many countries have adopted strict measures including border closures to prevent the virus from spreading. At the beginning of April 2020 up to 91% of the world's population lived in countries where pandemic measures included strict restrictions or even bans on the entry of foreigners. However, the pandemic has been gradually devastating the global economy in addition to human lives. Almost every industry has been currently hit by the pandemic, but no other industry has been hit as hard as the air transport and tourism. It is these sectors that are most vulnerable because they are very sensitive to sudden market changes. Aviation business has always been hit hard in previous crises, such as the terrorist attack in 2001 in the USA, the outbreak of the SARS epidemic or the global economic crisis in 2008. All of these crises had a negative impact on the aviation sector, which was reflected in particular in the decline in demand for air transport services.

The COVID-19 pandemic has caused the largest decline in airlines' seat capacity in early April 2020. This decline of more than 80 % forced some airlines to suspend their operations. The enormous decline in seat capacity was caused by the mass grounding of airline aircraft, at the beginning of April 2020 it was almost 60% of the global fleet.

Most airlines which were forced to ground their aircrafts and temporarily suspend commercial flights, provided assistance to individual states in the fight against coronavirus. The aircraft, which were originally intended for passenger transport, were adapted for the transport of cargo, including medical supplies and vaccines used in the fight against COVID-19. Some airlines have also provided free flights to transport paramedics to hard-hit regions of the world.

However in addition to the operational impact, the pandemic has also had a significant impact on the air transport market and airline costs. By closing countries' borders as well as some airports, airlines have been forced to dramatically disrupt international flights what has caused a significant reduction in passenger revenues and also a significant increase of the cost of pandemic measures and aircraft grounding, leading to mass redundancies to reduce employees costs.

2. LITERATURE OVERVIEW

The COVID-19 pandemic and the ongoing global political and economic crisis are currently the main topic of various research studies. Various studies and articles are currently examining the correlation between the COVID-19 pandemic and the economic performance of airlines.

2.1. THE IMPACT OF THE COVID-19 PANDEMIC ON AIRLINES

Authors Q. Aman et al. (2020) claim that "COVID-19 has had a significant impact on revenue in the airline industry. The passenger revenue average decreased to $237.25 billion. In contrast, the cargo revenue increase was $23.73125 billion. Thus, COVID-19 had no impact on the industry's cargo revenue." Then they claim that „regional airlines will clearly benefit from increasing their activity as hub feeders during the recovery period. This would, indeed, take the regional airline business model in Europe closer to the US model." Furthermore authors S.M. Iacus et al. (2020) assume that „a reduction of direct revenues passengers may impact the entire aviation sector proportionally, we can roughly estimate the expected number of job losses and impact on GDP at global scale." Also „the large employment reductions is seen by the major carriers. One explanation is that low-cost and regional airlines are built around low fares driven by low costs of operation. The already lean nature of these airlines may make them more able at allocate personnel in a cost-effective manner." what claims author Sobieralski (2020). On the other hand, S. Maneenop, S. Kotcharin (2020) say in their article that „the administrative measures should allow the airlines to change their business plans and establish alternative. Besides, they should be able to operate irregular flight schedules reflecting market demand."

P. Ozili et al. (2020) state that „the travel restrictions imposed by governments subsequently led to the reduction in the demand for all forms of travel which forced some airlines to temporarily suspend operations" Operational costs are also mentioned by authors T. Thepchalerm and P.Ho (2021) in their article where they claim that „the increasing costs of operation amplifies the damage to airlines. The infection preventive measures that airlines need to implement are costly." Authors Kokény et al. (2021) deal with the issue of the different business model of the airlines and claim that „smaller airlines, possibly including LCCs, might be more vulnerable to a serious crisis than FSCs. When the crisis reaches a higher magnitude, then smaller airlines (including LCCs) decline sharply." Authors H. Troyer et al. (2021) in their article indicate that „the "new normal" moving forward in the aviation industry and, specifically, airline travel will include social distancing measures and other public health safety measures."

An analysis of the articles shows that the COVID-19 pandemic has caused a significant damage to airlines, which have been forced to radically reduce their operations in order to reduce operating costs and thus maintain the necessary liquidity to overcome the crisis. However, the authors differ in the position of low-cost and traditional airlines and their vulnerability in times of crisis.

2.2. FUTURE OF THE AIRLINES

According to A. Curley et al. (2020) article, „airlines will experience a gradual and uneven return to operations that requires an unprecedented logistical effort. Done poorly, their strategy may be as costly as the crisis itself." The future of the airline in post-covid era is also mentioned by the authors D. Tay et al. (2020). They say that „Looking forward, airlines need to first and foremost look to strategically rebuild demand levels while reassuring passengers on the safety of air travel. In order to do this, airline carriers should understand the changes in passengers' sentiment and behaviour caused by the COVID-19 pandemic through analysing the market as a whole and by passenger segments." Data and digitalization are also considered as the future of airlines what is claimed authors D. Molenaar et.al (2020)„Companies that take a data-driven, action oriented, and digitally supported approach will have the best chance to emerge stronger from the COVID-19 crisis." The issue of the new revenue management is mentioned by author B. Vinod (2021) in his research article who says that „with the COVID-19 pandemic in our midst, historical booking data may not represent the future. What is required is an adaptive robust revenue management approach that does not rely on demand forecasts based on historical data but relies on monitoring key performance indicators in real time to take corrective action." Also authors L.B. Bauer et al. (2020) claim that „hub and Spoke model, on the premise that heavily scaled international feeder networks, as seen in Europe for example, will become impractical, more expensive to operate and face significantly lower Seat Load Factors. Simultaneously, the alternative concept of Point-to-Point travel looks set to become more attractive, with airlines and customers alike being afforded a unique array of advantages provided by direct flights in a post COVID-19 era."

The authors of the analysed articles agree that in order to overcome the crisis with the least possible losses and to successfully return to unlimited operations, airlines must focus on planning a successful strategy now and also sufficiently monitor current changes in demand, which will allow for a faster return to service.

2.3. AIRLINES'S REACTION TO PANDEMIC

„Keeping a proportion of the fleet in active mode is not without its costs in terms of labour, maintenance and fuel, but it does mean airlines that do can respond to changes in restrictions or an upturn in passenger demand before their competitors and so potentially gain market share and enjoy first mover advantage." say N. Adrienne et al. in their research article. Y.H. Akbar et al. (2020) claim that „the airlines response depends on the size of the health impacts on society of a particular policy measure proposed by a government as well as on economic impacts of a given measure on airlines." On the other hand S. Albers et al. (2020) argue that „some airlines have engaged in tactical moves with immediate effect: they have converted passenger aircraft into cargo transporters to benefit from the more stable cargo demand in the crisis, which has even seen a short-term "boom" due to the urgent delivery of medical protection gear." According to the article by two Slovakian authors M. Mrázová and A. Kazda (2021) „some airlines will bankrupt, some of them will be forced to change their core airline business and divert it to a more efficient way."

The authors of the articles furthermore state that the most frequent reactions of airlines to the COVID-19 pandemic and the resulting travel restrictions were flight cancelation, aircraft grounding and mass redundancies. They also agree that despite timely and sufficient measures to reduce operating costs, in the absence of State aid, some airlines will be forced to suspend or even to close down.

2.4. STATE AID TO THE AIRLINES

Authors M. Abate et al. (2020) claim that „the need for support and the actual support to airlines provided by governments vary significantly in each country. Analysis suggests that most governments give a high priority to maintaining air transport connectivity in order to protect economic activity and jobs, in aviation itself and in related sectors such as tourism. This often means that the support is primarily given to, at best, a handful of national operators in each country." Also „some airlines and related aviation sectors, such as airports and air traffic control providers, have signalled to their respective national governments the need for financial support in the form of loans, grants, other cash or fee waivers." According to J. Macilree's et al. (2020) article.

Although the authors of both articles focus on state aid to airlines from different perspectives, they clearly agree that the role of government not only in the form of state aid but also in the implementation of pandemic measures plays a key role in the future of the aviation.

3. METHODOLOGY

Based on the analysis of the research articles, differences in opinions have been discovered about the performance of low-cost nad traditional airlines, on which basis the goal of this analysis was determined.

This part deals with the economic analysis of selected European airlines based on the method of quantification of the influence of determining factors.

3.1. FUNCIONAL METHOD

The functional method allows quantification of the influence of factors in multiplicative links and is based on the coefficients of change of individual factors.

The principle of the functional method is to determine the overall change of the peak indicator X through the change of individual factors and to quantify the impact of these factors. The method allows quantification even in the case of a simple share, if X = a / b, without the need to convert the share into a product, as in the case of this analysis, which may make it difficult to interpret the indicators thus generated.

The analysis is based on three designed models where analysed peak indicators represent:

- Load factor
- Work productivity
- Aircraft productivity

These models use following equations:

Table 1: Equations used in three designed models of determining factors [Source: Author]

I. *MODEL OF DETERMINING FACTORS INFLUENCING LOAD FACTOR OF THE AIRLINES*

$$LF_0 = \frac{RPKM_0}{ASKM_0}, \quad LF_1 = \frac{RPKM_1}{ASKM_1}$$

$$A = \frac{RPKM_1}{RPKM_0} - 1, \quad B = \frac{ASKM_0}{ASKM_1} - 1$$

$$\Delta LF_{RPKM} = LF_0 \; x \; A\left[1 + \frac{B}{2}\right]$$

$$\Delta LF_{ASKM} = LF_0 \; x \; B\left[1 + \frac{A}{2}\right]$$

II. MODEL OF DETERMINING FACTORS INFLUENCING AIRLINES WORK PRODUCTIVITY

$$WP_0 \frac{number\ of\ PAX_0}{number\ of\ employees_0},$$

$$WP_1 = \frac{number\ of\ PAX_1}{number\ of\ employees_1}$$

$$A = \frac{number\ of\ employees_1}{number\ of\ PAX_0} - 1,$$

$$B = \frac{number\ of\ PAX_0}{number\ of\ employees_1} - 1$$

$$\Delta WP_{pax} = PP_0 \; x \; A\left[1 + \frac{B}{2}\right]$$

$$\Delta WP_{employees} = PP_0 \; x \; B\left[1 + \frac{A}{2}\right]$$

III. MODEL OF DETERMINING FACTORS INFLUENCING AIRLINES AIRCRAFT PRODUCTIVITY

$$AP_0 = \frac{number\ of\ flights_0}{number\ of\ aircraft_0},$$

$$AP_1 = \frac{number\ of\ flights_1}{number\ of\ aircraft_1}$$

$$A = \frac{number\ of\ aircraft_1}{number\ of\ flights_0} -$$

$$B = \frac{number\ of\ flights_0}{number\ of\ aircraft_1} - 1$$

$$\Delta AP_{number\ of\ flights} = AP_0 \; x \; A\left[1 + \frac{B}{2}\right]$$

$$\Delta AP_{number\ of\ aircraft} = PP_0 \; x \; B\left[1 + \frac{A}{2}\right]$$

By applying these equations, it is possible to find out which relative part of the determining factors affect the total value of three peak indicators. The pre-covid and covid periods are analyzed and compared.

3.2. AIRLINES SELECTION

15 air carriers were selected for the economic analysis. The analysis is focused on European carriers, so each of the analyzed carrier has its headquarters in Europe. However, it is important to note that the analysis includes carriers based in European countries, but not exclusively in the European Union. Turkish Airlines is also included in the selection of carriers. Although Turkey is only partially part of Europe, it is a member of the European Common Aviation Area (ECAA) and has therefore been selected for this analysis as one of the most important air carriers.

However, the selection of carriers was limited and had to be adapted to the availability of information for those carriers for which the required data were available. As many European airlines now tend to operate as a group, the choice of carriers had to be adapted to those carriers whose necessary data were available for the company itself and not for the group as a whole.

Table 2: Airline selection for the analysis [Source: Author]

Airline	***Established***	***Headquarter***	***Business model***
KLM	1919	Netherlands	Traditional
Turkish Airlines	1933	Turkey	Traditional

Lufthansa	1953	Germany	Traditional
Swiss Airlines	2002	Switzerland	Traditional
Austrian Airlines	1957	Austria	Traditional
Tap Portugal	1945	Portugal	Traditional
British Airways	1919	Great Britain	Traditional
Finnair	1923	Finland	Traditional
SAS	1946	Sweden	Traditional
Aer Lingus	1936	Ireland	Traditional
Eurowings	1990	Germany	Low-cost
Easyjet	1995	Great Britain	Low-cost
Vueling	2004	Spain	Low-cost
Norwegian	1993	Norway	Low-cost
Wizzair	2003	Hungary	Low-cost

Selected air carriers represent a diverse group. It includes both large and small companies, companies with many years of operation at the market for scheduled passenger air transport, as well as younger companies. However, this analysis considers the difference in the business model of selected carriers to be the most important. Airlines with either a traditional or low-cost business model are analyzed.

Information of selected airlines were obtained from annual reports which airlines publish annually on their official website.

4. RESULTS OF THE ANALYSIS

4.1. MODEL 1

Table 3: Results of the analysis of the model 1 [Source: Author]

Letecká spoločnosť	$\Delta LF_{2017-2018}$			$\Delta LF_{2018-2019}$			$\Delta LF_{2019-2020}$		
	ΔASKM	ΔRPKM	ΔLF	ΔASKM	ΔRPKM	ΔLF	ΔASKM	ΔRPKM	ΔLF
KLM	-0,028	0,035	0,007	-0,012	0,015	0,003	0,520	-0,892	-0,372
TURKISH AIRLINES	-0,041	0,069	0,028	-0,025	0,022	-0,003	0,827	-0,933	-0,106
LUFTHANSA	-0,038	0,036	-0,002	-0,065	0,077	0,012	1,166	-1,370	-0,204
SWISS AIRLINES	-0,065	0,079	0,014	-0,036	0,047	0,011	1,018	-1,248	-0,231
AUSTRIAN AIRLINES	-0,047	0,073	0,025	-0,023	0,038	0,015	1,444	-1,633	-0,189
TAP PORTUGAL	-0,095	0,075	-0,020	-0,090	0,081	-0,009	0,954	-1,108	-0,155
BRITISH AIRWAYS	-0,025	0,031	0,006	-0,007	0,018	0,011	1,005	-1,227	-0,222
FINNAIR	-0,114	0,099	-0,015	-0,088	0,087	-0,001	1,309	-1,495	-0,186
SAS	-0,011	0,003	-0,008	0,008	-0,014	-0,005	0,591	-0,737	-0,146
AER LINGUS	-0,078	0,076	-0,001	-0,034	0,042	0,008	1,172	-1,526	-0,354
EUROWINGS	-0,157	0,170	0,014	0,612	-0,602	0,010	1,137	-1,229	-0,092
EASYJET	-0,084	0,087	0,004	-0,094	0,083	-0,012	0,609	-0,593	0,016
VUELING	-0,072	0,079	0,007	-0,023	0,038	0,015	1,091	-1,251	-0,160
NORWEGIAN AIR SHUTTLE	-0,278	0,260	-0,017	-0,007	0,015	0,008	2,259	-2,372	-0,113
WIZZAIR	-0,145	0,158	0,013	-0,140	0,150	0,010	1,023	-1,309	-0,285

The calculated data in Table 3 show that in the analysed period 2017-2018, most airlines recorded a year-on-year increase in the total LF. The highest increase in LF was recorded by the Turkish carrier Turkish Airlines, by 2.8 percentage points. The exceptions in this case are Lufthansa, TAP Portugal, Finnair, SAS, Aer Lingus and Norwegian, which recorded a decrease in LF but this decrease did not represent a significant operational changes which did not represent significant operational changes. On the contrary, an increase in ASKM is recorded by all carriers, which can also be interpreted as an increasing demand in scheduled air transport services in this period to which air carriers responded with an increased offer. However, in order to achieve an increase in LF it is necessary that these offered seats are also used by customers, which is expressed by the RPKM indicator. For all carriers for which a year-on-year increase was recorded in the LF, the factor of used RPKM achieved a higher influencing value.

Also, in the period 2018-2019 most of the analyzed carriers recorded an increase in the total value of LF. The only exceptions are Turkish Airlines, TAP Portugal, Finnair, SAS and Easyjet. However, the recorded declines in LF are only slight. Other figures for other carriers, which show positive values again point to a growing year-on-year demand in scheduled passenger air transport services.

The analysed period 2019-2020 already represents the covid period where significant declines in the operation of analysed airlines are recorded. Since mid-March 2020, due to the outbreak of the COVID-19 pandemic, air carriers have been forced to significantly reduce their operations, as evidenced by the results in Table 3. All analyzed carriers recorded significant declines in LF during this period, which ranged from about -10 to -37 percentage points. The largest decrease in LF among the examined carriers was recorded by the Dutch flag carrier KLM together with the Irish flag carrier Aer Lingus, by as much as -37.2 percentage points for KLM and by 35.4 percentage points for the Irish carrier. By contrast, German low-cost carrier Eurowings saw the lowest decline of -9.2 percentage points, followed by Turkish Airlines with the second lowest decline in LF, by -10.6 percentage points.

All analyzed carriers responded to the outbreak of the pandemic by reducing the number of seats offered, which is clearly indicated by significant decreases in the ASKM. We can say that the decrease in the ASKM has a positive effect on the final value of LF. Norwegian low-cost carrier and Austrian flag carrier cut the offer the most. On the other hand, the carrier KLM reduced the offer the least, which also recorded the highest decrease in the total of LF. Despite the fact that carriers significantly reduced supply, interest in passenger air transport services fell so sharply at the time of the pandemic that all analyzed carriers recorded a higher decrease in RPKM than in ASKM, which had a significant impact on the resulting value of LF. This value decreased due to the higher influencing weight of the RPKM factor, which showed high negative values. On the other hand, the significant decrease in ASKM airlines' passenger kilometers offered partially offset the decrease in LF, as if the seat offer was not reduced, the LF drops in the analyzed carriers would be much higher, which would be very disadvantageous for carriers. The only exception for the analyzed carriers is the British low-cost carrier Easyjet, which as the only carrier did not record a decrease in LF during the covid period, but on the contrary its increase. This fact can be explained by the fact that as the only carrier, during the outbreak of the COVID-19 crisis estimated and reduced the supply of ASKM so well that the decrease in RPKM did not exceed the decrease in ASKM, thus not reducing LF.

4.2. MODEL 2

Table 4: Results of the analysis of the model 2 [Source: Author]

Letecká spoločnosť	$\Delta PP_{2017-2018}$			$\Delta PP_{2018-2019}$			$\Delta PP_{2019-2020}$		
	Δzam.	Δcest.	ΔPP	Δzam.	Δcest.	ΔPP	Δzam.	Δcest.	ΔPP
KLM	-24,098	46,227	22,129	-19,864	28,182	8,318	52,153	-749,356	-697,202
TURKISH AIRLINES	-211,449	118,817	-92,631	-95,797	-14,295	-110,092	51,564	-736,075	-684,511
LUFTHANSA	-56,448	124,987	68,539	-250,200	63,818	-186,381	55,744	-1409,797	-1354,053
SWISS AIRLINES	-91,857	182,007	90,149	-118,202	109,020	-9,182	61,154	-1541,094	-1479,940
AUSTRIAN AIRLINES	-46,217	155,342	109,125	27,105	96,224	123,329	107,472	-1715,014	-1607,542
TAP PORTUGAL	68,993	140,264	209,257	-85,149	121,031	35,882	126,684	-1203,586	-1076,903
BRITISH AIRWAYS	4,559	46,741	51,300	-0,907	19,835	18,927	100,271	-985,921	-885,651
FINNAIR	-179,137	222,724	43,587	-103,794	206,827	103,033	149,456	-1736,728	-1587,272
SAS	48,787	16,513	65,300	-325,422	-31,857	-357,279	725,906	-1694,251	-968,345
AER LINGUS	6,291	183,083	189,373	19,640	105,204	124,844	1676,406	-4764,797	-3088,391
EUROWINGS	-898,252	709,373	-188,879	6000,430	-2300,688	3699,742	555,145	-6070,887	-5515,743
EASYJET	-947,517	629,278	-318,238	-531,535	511,637	-19,898	396,799	-3225,265	-2828,466
VUELING	-1316,767	956,587	-360,180	-1573,55	475,290	-1098,26	394,214	-6075,312	-5681,098
NORWEGIAN AIR SHUTTLE	-223,429	424,490	201,060	316,921	-112,428	204,493	1089,461	-3866,107	-2776,646
WIZZAIR	-1943,942	1307,433	-636,509	-352,887	1255,841	902,954	685,422	-7128,476	-6443,054

The results of this model also indicate an increasing demand in scheduled passenger air transport services in the pre-covid period which in this case indicates in particular a year-on-year increase in the number of passengers carried for all analyzed carriers. According to the data in Table 12, it can also be argued that the increasing number of passengers carried motivates air carriers to hire new staff, an increase of which is recorded for most of the air carriers analyzed in the pre-covid period. As for the work productivity indicator, it is clear from the obtained data that higher values of total work productivity are achieved by low-cost carriers. This argument can be explained in particular by the fact that carriers with a traditional business model place great emphasis on the quality of the services offered, which ensures a higher number of crew during the flight than low-cost carriers that comply with minimum mandatory crew numbers. Therefore, the number of passengers carried per one employee is lower for traditional carriers, which in this case reduces the work productivity of traditional carriers compared to the low-cost ones.

In the analyzed covid period, all carriers recorded a significant decrease in the number of transported passengers, which was also reflected in a significant decrease in the work productivity indicator. The highest decrease in the number of passengers carried was recorded by the carrier Wizzair and on the other hand the lowest decrease was recorded by the carrier Turkish Airlines. The carriers responded to these declines in operation by reducing the number of employees, thus at least partly trying to reduce their operating costs during the peak of the crisis and partly to compensate for the declines in the work productivity indicator. The Irish carrier Aer Lingus cut its workforce the most, by almost half. On the contrary the lowest decrease in the workforce was again recorded for the Turkish carrier. However, despite the significant reduction in the workforce recorded by all carriers analyzed, the negative development of the work productivity indicator towards the reduction, which caused a rapid decline in the number of passengers carried, failed to reverse. The lowest declines in work productivity were recorded by low-cost carriers Wizzair, Vueling and Easyjet, and conversely, the lowest declines were recorded by Turkish Airlines and KLM.

4.3. MODEL 3

Table 5: Results of the analysis of the model 3 [Source: Author]

Letecká spoločnosť	$\Delta PL_{2017-2018}$			$\Delta PL_{2018-2019}$			$\Delta PL_{2019-2020}$		
	Δusk.lety	Δlietadlá	ΔPL	Δusk.lety	Δlietadlá	ΔPL	Δusk.lety	Δlietadlá	ΔPL
TURKISH AIRLINES	83,950	-13,656	70,295	-11,005	-78,876	-89,881	-749,127	-38,251	-787,378
LUFTHANSA	112,988	26,942	139,930	-47,456	-58,423	-105,879	-956,603	-140,956	-1097,559
SWISS AIRLINES	85,323	-245,258	-159,935	-41,787	-30,144	-71,931	-1039,756	-19,031	-1058,786
AUSTRIAN AIRLINES	83,904	0,00	83,904	-142,223	21,319	-120,904	-1204,393	42,036	-1162,357
SAS	-39,315	11,892	-27,422	-25,010	-11,688	-36,698	-950,299	235,918	-714,381
EUROWINGS	274,072	-742,992	-468,920	-456,146	99,227	-356,918	-1365,014	993,224	-371,791
EASYJET	145,102	-220,538	-75,436	142,632	-89,446	53,187	-875,188	-44,571	-919,759
WIZZAIR	214,614	-326,722	-112,108	207,950	-134,224	73,725	-1038,000	-142,379	-1180,379

In the analyzed period 2017-2018, most of the analyzed carriers increased the number of their aircraft in the fleet which can also be explained in response to the growing demand of scheduled passenger air transport services. However, the increase in the influencing value of the factor of the number of aircraft in the fleet has led to a decrease in the overall productivity of aircraft for most carriers. This could be meaning that increasing the number of aircraft in the fleet, while other variables remain unchanged, will have a negative effect on overall aircraft productivity. On the contrary, the reduction in the number of aircraft in the fleet has a positive effect on the overall change in the aircraft productivity indicator.

Not so significant declines in aircraft productivity were also recorded for most of the analyzed carriers in the period 2018-2019. Turkish Airlines, Lufthansa, Swiss Airlines and SAS increased the amount of aircraft, but there was a decrease in the number of flights performed, which caused a decrease in the productivity of these carriers' aircraft. A decrease in aircraft productivity was also recorded for Austrian Airlines, which, although it reduced the amount of aircraft in the fleet, also saw a more significant decrease in the number of flights performed, which was reflected in a decrease in aircraft productivity. Out of the carriers analyzed, the low-cost carrier Eurowings recorded the highest decrease in aircraft productivity during this period, while the low-cost carriers Easyjet and Wizzair increased the amount of aircraft in the fleet but also recorded a significant increase in aircraft productivity.

However, the recorded declines in aircraft productivity for the analyzed carriers in the pre-covid period are only slight compared to the decreases of this indicator in the covid period. At that time, there was a significant decrease in the aircraft productivity indicator for all carriers analyzed. The lowest decrease was recorded by the low-cost carrier Wizzair and the lowest decrease was also recorded by the low-cost carrier Eurowings. The significant decrease in this indicator was mainly influenced by a high drop of the number of flights performed by all analyzed carriers. However, a reduction o the amounts of aircraft in the fleet, which has a positive effect on the growth of the aircraft productivity indicator, was recorded for only 3 carriers (Austrian Airlines, SAS, Eurowings). The carrier Eurowings reduced its fleet the most, but it also recorded the highest decrease in the number of flights performed. For other carriers, there was an increase in the number of aircraft even during the crisis, which was reflected in significant declines in aircraft productivity

4.4. SUMMARY

The analysis of the designed quantification models of determining factors shows that in the case of the first model, which examined changes in the aircraft Load Factor, carriers with a low-cost business model recorded better results in the covid period. On the other hand, in the second model which examined changes in the work productivity indicator and its influencing factors, carriers with the traditional business model applied performed better in the covid period, with the exception of Aer Lingus. Regarding the results of the third model, which examined changes in the aircraft productivity indicator and its influencing factors, in this case it is not possible to clearly determine which applied business model achieved better results in times of crisis.

5. CONCLUSION

The aviation industry together with other transport industries and tourism is one of the most sensitive industries to external factors. Since the beginning of the new millennium, the aviation has gone through many serious crises, but the COVID-19 pandemic can be considered the most serious crisis to hit the aviation industry worldwide. Strict travel restrictions imposed by national governments have led to enormous restrictions on air carriers' operations, which has also been reflected in a significant drop in their market values. However, in general, only the strongest will overcome the crisis, so it is important to find out which applied model of air carriers' business is easier to overcome the crisis and is stronger - traditional or low-cost.

Based on the economic analysis and the results achieved from the three quantification models, it is not possible to clearly determine which business model of the analyzed carriers achieves better results in times of crisis. The first model showed better performance of low-cost carriers. On the contrary the second model showed better results of traditional carriers and the third model showed mixed results, as it was reduced to only 8 carriers due to the unavailability of data. However, the ambiguous results of the analysis can also be explained by the fact that nowadays there is no longer a purely traditional or purely low-cost business model, because there is a mutual hybridization, they take over the characteristics and the boundaries between individual business models gradually disappear. Therefore, in order to achieve clear results, a more comprehensive analysis of a larger number of air carriers is needed, focusing not only on operational indicators but also on financial ones that would provide comprehensive results on the performance of air carriers in times of crisis. Such an analysis should also work with the individual attributes of the air carriers' business models, which would be a more comprehensive approach compared to the chosen procedure in this work, where the examined air carriers were strictly divided into only two groups.

It should also be noted that the paper was written during the ongoing pandemic, so the results achieved in this thesis are not final and full research will require future research after the end of the pandemic.

6. REFERENCES

[1] CURLEY, A. a kol. 2020. Coronavirus: Airlinesbrace for severe turbulance. In Travel, Logistics and Infrastructure Practise [online]. 2020 [cit. 2022-02-01]. Website: ttps://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/coronavirus-airlines-brace-for-severe-turbulence.

[2] AMAN, Q. a ALTASS, S. 2020. Pre- and post-COVID-19 condition, performance and future of the airline industry: Evidence from accounting data. In Amazonia Investiga [online]. 2020, vol. 10, no. 37 [cit. 2022-01-31]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S0969699721000454. ISSN 2322-6307

[3] THEPCHALERM, T. a HO, P. 2021. Impacts of COVID-19 on airline business: An overview. In GATR Journal of Business and Economics Review [online]. 2021, [cit. 2022-01-31]. Dostupné na internete: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3874441. ISSN 0128-259X

[4] TROYER, H. a kol. 2021. COVID-19 and aviation. In Journal of Infectious Disease and Case Reports [online]. 2021, vol. 2, no. 3 [cit. 2022-01-31]. Dostupné na internete: https://www.onlinescientificresearch.com/articles/covid19-and-aviation.pdf. ISSN 2634-8861

[5] MANEENOP, S. a KOTCHARIN, S. 2020. The impacts of COVID-19 on the global airline industry: An event study approach. In Journal of Air Transport Management [online]. 2020, vol. 89 [cit. 2022-01-31]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S0969699720305032 . ISSN 0969-6997

[6] OZILI, P. a ARUN, T. 2020. Spillover of COVID-19: Impact on the Global Economy [online]. [cit. 2022-01-31]. Dostupné na internete: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3562570

[7] SUAU-SANCHEZ, P. a kol. 2020. An early assessment of the impact of COVID-19 on air transport: Just another crisis or the end of aviation as we know it? In Journal of Transport Geography [online]. 2020, vol. 86 [cit. 2022-01-31]. Dostupné na internete:

https://www.sciencedirect.com/science/article/pii/S0966692320304841. ISSN 0966-6923

[8] KÖKÉNY, L. a kol. 2021. Impact of COVID-19 on different business models of European airlines. In Jounal of Current Issues of Tourism [online]. 2021, vol. 25, no.3 [cit. 2022-01-31]. Dostupné na internete: https://www.tandfonline.com/doi/full/10.1080/13683500.2021.1960284 .

[9] IACUS, S. M. a kol. 2020. Estimating and projecting air passenger traffic during the COVID-19 coronavirus outbreak and its socio-economic impact. In Safety Science [online]. 2020, vol. 129 [cit. 2022-01-31]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S0925753520301880.

[10] SOBIERALSKI, J.B. 2020. COVID-19 and airline employment: Insights from historical uncertainty shocks to the industry. In Transportation Research Interdisciplinary Perspectives [online]. 2020, vol. 5 [cit. 2022-01-31]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S2590198220300348.

[11] TAY, D. a kol. 2020. The Aviation Industry: Tackling the turbulance caused by COVID-19. In IETI Transactions on Economics and Management [online]. 2020, vol. 1, no. 1 [cit. 2022-02-01]. Dostupné na internete: http://paper.ieti.net/tem/2020V1S1/04.pdf.

[12] MOLENAAR, D. a kol. 2020. The post-COVID-19 flight plan for airlines. 2020 [cit. 2022-02-01]. Dostupné na internete: https://www.bcg.com/publications/2020/post-covid-airline-industry-strategy.

[13] VINOD, B. 2021. Airline revenue planning and the COVID-19 pandemic. In Journal of Tourism Futures [online]. 2021 [cit. 2022-02-01]. Dostupné na internete: https://www.emerald.com/insight/content/doi/10.1108/JTF-02-2021-0055/full/html. ISSN 2055-5911

[14] [BAUER, L.B. a kol. 2020. Ultra Long-Haul: An emerging business model accelerated by COVID-19. In Journal of Air Transport Management [online]. 2020, vol. 89 [cit. 2022-02-01]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S0969699720304853.

[15] ADRIENNE, N. a kol. 2020. Grounded aircraft: An airfield operations perspective of the challenges of resuming flights post COVID. In Journal of Air Transport Management [online]. 2020, vol. 89 [cit. 2022-02-03]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S0969699720305044.

[16] AKBAR, Y.H. a KISILOWSKI, M. 2020. To bargain or not to bargain: Airlines, legitimacy and nonmarket strategy in a COVID-19 world. In Journal of Air Transport Management [online]. 2020, vol. 88 [cit. 2022-02-03]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S0969699720304518.

[17] ALBERS, S. a RUNDSHAGEN, V. 2020. European airlines strategic responses to the COVID-19 pandemic. In Journal of Air Transport Management [online]. 2020, vol. 87 [cit. 2022-02-03]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S0969699720303410.

[18] MRÁZOVÁ, M. a KAZDA, A. 2021. The direction of airlines business models – up or down? (Post Covid-19 crisis – case study). In INCAS Bulletin [online]. 2021, vol. 13 [cit. 2022-02-03]. Dostupné na internete: https://www.researchgate.net/publication/349865384_The_direction_of_airlines_business_models_-_up_or_down_Post_Covid-19_crisis_-_case_study. ISSN 2247-4528

[19] ABATE, M. a kol. 2020. Government support to airlines in the aftermath of the COVID-19 pandemic. In Journal of Air Transport Management [online]. 2020, vol. 89 [cit. 2022-02-04]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S0969699720305147.

[20] MACILREE, J. a DUVAL D.T. 2020. Aeropolitics in a post-COVID-19 world. In Journal of Air Transport Management [online]. 2020, vol. 88 [cit. 2022-02-04]. Dostupné na internete: https://www.sciencedirect.com/science/article/pii/S096969972030301X.

[21] ZALAI, K. a kol. 2016. Finančno-ekonomická analýza podniku. 9. vyd. Bratislava : Sprint 2 s.r.o., 2016. 487 s. ISBN 978-80-89710-22-5

[22] TOMOVÁ, A. a kol. 2017. Ekonomika leteckých spoločností pravidelná osobná doprava. 1. vyd. Žilina : EDIS, 2017. 274 s. ISBN 978-80-554-1359-4

[23] TOMOVÁ, A., HAVEL, K. 2015. Ekonomika poskytovateľov leteckých navigačných služieb. vyd. - V Žiline : Žilinská univerzita, 2015. - 154 s. ISBN 978-80-554-1153-8.

[24] TOMOVÁ, A., MATERNA, M. 2017. The Directions of On-going Air Carriers' Hybridization: Towards Peerless Business Models? Procedia Engineering, 2017, 192, pp. 569–573

https://doi.org/10.26552/ pas.Z.2022.2.08

CHINA AS A NEW COMPETITOR ON THE GLOBAL MARKET OF CIVIL AIRCRAFT

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Abstract

This paper deals with the Chinese aviation industry and its current state, and the main goal of this paper is to find out whether China, in terms of its position, can compete with the current Airbus-Boeing duopoly in the coming years on the large civil aircraft market, while it also aims to set possible scenarios of the development of the large civil aircraft market. The paper approaches the matter through the historical development and the current state of the large civil aircraft market to find out whether there is any perspective and chance for a new competitor to succeed, and the Chinese aviation industry, which allows a better understanding of the problems that China faces in the production of large civil aircraft. In the third chapter, a comparative method is used and its result is the determination of the competitiveness of large civil aircraft produced by China in comparison with those produced by European and American manufacturers, while it also points out their strengths, weaknesses and potential customers. In the last chapter of the paper, the "Compound Annual Growth Rate" method is used along with findings gained from pervious chapters in order to determine possible development scenarios of the large civil aircraft market regarding the position of China. While determining the scenarios, the current and possible future geopolitical situation, political relations of China and the resulting factors with the potential of affecting the Chinese aviation industry were taken into account. This paper also points out China's biggest problem, due to which, despite the enormous effort, it has not yet entered the market of large civil aircraft, with the problem being the dependence on foreign aviation technologies caused by the lack of expertise and experience stemming mainly from the historical development of the Chinese aviation industry. The paper also points out that, despite the slow development of the Chinese aviation industry, the entrance of China to the large civil aircraft market is only a matter of time. The results of paper about diploma thesis can be used to help to decide what threat China does pose to the Airbus-Boeing duopoly.

Keywords

China, Chinese aviation industry, COMAC, CRAIC, Large civil aircraft, Large civil aircraft market, Airbus, Boeing, The future state of the global aircraft fleet

1. INTRODUCTION

The global market of large civil aircraft is currently duopolistic and the only two competitive manufacturers are American company Boeing and European company Airbus. However, this market has historically not always been duopolistic and has gradually evolved into its current form. The development of the global market of large civil aircraft began in the late 1950s. Right after the Second World War, new technologies were used in the field of civil aviation industry too, which led to the development of the first civil jet airliner De Havilland DH-106 Comet by the United Kingdom [1]. This aircraft, however, had shortcomings, from which the manufacturers in the USA learned, and American company Boeing developed the first American civil jet aircraft Boeing B707, which completed its maiden flight in 1957 making it the world's first large civil aircraft, followed by Douglas DC-8 with its maiden flight in 1958 [1]. These two aircraft marked the beginning of a new era in civil aviation, the era of large civil aircraft.

At its beginnings, large civil aircraft market was dominated by American manufacturers McDonnell Douglas (created by merging McDonnell Aircraft and Douglas Aircraft in 1967), Lockheed Aircraft and mainly Boeing [1], [2]. European manufacturers were unable to compete with American ones mostly due to the competition among themselves in politically fragmented Europe, due to their decimated aviation industries and economies as a result of the Second World War. World War II also helped to kick up the aircraft production capacity of the US, which the US could use in the civil aviation industry. Author Burns [3] also came to this conclusion. Due to the inability of European civil aircraft manufacturers to compete with the US ones, some European governments decided to cooperate in order to produce a large civil aircraft capable of competing with Boeing and ensuring the survival of their own aircraft manufacturing industry, which led to the establishment of Airbus in 1970 [3]. The foundation of European manufacturer Airbus, which composed of several aircraft manufacturers with experience and was subsidized by governments, gradually led to changes in the competition on the large civil aircraft market. The market share of Airbus began to increase in 1980s and was driven by an increase in demand for air transport services in these years, to which American manufacturers were unable to respond promptly, and in combination with another innovations implemented by Airbus, like fly-by-wire and glass cockpit and the introduction of Airbus A320, American large civil aircraft manufacturers began to experience problems, which led to Lockheed leaving the large civil aircraft market in 1986, as it was not competitive enough [1-4]. McDonnell Douglas, however, could not design a competitive aircraft anymore and kept losing its market share too [5]. Therefore, in order to get better competing position of American manufacturers against Airbus, a merger of Boeing and McDonnell Douglas happened and took place in 1997, which meant the beginning of the Airbus-Boeing duopoly [1]. This merger, however, did not come into fruition as expected since Boeing was unable to integrate McDonnell Douglas effectively at first, which led to dissatisfaction of their customers [3], [11]. In combination with airlines and aircraft leasing companies not wanting a monopoly this represented another chance for Airbus to increase its market share and so it has come to pass in 2003 [5] regarding the number of deliveries. After that, in 2004, the US government accused European Union of breaking the 1992 EU-US Large Civil Aircraft Agreement through illegal subsidies provided to Airbus. European Union reacted respectfully and made the same accusation, which led to Airbus-Boeing dispute [4], [7]. This dispute lasted for 17 years and was settled in 2021 due to the threat of a new emerging competitor – Chinese COMAC, and CRAIC in cooperation with Russian Federation (Chinese COMAC and Russian UAC) [7].

This new competitor possesses all factors that are behind the Airbus' success – government subsidies, drive, and experience with aircraft production. Therefore, Chinese COMAC, and CRAIC also, could succeed in a similar way Airbus did, since according to market forecasts published by Airbus, Boeing and COMAC, there will be high demand for new large civil aircraft in the next 18 years, especially in China with the need of more than 8000 new aircraft [8-10]. This means a good perspective and a chance for a new competitor to succeed.

2. HISTORICAL DEVELOPMENT OF THE CHINESE AVIATION INDUSTRY

In order to be able to determine the extent to which China can compete with the current Airbus-Boeing duopoly, and to identify the problems Chinese aviation industry faces along with their causes, it was necessary to look at the historical development of the Chinese aviation industry. We approached the historical development of the Chinese aviation industry from two perspectives – the first perspective in terms of organizational development and the second perspective in terms of the development and production of Chinese domestic aircraft. All the conclusions and findings were based on the literature used to create the timeline in figure 1 and literature used in this chapter.

In the organizational development approach, based on the most important milestones we have identified, we have divided the development of the Chinese aviation industry into 3 stages, which are shown in the figure 1 above the timeline.

We consider year 1918 as the beginning of the Chinese aviation industry from the organizational point of view since it was the year when the "Office to make preparations for matters concerning aviation" was established. However, this is a different opinion from Jin et al. [14] who consider the year 1920 as the beginning of the Chinese aviation industry because of the first commercial flight between Beijing and Tianjin, with which we can't agree since it has nothing to do with the organizational development, nor the aircraft development and production. According to the small number of milestones in this first stage, we consider the development of the Chinese civil aviation industry slow in this period of time, which is also the opinion of Zhao and Wan [27]. The second stage lasted from 1949 until 1980 and the focus was given to Chinese military aviation, while the development of civil aviation was practically abandoned, for the aviation industry was wholly controlled by military part of Chinese government and later by combination of military and civil part of the government. We set the end of this stage to the year of 1980 because the CAAC came fully under the control of the civil part of Chinese government meaning the beginning of aviation deregulation in China, which also agrees with the opinion of Zhang and Round [15]. On the other hand, we do not agree with the opinion of Wang et. al [28] and Jin et al. [14], who consider year 1978 as the end of the strict regulation period and the beginning of the deregulation, since in 1978 economic reforms started in China, but we consider it to be only the cause of the aviation deregulation in China. However, we came to a conclusion that the civil aviation industry development was slow in this stage mostly because of China's focus on military aviation, which also agrees with opinions of all the authors mentioned above. The year 1980, in our opinion, marked the beginning of the Chinese aviation industry deregulation, which led to more effective and stronger Chinese aviation industry. Wang et al. [16] say the deregulation was partially successful, and they connect it with a fast growth of the demand for air transport, while they also say the deregulation wasn't effective enough to stop the dominance of "The Big Three". We agree, that the deregulation helped the demand for air transport in China, however, even though we describe Chinese aviation industry as partially deregulated as the CAAC (Civil Aviation Administration of China) retained control over the development of airports, airlines and controls the entry of airlines on certain flight routes, we can't say the deregulation wasn't effective enough to stop the dominance of "The Big Three" [29]. We think it was effective as Chinese government intended and that the consolidation helped "The Big Three" to keep their dominance, just like Chinese government intended.

In the approach in terms of the development and production of Chinese domestic aircraft, we have divided the development of the Chinese aviation industry into 4 stages based on the most important milestones. These stages and milestones are also shown in the figure 1 but below the timeline. Each of these stages has its own features but overall, we characterize Chinese aviation industry in terms of the development and production of Chinese domestic aircraft as slow and dependent. Slow because it always took China a long time to develop its own aircraft, besides the second stage where it had help from Soviet Union, and dependent because China has needed foreign help and has been dependent on foreign technology during every single stage of their aviation industry development.

In this approach, we consider year 1913 as the beginning of the development of the Chinese aviation industry in the aircraft development and production, and we also consider it as the beginning of the first stage we named "Stage of low production and import", which lasted until 1949. Niosi and Zhao [30] described Chinese aviation industry in terms of aircraft development and production basically as non-existing, since according to their findings China had no capabilities of designing, developing or producing any aircraft whatsoever and, therefore, had to import them. Author Fai [31] came to the same conclusion as she said that before 1949 China could not produce its own aircraft. However, that is not certainly true, since according to findings of Andersson (2008) [20], China was able to produce a small amount of aircraft and had to import the rest, and these aircraft were mostly for military purposes of warlords. The next stage started in 1949 when People's Republic of China and CAAC have been founded. We named this stage as a "Stage of Soviet technology", since the Soviet Union was the main ally of China with more sophisticated technology, which was being transferred to China thanks to this cooperation. China made many leaps in this stage, which lasted up to Sino-Soviet split in 1966, which led to the withdrawal of Soviet scientists from China and to the cessation of cooperation between China and the Soviet Union. According to aircraft China produced at this time [22] and according to the findings about how the Chinese aviation industry was controlled at this time, we concluded that domestic aircraft development and production was focused mainly on military aircraft. However, China made many great leaps during this stage, even though practically all its designs were based on Soviet designs and technology. Niosi and Zhao [30] and Crane et al. [23] concluded the same regarding Soviet technology dependency and the focus on military aircraft. Even though this cooperation helped the Chinese aviation industry, it also marked its continuous downfall. The combination of Sino-soviet split in 1966, The Great Leap Forward and the Cultural Revolution slowed down the development of the Chinese aviation industry in terms of the development and production of aircraft, since they meant stoppage of technology transfer, decimation of China's economy and loss in the intellectual potential of China. The third stage we defined was "Stage of Reverse engineering and western technology", which lasted from 1966 up to 2002.

At the beginning of this stage, China led isolationistic policy and had no foreign technology feed, nor it had its own because of negative factors which affected its aviation industry and the low level of aviation industry before the World War II. Therefore, China had to turn to reverse engineering and in spite of all the negative factors named above, China tried to develop civil jet aircraft Shanghai Y-10. However, as China didn't have enough experience, expertise and technology, this project failed and was cancelled in 1983 because China could not make it work. Because reverse engineering did not bring the required result and Sino-Soviet relations were bad, China decided to cooperate with west in order to gain technology, expertise and experience needed to develop their own civil jet aircraft. This was also the goal of a "Three-Step Plan" China made in 1983, which was supposed to make China independent on foreign aviation technology and help, so it could develop domestic civil jet aircraft on its own by 2010. However, China did not manage to reach this goal set by the "Three-step plan", which can be seen in COMAC ARJ21 and C919 component suppliers. Therefore, we agree with the opinion of Fai (2013) [31] who said that the technology transfer wasn't as big as China expected it to be.

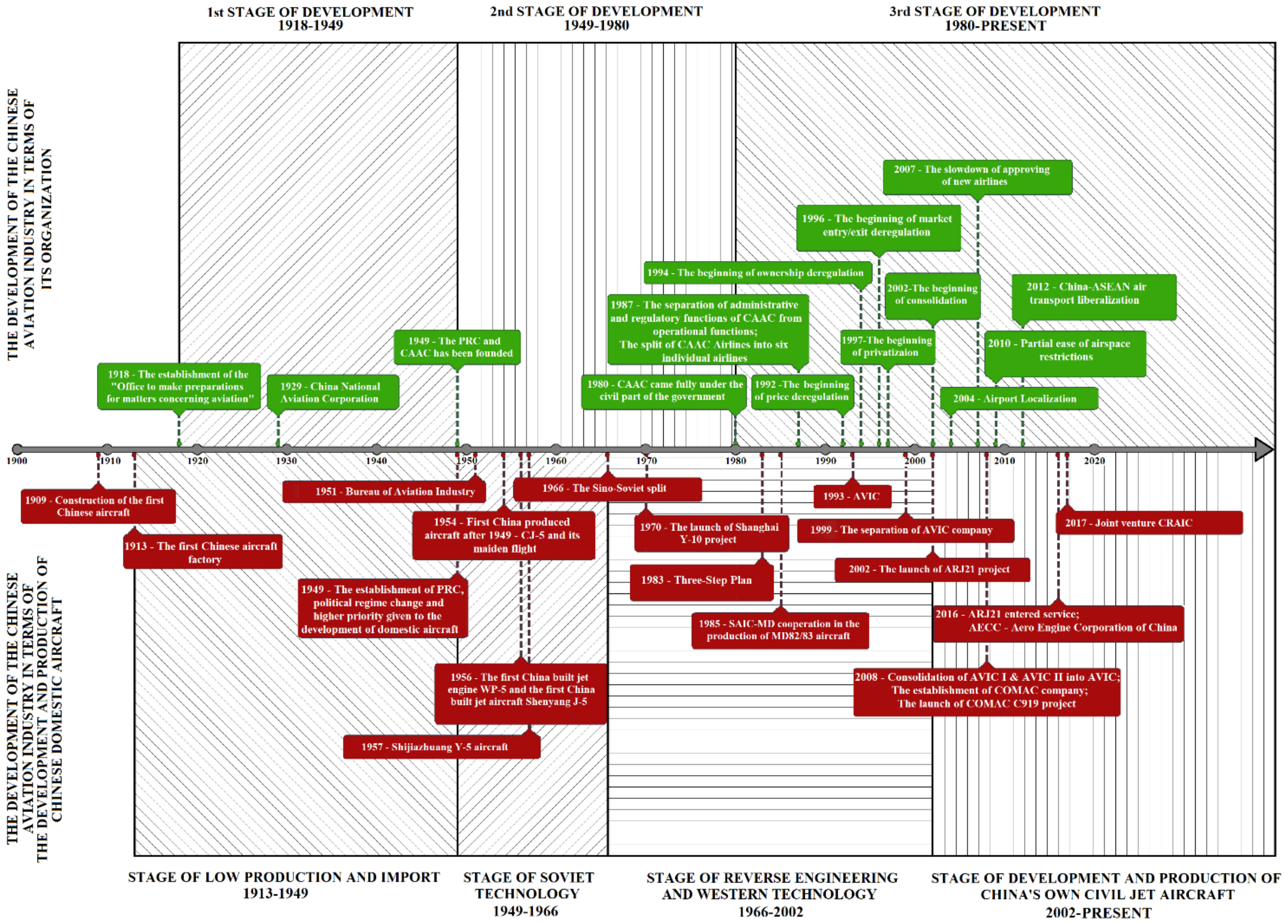

Fig. 1. The timeline of the development of the Chinese aviation industry. (Compiled by author, based on [5-12], [14], [21-24], [27], [30], [31], [33]. Full resolution may be provided by author on request.)

According to Wood et al. [24] the long-lasting problem of Chinese aviation industry, which is present even today, is the inability of developing its own aviation jet engine for civil aircraft. Despite the fact that China is still dependent on foreign technology, the plan led to the extension of cooperation between China and foreign countries in the field of aviation industry and aircraft production, thanks to which China managed to transfer technology and gain experience, which it subsequently began to use in the development of its own civil jet aircraft since 2002 when China started the development of the ARJ21. This is the last stage of the development of the Chinese aviation industry so far, which is still ongoing and its main domain is the development of the C919 aircraft and the CR929 aircraft. Already mentioned author Fai (2013) [31] also said, nine years ago, that Chinese aviation industry had enough experience to be successful thanks to the cooperation with foreign firms. However, we can't agree with her opinion, since it is already 2022 and China can't build the whole large civil aircraft with all its components on its own, nor it does have its own aviation jet engine for this type of aircraft.

3. COMPARISON OF LARGE CIVIL AIRCRAFT PRODUCED BY THE USA, THE EU AND CHINA

China tried to enter the large civil aircraft market as early as 1970, when it launched the development of the Shanghai Y-10 civil jet aircraft. However, this project was unsuccessful and was cancelled in 1983. After that, China realized that it was unable to develop a competitive civil jet aircraft on its own and, therefore, it began to cooperate and to expand cooperation with foreign countries. Throughout this cooperation China gained experience in the assembly of aircraft, the aircraft production and the production of aircraft components, but thanks to this cooperation the foreign technology transfer to China took place too. The goal of China was to learn, gain the necessary experience, expertise and technology in order to be able to develop its own large civil aircraft. These experience and technologies are currently being applied in the development of Chinese large civil aircraft C919 and CR929, which are to get China to the large civil aircraft market. However, in order for these aircraft to enter the market successfully, not only good market perspective, gained technologies and experience, and state subsidies of the manufacturer are needed, but these aircraft must also be competitive with the products of the established Airbus-Boeing duopoly on the large civil aircraft market.

In order to determine the competitiveness of large civil aircraft produced by China (COMAC C919 and CRAIC CR929), this chapter uses comparative method and focuses on the technical, performance and economic attributes of aircraft, but also takes into account the dependence on component suppliers.

3.1. Comparison of COMAC C919, Airbus A320 and Boeing B737 aircraft

It is known that the aircraft C919 is supposed to compete with Airbus A320 and Boeing B737. The problem, however, is that these aircraft have been on the market for a longer period of time and entire families of these aircraft have been created, which, nowadays, include both older and newer types. However, the older types are gradually being replaced by newer ones. Therefore, in order for the comparison to be the least biased, we compared the C919 with the latest aircraft of these large families – the A320neo family and the B737 MAX family. As there are no extended and shortened version of the C919 yet, the comparison was made with the base aircraft of these families – the Airbus A320neo and the Boeing B787 MAX 8. The first among compared were technical specifications, which are listed in table 1.

TABLE I. TECHNICAL SPECIFICATIONS OF C919, C919(ER), A320NEO AND B737 MAX 8. (COMPILED BY AUTHOR [32-44])

	C919	C919 (ER)	A320neo	B737 MAX 8
Length [m]	38,9	38,9	37,57	39,52
Wingspan [t]	35,8	35,8	35,80	35,9
MTOW [t]	72,5	77,3	79	82,19
Payload [t]	20,4	20,4	20	20,88
Range [km]	4075	5555	6300	6570
Cruising speed [km/h]	834	834	828	839
Ceiling [m]	12100	12100	12100	12500
Take-off runway length [m]	2000	2200	1951	2500
Max. seating capacity	190	190	194	210
2-class seating capacity	158-168	158-168	150-180	162-178
Cabin width [m]	3,96	3,96	3,70	3,53
Cabin height [m]	2,25	2,25	2,24	2,19

According to the main technical specifications listed in table 1, all three compared aircraft are quite similar. However, the C919 aircraft has a slight advantage thanks to its cabin width, thanks to which it can provide higher seating comfort for passengers. There are, however, more disadvantages to this aircraft than advantages according to specifications. One of the main disadvantages is lower seating capacity, in both maximum seating configuration and 2-class seating configuration. Nonetheless, more severe disadvantage because of which C919 lags behind is its significantly shorter flight range compared to A320neo and B737 MAX 8, even in the C919(ER) extended range version. The competitive position of C919 and C919(ER) version is better described by the figure 2. We also used older aircraft of the A320 and B737 families to better illustrate C919's competitiveness. As the figure 2 shows, the C919 aircraft in its basic version does not compete even with older A320 and B737 aircraft regarding the range. The version with extended range C919(ER), even though it is competitive with older types regarding the range, it still lags behind the current competition, the A320neo and the B737 MAX 8 families.

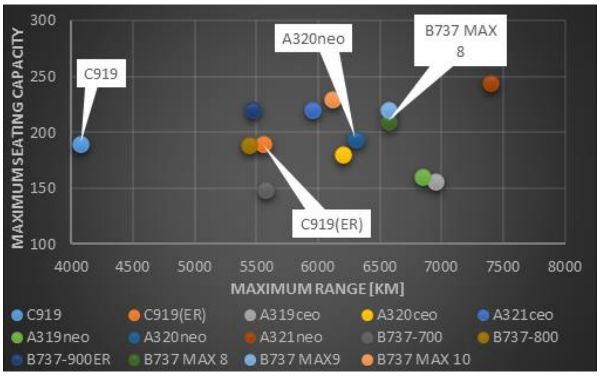

Fig. 2. The position of C919 and C919(ER) aircraft against the competition in terms of maximum capacity and range. (Compiled by author [32, 37, 44, 56-58]

However, this major disadvantage in the form of the C919's short flight range should be compensated by its economic advantage, which should be lower acquisition costs. The C919 aircraft should cost around $50 million and should be up to 55.3% cheaper than the A320neo aircraft and up to 60.8% cheaper than the B737 MAX 8 aircraft. An overview of aircraft prices is given in the table 2.

TABLE II. THE PRICE OF C919 AIRCRAFT, A320NEO AND B737 MAX AIRCRAFT FAMILIES (NOT INCLUDING B737 MAX 7). (COMPILED BY AUTHOR [45-47])

Aircraft	Price [mil. $]
A319neo	101,5
A320neo	110,6
A321neo	129,5
B737 MAX 8	121,6
B737 MAX 9	128,9
B737 MAX 10	134,9
C919	±50

The last compared attribute was the dependence of the aircraft on foreign technology. This is one of the biggest drawbacks of C919, since it is heavily dependent on foreign technology – mostly American. Even though B737 MAX and A320neo aircraft make use of components from all around the globe, suppliers of major components such as aircraft jet engines are from domestic countries of Airbus and Boeing [69]. China, on the other hand, can't provide COMAC with domestic suppliers of more complex aviation technologies, especially jet engines for civil aircraft, since China has problems developing them. The dependency of COMAC's C919 aircraft on foreign technology is shown in the figure 3.

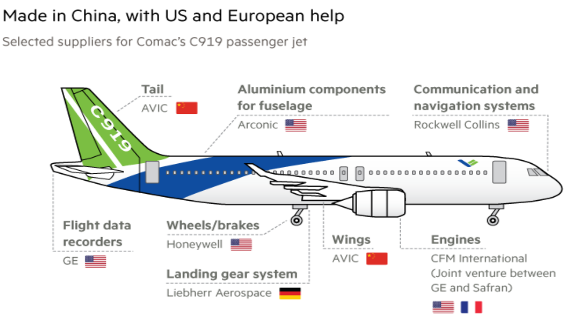

Fig. 3. C919's main component suppliers [48].

3.2. Comparison of CRAIC CR929, Airbus A350 and Boeing B787 aircraft

Another aircraft that China wants to finish developing and to produce is CRAIC CR929, which China develops in cooperation with Russia. Aircraft CR929 is a wide-body aircraft being developed by Russian company UAC and Chinese company COMAC in a joint venture CRAIC. According to the UAC president Yury Slyusar, CR929 is set to compete with Airbus A350 and Boeing B787 aircraft [66]. Several variants were produced from the Airbus A350 family and Boeing B787 family, but for the purpose of the comparison, we used those aircraft of these two families, that are closest to the basic version of the CR929 (also named CR929-600) regarding technical characteristics. Chosen aircraft were the Airbus A350-900 and the Boeing B787-9.

In comparison, we proceeded in the same way as with the C919 aircraft, and the first compared attributes were technical characteristics.

TABLE III. TECHNICAL SPECIFICATIONS OF CR929-600, A350-900 AND B787-9. (COMPILED BY AUTHOR [49-55])

	CR929-600	A350-900	B787-9
Length [m]	63,3	66,8	63
Wingspan [t]	63,9	64,75	60
MTOW [t]	245	280	254
Payload [t]	50,4	53,3	52
Range [km]	12000	15000	14010
Cruising speed [km/h]	908	903	903
Ceiling [m]	-------	13100	13100
Max. seating capacity	440	440	420
3-class seating capacity	280	300-350	280
Cabin width [m]	5,61	5,61	5,49

As the table 3 shows, CR929 lags behind its competition too. The CR929 has lower MTOW and a little bit lower payload, and even though the cruising speed of it is a tiny bit higher, the CR929's hour productivity is lower than the hour productivity of its competitors, which is one of the CR929's disadvantages. The hour productivity of CR929 reaches 45763.2 tonne-kilometres per hour, while A350-900 reaches 48129.9 tonne-kilometres per hour and B787-9 reaches 46956 tonne-kilometres per hour. Another and much more significant drawback of the CR929 aircraft is its short flight range, just like in the case of C919. Its lower seating capacity in 3-class seating compared to A350-900 is also a slight disadvantage, however, even B787-9 has just 280 seating capacity in this configuration and is successful on the large civil aircraft market. The competitive position of the CR929 aircraft compared to the potential wide-body aircraft competition is shown in the figure 4.

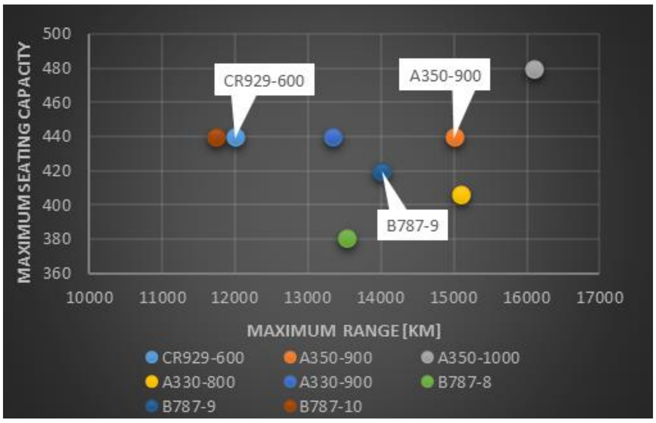

Fig. 4. The position of CR929 aircraft against the competition in terms of maximum capacity and range. (Compiled by author [49-55], [59])

In contrast with these disadvantages, mainly the disadvantage regarding shorter flight range, the CR929 aircraft provides interesting advantages too. These advantages are of economic nature, just like in the case of C919. The first advantage is predicted 15% lower operating costs compared to A350 and B787 [66], which could be rather interesting for every airline. And the second advantage is lower acquisition costs. The price of CR929 is yet to be set, but it is expected to cost $113.5-117.8 million, while B787-9 costs $292.5 million and A350-900 costs $317.4 million [46], [47], [65]. This makes CR929 59.7-61.2% cheaper compared to B787-9 and 62.9-64.2% cheaper than A350-900.

The last compared attribute is the dependency on foreign technology suppliers. While COMAC C919 was dependent mostly on American and European technology, CR929 is different. Although CR929 is still dependent on foreign technology, it is not dependent on American and European technology suppliers as much as C919 is, and that is only thanks to the cooperation with Russia. However, there are still some western technologies used and one of them are jet engines, which are, in this case, most important since nor China, nor Russia have engines for this type of aircraft at their disposal yet. Therefore, the first aircraft are to be fitted with American General Electric GEnx-1B76 engines or British Rolls-Royce Trent 1000 engines. These engines should be replaced by Russian PD-35 engine, which is currently under certification process, or by Chinese engine CJ-2000, which is expected to enter into service around the year 2030 [64]. Up until the moment of successful certification and entry into service of Russian or Chinese engine, the CR929 aircraft will stay heavily dependent on foreign technology. According to Airframer [69], Airbus A350 and Boeing B787 aircraft are more "international" products, since they have a lot of suppliers. Nevertheless, compared to the CR929 aircraft, they are less dependent because the main component suppliers of Airbus and Boeing are from domestic countries of these manufacturers or from politically friendly countries, while engine suppliers of CR929 are from countries Russia and China have bad relations with.

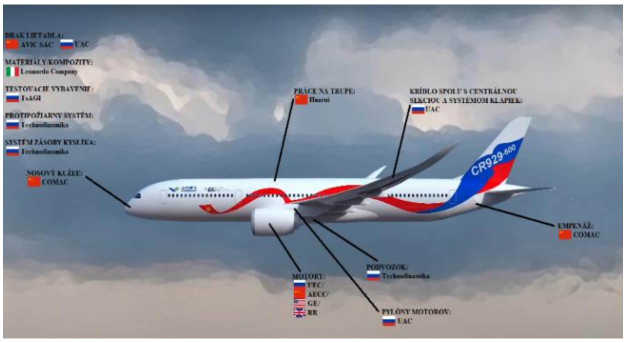

Fig. 5. Main component suppliers of the CR929 aircraft. (Compiled by author [60-64])

To sum it up, C919 and CR929 are rather interesting aircraft, which may become serious competition for Airbus and Boeing despite their main disadvantage – shorter flight range. There is also another disadvantage, the dependency on foreign technology, mostly American and European. This second disadvantage may cause lower competitiveness of these two aircraft and lower rate of production because of possible aviation technology tightening rules that may be applied in relation with bad and worsening political relation between Russia, China and USA, EU. If China will overcome problems regarding the dependency on western technology, the chances of its large civil aircraft will be much higher. However, even then COMAC and CRAIC will have to deal with another problems – certification (according to foreign countries' standards too), maintenance organization network and training organization network. If COMAC and CRAIC will be able to overcome these problems, thanks to the low price of C919 and CR929 compared to its competitors, it may succeed mostly on developing aviation markets where many new airlines will emerge, or in economically developing countries where possible customers are more price sensitive and will welcome a cheaper alternative to Airbus and Boeing aircraft. Another potential customers are low-cost airlines such as Ryanair or easyJet, which operate their flights mostly on shorter routes and, therefore, would not mind the shorter flight range.

4. SETTING MARKET TRENDS AND POSSIBLE DEVELOPMENT SCENARIOS OF THE GLOBAL MARKET OF LARGE CIVIL AIRCRAFT IN TERMS OF THE POSITION OF CHINA

In the last part of this paper, we focused on possible development scenarios of the global market of large civil aircraft considering current China's position and the current state of its aviation industry. In the previous parts of this paper, we have identified several factors that may significantly affect the development of this market and the China's large civil aircraft production capacity. In particular, these factors are the dependence of the Chinese aviation industry on foreign technology, since China is unable to develop more complex technologies e.g. civil aviation jet engines due to lack of experience and expertise, another factor is the settlement of Airbus-Boeing dispute in order to eliminate potential threat of a new competitor entering the market of large civil aircraft, China-US and China-EU political relations, China's commitment to enter this market and the fact that Chinese government owns majority share of Chinese largest airlines.

In setting possible development scenarios, we focused mainly on the Chinese domestic market of large civil aircraft for three reasons:

- Because we consider it a lucrative market, since according to Airbus, Boeing and COMAC market forecasts China will become the largest air transport market by 2040 and up to this year, it will need the largest number of new large civil aircraft with the estimation of 8230 units.
- The second reason is that the largest increase in air traffic volume and the largest increase on the global market of large civil aircraft is expected in China and Southeast Asia. This would mean the emergence of many new airlines for which cheaper Chinese aircraft could be a great substitute product for Airbus and Boeing aircraft in these developing countries. Therefore, we assume that the development of the world market, because of its growth predictions, will follow the development of the Chinese domestic market.
- The last reason is that the success of large civil aircraft produced by China on the global market will depend on their success on the Chinese domestic market, and whether these aircraft will meet the certification standards of other countries.

We set several possible scenarios of the development of the large civil aircraft market in China and we anticipate that the development of the global market of large civil aircraft will follow the same or very similar trend, mainly due to the fact that the largest increase in air traffic and on the market of large civil aircraft up to year 2040 is expected to take place in China and in Southeast Asia, where more cost-effective substitute to Airbus and Boeing could succeed. In setting these scenarios, we focused on the market share that China could gain and the volume of its large civil aircraft production, which China would have to meet in order to achieve the desired market share, while we also took into account various factors that could affect this. As a basic value of market share China plans to achieve, we used

10% of market share its joint venture CRAIC plans to achieve by year 2040 [66] and we applied It to large civil aircraft as a whole. To set the needed production volume, we used CAGR method and every single scenario is based on the assumption that China will have managed to certify and deliver the first three planned units of its C919 aircraft by the end of 2022.

The first scenario we set is based on China's goal of achieving at least a 10% market share on its own market of large civil aircraft by 2040. Based on this premise and by the use of the CAGR method, we determined what production of large civil aircraft China would have to meet in order to achieve this 10% share of its domestic market. This scenario is neutral, influenced only by factors currently affecting Chinese aviation industry, and is illustrated in figure 6. In order to achieve 10% market share on its domestic market, China would have to ramp up its large civil aircraft production capacity 25.025% each year reaching the annual production of 167 aircraft in 2040. This way, China would produce 823 units of large civil aircraft by 2040, which represents 10% of 8230 units this market will need.

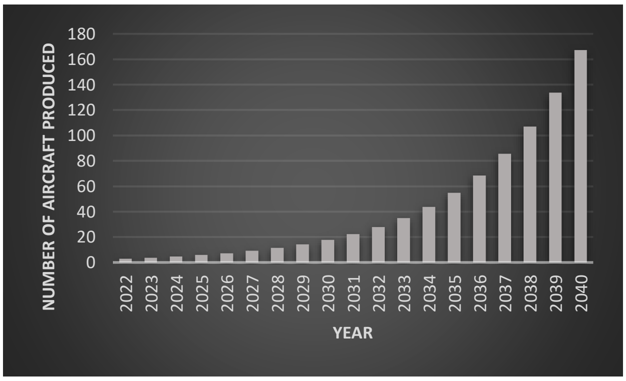

Fig. 6. The neutral scenario of the development of chinese large civil aircraft production.

Even though neutral scenario is possible, there are various factors that can affect every aviation industry in a positive or negative way and can have an effect on subjects competing on the large civil aircraft market. Only two giants Airbus and Boeing has been competing on this market since 1997 and their market share was roughly equal for a longer period of time until two Boeing B737 MAX accidents in 2018 and 2019. As a consequence of these accidents, Boeing's number of deliveries decreased by 52.85% between 2018 and 2019. Since then, there has been a big distrust towards Boeing's technology especially in China, where another Boeing aircraft B737-800 crashed in march 2022. When negative events like these happen, it damages the name of the manufacturer and it may provide room for another competitor to get his own market share. Therefore, our first positive scenario is based on one of the most serious factors that may affect large civil aircraft market share in the future and may positively affect the market share of aircraft produced by China, which is these negative events represented by accidents of competing aircraft. Our first positive scenario is based on the assumption that such tragic events may happen in the future and on the finding that Boeing's annual deliveries have dropped by 52.85% [68] as a result of the B737 MAX accidents, and we therefore assume that aircraft from China's production could reach a 52.85% higher market share than in the neutral scenario and thus 15.29%. Using the CAGR method, we found out that to achieve this market share, China would have to increase its production capacity by 28.744% year-on-year, which would lead to reaching annual production of 283 aircraft in 2040 and the total number of aircraft produced in 2022-2040 would be 1258 units.

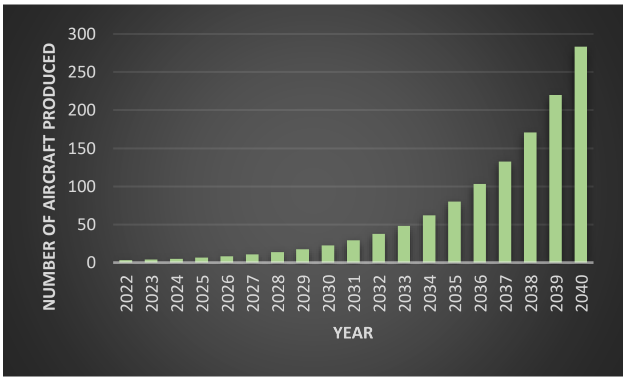

Fig. 7. The positive scenario no. 1 of the development of chinese large civil aircraft production.

The second positive scenario is based on a combination of various factors. The first of the factors is the assumption that China will manage to get its own aircraft into service as soon as possible – C919 in 2022 and CR929 in 2025. That would give China more time until 2040 to tune its supply chain and, therefore, reach higher rate of production. The second factor is the reduction of the dependency on foreign technology, mainly western one, since even now there are aviation technology export rules from US to China due to which China could not certify C919 in 2021 because it lacked spare parts [67]. Therefore, if China managed to find alternative suppliers or develop its own technology (mainly engines), China would reduce the foreign technology dependency and increase the production of its own large civil aircraft. The other possibility is an improvement of China-US and China-EU political relations. The other factors that could cause a more positive development on market for Chinese produced large civil aircraft are higher demand for domestic aircraft caused by national pride in terms of preference of domestically produced aircraft by passengers, which would force Chinese airlines to buy these aircraft, possible government pressure on airlines to buy domestic aircraft, and an effective use of experience gained from the production of regional jet ARJ21 and from participating in Airbus and Boeing aircraft production. We expect that this way China could reach 17%-20% share on domestic market. However, in order to achieve this, China would have to increase the domestic large civil aircraft production rate by 29.675% every year to reach 17% market share) or by 31.103% each year to reach 20% market share, and produce at least 1399 or 1646 aircraft respectfully by 2040. Reaching this high scale of production depends on whether China can reduce its dependency on foreign technology suppliers and optimise its supply chain and production process.

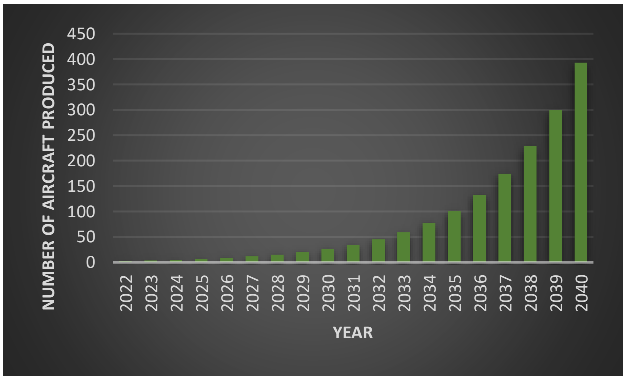

Fig. 8. The positive scenario no. 2 of the development of chinese large civil aircraft production needed to achieve 20% market share.

However, negative scenarios are possible too and they represent lower volume of Chinese domestic large civil aircraft production and thus lower share on the Chinese domestic market and subsequently on the global market of large civil aircraft. The negative scenarios we set are based on the Chinese aviation industry dependency on foreign technology, settlement of Airbus versus Boeing case between US and EU so they could better face the challenge represented by COMAC and CRAIC, and the scenarios are also based on China-US and China EU political relations. We did set three negative and one catastrophic scenarios, which are based on number of factors that could lead to lower production capacity of Chinese large civil aircraft and to lower market share than 10%. Since China does not possess own jet engine for large civil aircraft and is dependent on foreign technologies, especially American, we deem these negative scenarios more likely to happen than positive ones. In any case, we expect a larger increase in production of Chinese large civil aircraft around 2030, because Chinese CJ-1000 engine should have been completed by then.

The first and the least serious negative scenario we set assumes that there will be no reduction in Chinese domestic aircraft production by further restricting aviation technology exports to China, but nevertheless China will achieve only 8% market share delivering a total of 658 aircraft by 2040. In order to achieve this number of deliveries, China would have to increase production capacity by 23.07% year-on-year. This negative scenario is based on US-EU common approach to a new potentially strong competitor represented by China, which is also the main reason why the Airbus versus Boeing dispute was settled so that this duopoly would not lose its market share to COMAC and possibly CRAIC. A prerequisite for this scenario is an adjustment of the bilateral agreement between the US Government and EU concerning the trade in large civil aircraft in order to allow greater government subsidies in order to reduce the prices of Airbus and Boeing aircraft, which would lead to a reduction of the competitiveness of large civil aircraft produced in China, but even then we do not expect them to match prices of Chinese aircraft. However, we also considered the possibility that Chinese aircraft will not have as sophisticated technical equipment as Airbus and Boeing, while also being less cost-effective. In this case, China could gain 8% market share thanks to still lower acquisition costs of their aircraft making them more suitable for start-up airlines, and possible Chinese government pressure on airlines to buy domestic aircraft, even if the government itself would prefer foreign aircraft more for reasons of operational efficiency.

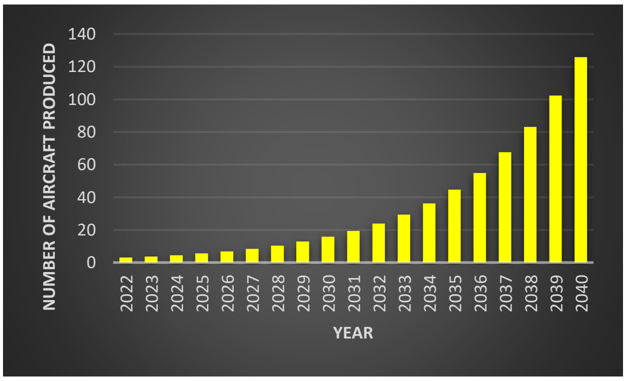

Fig. 9. The negative scenario no. 1 of the development of chinese large civil aircraft production.

The second negative scenario, in which China would be able to achieve only a 5% share of the domestic market of large civil aircraft is based on the assumption that measures on aviation technology export to China will be tightened, leading to a slowdown in the production rate growth and consequently lower market share of Chinese large civil aircraft on the domestic market, as well as on the global market later on. It's because Chinese large civil aircraft are dependent on foreign technology and China does not have any substitute for some of them, such as engines. Tightening aviation technology exports to China may be one of the measures the United States and the European Union may take in order to slow down the production of China's domestic large civil aircraft, thereby reducing China's competitiveness. If China would not be able to find suitable alternative suppliers and would have to develop its own technologies, a more significant increase in production could occur around 2030, when Chinese engines for large civil aircraft are expected to have been developed. In this case, China would have to produce a total of 412 aircraft during the 2022-2040 period to achieve 5% market share. The year-on-year increase in production China would have to achieve is 18.94%.

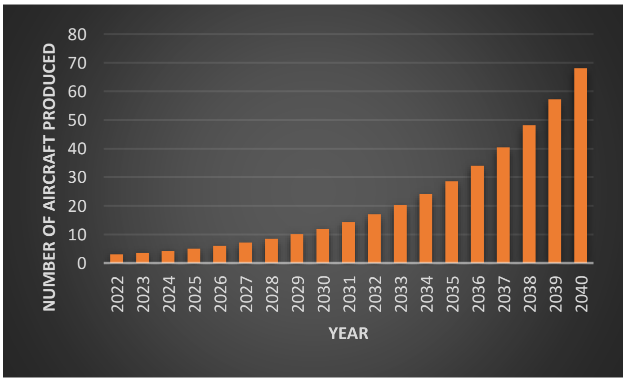

Fig. 10. The negative scenario no. 2 of the development of chinese large civil aircraft production.

The third negative development scenario for China's large civil aircraft, which we set, assumes that China will be significantly unsuccessful and will reach only 3.33% of its market by 2040, which would mean that out of the target number of 823 aircraft produced, China would achieve only the number of 274 domestic large civil aircraft produced. This negative scenario is based on the Chinese aviation industry's dependence on foreign technologies, but also on political relations and possible geopolitical situations that would affect China's production capacity of large civil aircraft. China's relation with the West are strained, especially with the United States, and if they'll strain even more, which could be caused by the war between China and Taiwan, the United States and even European Union could react in a similar way they reacted to the conflict between Russia and Ukraine and completely cease to supply aviation technologies to China. In this case, the production of Chinese large civil aircraft would be severely limited and China would be forced to look for alternative suppliers or develop the technology itself. Initially, China could still use components and systems that had already been supplied or apply some military technology in the civil aviation. However, provided China could not find suppliers, especially suppliers of engines, the production of large civil aircraft would practically start after China developed its own engines and that should be around 2030. One of the options for China would be Russian engines and technologies, but given the current situation, Russian suppliers will more likely supply their domestic Irkut MS-21 aircraft, and therefore we expect that if this scenario was to occur, China could achieve only 3.33% share of its domestic market by 2040, and that would mean that during 2022-2040 period China would supply only 274 aircraft. In average, China would have to increase its production by 15.32% each year to reach 3.33% on its own market. The possibility of a ban on US and EU aircraft imports to China could be a counter-argument to this scenario, but it's needed to take into account a fact that due to the lucrativeness of Chinese aviation market such option would not be in the interest of any of the manufacturers, nor China, since China would not be able to achieve sufficient production capacity of its own large civil aircraft to meet the rapidly growing air transport market and the resulting demand for aircraft. The rapid growth could be slowed down by the conflict, but not stopped.

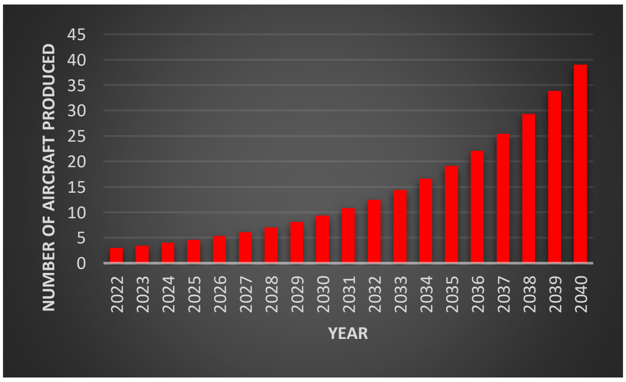

Fig. 11. The negative scenario no. 3 of the development of chinese large civil aircraft production.

The last scenario we considered would be catastrophic. This scenario is based on the possibility of absolute failure of large civil aircraft produced by China due to technical problems and tragic accidents of Chinese aircraft. In this case, the worst possible influence on the development on the market would be caused by C919 aircraft accidents shortly after their introduction into operation, as this would lead into a wave of mistrust and criticism towards a new manufacturer to the large civil aircraft market, whose name would be heavily damaged from his beginnings. Should such a development occur, we also expect only a little interest in the CR929 aircraft and thus, practically speaking, zero share on the Chia's domestic and global market of large civil aircraft.

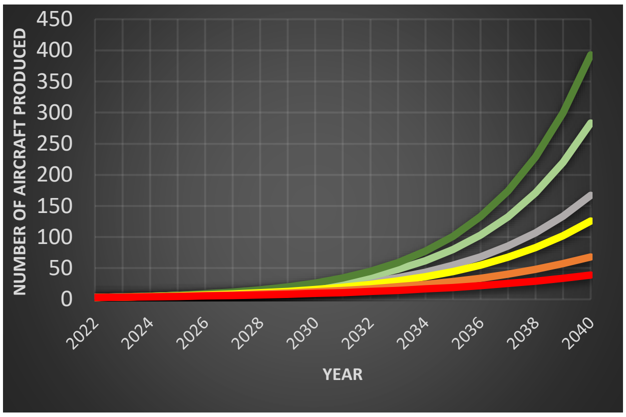

Fig. 12. Graphic comparison of all scenarios mentioned. Grey line – neutral scenario; Light green – the first positive scenario; Dark green – the second positive scenario; Yellow – The first negative scenario; Orange - the second negative scenario; Red – the third negative scenario.

5. CONCLUSION

All of the scenarios we set are possible, however, we consider The Neutral Scenario and The First Negative scenario as the most probable, since we do not expect that the US or EU would like to impose more restriction on supplying China with aviation technology in order to protect their own aviation component manufacturers. We also expect that large civil aircraft produced in China will not be as effective as those from the production of the US or EU, which could lower the prices of their aircraft through commonly agreed government subsidies provided to their manufacturers of large civil aircraft. The second positive scenario is really unlikely, since it takes China a long time to develop something in the area of aviation and that is why we do not expect it to develop engines before 2030. We don't even expect China-US and China-EU relations to get any better in the near future so we do not expect any ease of export measures imposed on aviation technology from US to China. The only possible alternative for engines and technology, if China-US and China-EU relations got worse, is Russia, which is most likely to supply its own domestic aircraft Irkut MS-21 because of its current geopolitical situation.

Nevertheless, the success of Chinese large civil aircraft on the global market will depend on their success on the domestic market. If these aircraft will be safe to fly, cost-effective and China will manage to certify them according to foreign countries' standards, they will definitely pose a threat to Airbus and Boeing. However, China will have to overcome problems regarding the dependency on western technology if it wants to reach full scale production as soon as possible, since this dependency in combination with political relations represent the greatest danger for reaching large-scale production of Chinese large civil aircraft. Besides, China will also have to build maintenance and training organization network.

We do not expect China to pose a big threat to Airbus-Boeing duopoly in the near future, but nor Airbus, nor Boeing can overlook China and its efforts to enter the large civil aircraft market through COMAC and joint venture CRAIC in the long term. Even though China will not be a significant competitor in the coming years with high probability, if its aircraft will be safe, effective and China will manage to overcome barriers in terms of the foreign technology dependency, the certification according to foreign countries' standards and the creation of maintenance and training organizations network, the large civil aircraft market will no longer be duopolistic but "triopolistic." However, everything depends on whether Chinese aircraft will prove themselves in operations and on the production capacity China will be able to achieve. In any case, Chinese ability to penetrate markets can't be underestimated.

REFERENCES

[1] BRITANNICA. Aerospace Industry. [online]. Available on the internet: <https://www.britannica.com/technology/aerospace-industry>. [cit. 2022-03-12]

[2] BUGOS, G. E. 2001. History of the Aerospace Industry. In EH.Net Encyclopedia. [online]. 2001. [cit. 2022-03-12]. Available on the internet: <https://eh.net/encyclopedia/the-history-of-the-aerospace-industry/>.

[3] BURNS, W. A. 2007. How Airbus Surpassed Boeing: A Tale of Two Competitors: Master's Thesis. Knoxville: University of Tennessee, 2007. 74 s. [online]. [cit. 2022-03-12]. Available on the internet: <https://trace.tennessee.edu/cgi/viewcontent.cgi?article=1284&context=utk_gradthes>.

[4] PETRESCU, R. V. et al. 2017. Home at Airbus. In Journal of Aircraft and Spacecraft Technology. [online]. 2017, vol. 1, no. 2. [cit. 2022-03-12]. Available on the internet: <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3073999>. Online ISSN: 2523-1197.

[5] SZEPAN, M. 2012. Changing the rules of the game: The commercial aircraft industry in China. In Harvard Asia Quarterly. [online]. 2012, vol. 14, no. 1 & 2. [cit. 2022-03-13]. Available on the internet: <http://www.andrewerickson.com/wp-content/uploads/2012/08/Szepan_Changing-the-Rules-of-the-Game_HAQ_2012.pdf>. ISSN: 1522-4147

[6] MORRISON, J. et al. 2011. Game Theory Analysis of Aircraft Manufacturer Innovation Strategies in the Face of Increasing Airline Fuel Costs. [online]. [cit. 2022-03-13]. Available on the internet: <https://www.researchgate.net/publication/265867776_Game_Theory_Analysis_of_Aircraft_Manufacturer_Innovation_Strategies_in_the_Face_of_Increasing_Airline_Fuel_Costs>.

[7] REUTERS. 2021. Highlights of the 17-year Airbus, Boeing trade war. [online]. Available on the internet: <https://www.reuters.com/world/highlights-17-year-airbus-boeing-trade-war-2021-06-15/>. [cit. 2022-03-15]

[8] BOEING. 2021. Commercial Market Outlook 2021-2040. [online]. Available on the internet: <https://www.boeing.com/commercial/market/commercial-market-outlook/>. [cit. 2022-03-23]

[9] AIRBUS. 2021. Airbus Global Market Forecast 2021-2040. [online]. Available on the internet: <https://www.airbus.com/sites/g/files/jlcbta136/files/2021-11/Airbus-Global-Market-Forecast-2021-2040.pdf>. [cit. 2022-03-23]

[10] COMAC. 2021. COMAC releases Market Forecast Report (2021-2040). [online]. Available on the internet: <http://english.comac.cc/news/latest/202111/01/t20211101_7330736.shtml>. [cit. 2022-03-23]

[11] ANDERSEN, P. A. 1998. The Changing Structure of the Global Large Civil Aircraft Industry and Market: Implications for the Competitiveness of the U.S. Industry: výskumná správa. Washington, DC: U.S. International Trade Commission, 1998. 228 s. [online]. [cit. 2022-03-12]. Available on the internet: <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1452731>.

[12] BRAZELTON, , M. A. 2021. Aviation infrastructures in the Republic of China, 1920-1937. In History of Science. [online]. 2021 [cit. 2022-02-18]. Available on the internet: <https://journals.sagepub.com/doi/pdf/10.1177/0073275321995638>. Online ISSN: 1753-8564.

[13] SAN FRANCISCO AIRPORT COMMISSION – AVIATION MUSEUM & LIBRARY. 2015. The Legend of CNAC: China National Aviation Corporation, 1929-1949. [online]. Available on the internet: <https://www.sfomuseum.org/exhibitions/legend-cnac-china-national-aviation-corporation-1929-1949>. [cit. 2022-02-20]

[14] JIN, , F. et al. 2004. Geographic Patterns of Air Passenger Transport in China 1980-1998: Imprints of Economic Growth, Regional Inequality, and Network Development. In The Professional Geographer. [online]. 2004, vol. 56, no. 4. [cit. 2022-02-20]. Available on the internet: <https://www.researchgate.net/publication/253039480_Geographic_Patterns_of_Air_Passenger_Transport_in_China_1980-1998_Imprints_of_Economic_Growth_Regional_Inequality_and_Network_Development >. ISSN: 1467-9272.

[15] ZHANG, Y. – ROUND, D. K. 2008. China's airline deregulation since 1997 and the driving forces behind the 2002 airline consolidations. In Journal of Air Transport Management. [online]. 2008, vol. 14, no. 3. [cit. 2022-02-20]. Available on the internet: <https://eprints.usq.edu.au/5683/1/Zhang_Round_JATM_v14n3_SV.pdf>. ISSN: 0969-6997.

[16] WANG, J. et al. 2015. Air deregulation in China and its impact on airline competition 1994-2012. In Journal of Transport Geography. [online]. 2016, vol. 50. [cit. 2022-02-20]. Available on the internet: <https://www.sciencedirect.com/science/article/pii/S0966692315000472>. ISSN: 0966-6923.

[17] LEI, Z. – O'CONNELL, J. F. 2010. The evolving landscape of Chinese aviation policies and impact of a deregulating environment on Chinese carriers. In Journal of Transport Geography. [online]. 2011, vol. 19, no. 4. [cit. 2022-02-21]. Available on the internet: <https://www.sciencedirect.com/science/article/pii/S0966692310001687?casa_token=spaD1Bm3r34AAAAA:yE7BhY7rri7yMqW-

v_R6S7YR9nfBImjkOjBmTXUhTiiY9Fk18lSCLnpDvzs55k4J7UOju0sgfkM>. ISSN: 0966-6923.

[18] KOLIOUSIS, I. 2019. China's airline industry deregulation: assessing the impact on the operational performance of dominant carriers. In International Journal of Aviation Management. [online]. 2019, vol. 4, no. 3. [cit. 2022-02-21]. Available on the internet: <https://pure.coventry.ac.uk/ws/portalfiles/portal/22533866/Binder2.pdf>. ISSN: 1755-9901.

[19] JIN, Y. et al. 2019. Study on Structural Characteristics of China's Passenger Airline Network Based on Network Motifs Analysis. In Sustainability. [online]. 2019, vol. 11, no. 9. [cit. 2022-02-21]. Available on the internet: <https://www.mdpi.com/2071-1050/11/9/2484/htm>. ISSN: 2071-1050.

[20] ANDERSSON, L. 2008. A History of CHINESE AVIATION. Encyclopedia of Aircraft and Aviation in China until 1949. ROC, Taiwan, Taipei: Ko-lo Color Printing Co/Chu-men Co, 2008. 322 p. [cit. 2022-02-21]. Available on the internet: <https://www.pdfdrive.com/a-history-of-chinese-aviation-encyclopedia-of-aircraft-and-aviation-in-china-until-1949-e184744155.html>. ISBN: 978-957-28533-3-7.

[21] MAKSEL, R. 2008. The Father of Chinese Aviation. [online]. Available on the internet: <https://www.smithsonianmag.com/air-space-magazine/the-father-of-chinese-aviation-7979767/>. [cit. 2022-02-23]

[22] AVIC. History. [online]. Available on the internet: <https://en.avic.com/en/aboutus/history/>. [cit. 2022-02-26]

[23] CRANE, K. et al. 2014. The Effectiveness of China's Industrial Policies in Commercial Aviation Manufacturing. [online]. California, Santa Monica: RAND Corporation, 2014. 114 p. [cit. 2022-02-27]. Available on the internet: <https://www.rand.org/content/dam/rand/pubs/research_reports/RR200/RR245/RAND_RR245.pdf>.

[24] WOOD, P. et al. 2019. China's Aviation Industry: Lumbering Forward. [online]. United States of America: China Aerospace Studies Institute, 2019. 112 p. [cit. 2022-02-27]. Available on the internet: <https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/Infrastructure/CASI_Aeroengines%20041520.pdf?ver=2020-04-22-133912-480>. ISBN: 9781082740404.

[25] AIRWAYSMAG. First Flight COMAC ARJ21. [online]. Available on the internet: <https://airwaysmag.com/today-in-aviation/first-flight-comac-arj21/>. [cit. 2022-02-27]

[26] GOH, B. 2017. China, Russia set up wide-body jet firm in new challenge to Boeing, Airbus. [online]. Available on the internet: <https://www.reuters.com/article/us-china-comac-russia-idUSKBN18I0KZ>. [cit. 2022-02-27]

[27] ZHAO, Y. – WAN, J. 2019. Analysis of development and evolution rules of civil aviation in China based on life cycle theory. In Plos One. [online]. 2019, vol. 14, no. 2. [cit. 2022-02-22]. Available on the internet: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0212338#sec002>. ISSN: 1932-6203.

[28] WANG, J. et al. 2019. The Evolution of China's International Aviation Markets from a Policy Perspective on Air Passenger Flows. In Sustainability. [online]. 2019, vol. 11, no. 13. [cit. 2022-02-22]. Available on the internet: <https://www.mdpi.com/2071-1050/11/13/3566/htm>. ISSN: 2071-1050.

[29] DONG, X. – RYERSON, M. S. 2019. Increasing civil aviation capacity in China requires harmonizing the physical and human components of capacity: A review and investigation. In Transportation Research Interdisciplinary Perspectives. [online]. 2019, vol. 1. [cit. 2022-02-23] Available on the internet: <https://www.sciencedirect.com/science/article/pii/S2590198219300053>. ISSN: 2590-1982.

[30] NIOSI, J. – ZHAO, J. Y. 2013. China's catching up in aerospace. In International Journal of Technology and Globalisation. [online]. 2013, vol. 7, no. 1/2. [cit. 2022-02-26]. Available on the internet: <https://www.inderscienceonline.com/doi/pdf/10.1504/IJTG.2013.052032>. ISSN online: 1741-8194.

[31] FAI, F. 2013. Sectoral Systems of Learning in Late Industrialising Nations – A study of the Chinese Civil Aviation Industry. In the 35th DRUID Celebration Conference. [online]. 2013. [cit. 2022-02-26]. Available on the internet: <https://conference.druid.dk/acc_papers/uat5ak153sd3n29pj66tnun7kuht.pdf>.

[32] COMAC. C919. [online]. Available on the internet: <http://english.comac.cc/products/ca/>. [cit. 2022-03-25]

[33] AIRLINES INFORM. COMAC C919. [online]. Available on the internet: <https://www.airlines-inform.com/commercial-aircraft/comac-c919.html>. [cit. 2022-03-25]

[34] PERRETT, B. 2020. COMAC C919 Testing Exceeds Cruise Speed, Reaches Ceiling. In Aviation Week. [online]. Available on the internet: <https://aviationweek.com/aerospace/comac-c919-testing-exceeds-cruise-speed-reaches-ceiling>. [cit. 2022-03-25]

[35] MODERN AIRLINERS. COMAC C919. [online]. Available on the internet: <https://modernairliners.com/comac-c919/>. [cit. 2022-03-25]

[36] AEROSPACE TECHNOLOGY. COMAC C919 Passenger Aircraft. [online]. Available on the internet: <https://www.aerospace-technology.com/projects/comac-c919-aircraft-china/>. [cit. 2022-03-25]

[37] BOEING. 737 MAX. [online]. Available on the internet: <https://www.boeing.com/commercial/737max/>. [cit. 2022-03-26]

[38] TAGLIAFERRI, D. – CAPSONI, C. 2016. SNIR predictions for on-aircraft VLC systems. In 2016 International Conference on Broadband Communications for Next Generation

Networks and Multimedia Applications (CoBCom). 2016. [cit. 2022-03-26]. Available on the internet: <https://www.researchgate.net/figure/Section-of-the-Boeing-737-fuselage-cabin-with-the-main-dimensions-20_fig2_309327917>.

[39] MODERN AIRLINERS. Boeing 737 Specifications. [online]. Available on the internet: <https://modernairliners.com/boeing-737/boeing-737-specifications/>. [cit. 2022-03-26]

[40] AEROCORNER. Boeing 737 MAX 8. [online]. Available on the internet: <https://aerocorner.com/aircraft/boeing-737-max-8/>. [cit. 2022-03-26]

[41] AIRBUS. A320neo. [online]. Available on the internet: <https://aircraft.airbus.com/en/aircraft/a320/a320neo>. [cit. 2022-03-26]

[42] AEROCORNER. Airbus A320neo. [online]. Available on the internet: <https://aerocorner.com/aircraft/airbus-a320neo/>. [cit. 2022-03-26]

[43] MODERN AIRLINERS. Airbus A320 Specs – What is behind one of the most popular short-haul airliners?. [online]. Available on the internet: <https://modernairliners.com/airbus-a320-introduction/airbus-a320-specs/>. [cit. 2022-03-26]

[44] PANDE, P. 2021. What to Expect From The COMAC C919. [online]. Available on the internet: <https://simpleflying.com/what-to-expect-from-the-comac-c919/>. [cit. 2022-03-26]

[45] RAINS, T. 2022. Meet the Comac C919, the first mainline airliner made by a Chinese company that could begin deliveries this year. In Business Insider. [online]. Available on the internet: <https://www.businessinsider.com/comac-c919-chinese-commercial-jet-built-rival-boeing-and-airbus-2022-2>. [cit. 2022-03-27]

[46] SALAS, E. B. 2021. Boeing aircraft prices 2021. [online]. Available on the internet: <https://www.statista.com/statistics/273941/prices-of-boeing-aircraft-by-type/>. [cit. 2022-03-27]

[47] AHLGREN, L. 2021. How Much Do Airbus Aircraft Cost?. [online]. Available on the internet: <https://simpleflying.com/how-much-do-airbus-aircraft-cost/>. [cit. 2022-03-28]

[48] PFEIFER, S. – RIORDAN, P. 2021. China's rival to Boeing and Airbus set to join battle for the skies. [online]. Available on the internet: <https://www.ft.com/content/09024b14-6829-4e4e-84a9-3310afc5151b>. [cit. 2022-03-27]

[49] UNITED AIRCRAFT CORPORATION (UAC). CR929. [online]. Available on the internet: <https://www.uacrussia.ru/en/aircraft/lineup/civil/cr929/>. [cit. 2022-03-27]

[50] AIRLINES INFORM. CR929. [online]. Available on the internet: <https://www.airlines-inform.com/commercial-aircraft/cr929.html>. [cit. 2022-03-27]

[51] AIRBUS. A350-900. [online]. Available on the internet: <https://aircraft.airbus.com/en/aircraft/a350/a350-900>. [cit. 2022-03-27]

[52] BOEING. Boeing 787 Dreamliner. [online]. Available on the internet: <https://www.boeing.com/commercial/787/>. [cit. 2022-03-28]

[53] EUROPEAN UNION AVIATION SAFETY AGENCY (EASA). 2021. EASA Type-Certificate Data Sheet No.: EASA.IM.A.115 for Boeing 787. [online]. Available on the internet: <https://www.easa.europa.eu/sites/default/files/dfu/TCDS%20EASA%20IM%20A%20115%20B787%20Issue%2026.pdf>. [cit. 2022-03-28]

[54] MODERN AIRLINERS. What are the Boeing 787 Dreamliner Specs?. [online]. Available on the internet: <https://modernairliners.com/boeing-787-dreamliner/boeing-787-dreamliner-specs/>. [cit. 2022-03-28]

[55] AIRLINES INFORM. Boeing 787-9. [online]. Available on the internet: https://www.airlines-inform.com/commercial-aircraft/boeing-787-9.html>. [cit. 2022-03-28]

[56] AIRBUS. A320 Family. [online]. Available on the internet: <https://www.airbus.com/en/products-services/commercial-aircraft/passenger-aircraft/a320-family>. [cit. 2022-03-26]

[57] BOEING. Boeing Next-Generation 737. [online]. Available on the internet: <https://www.boeing.com/commercial/737ng/>. [cit. 2022-03-26]

[58] BOEING. 737 MAX By Design: 737 MAX Flies Farther Than the Next-Generation 737. [online]. Available on the internet: <https://www.boeing.com/commercial/737max/by-design/#/flies-farthest>. [cit. 2022-03-26]

[59] AIRBUS. A350-1000. [online]. Available on the internet: <https://aircraft.airbus.com/en/aircraft/a350/a350-1000>. [cit. 2022-03-28]

[60] AIRFRAMER. CRAIC CR929. [online]. Available on the internet: <https://www.airframer.com/aircraft_detail.html?model=CR_929>. [cit. 2022-03-28]

[61] HUARUI AEROSPACE MANUFACTURING. 2021. COMAC Announces Huarui as the Primary Supplier for CR929 Mid-Fuselage. [online]. Available on the internet: <http://www.huaruiaero.com/news_show.aspx?id=52>. [cit. 2022-03-28]

[62] ROSTEC. 2018. Rostec Develops Components for Russian-Chinese CR929 Aircraft. [online]. Available on the internet: <https://rostec.ru/en/news/rostec-develops-components-for-russian-chinese-cr929-aircraft/>. [cit. 2022-03-28]

[63] UNITED AIRCRAFT CORPORATION (UAC). Russia-China Project is nearing the stage of choosing system suppliers for the new widebody CR929. [online]. Available on the

internet: <https://uacrussia.ru/upload/CR929.pdf>. [cit. 2022-03-28]

[64] KARNOZOV, V. 2019. Sino-Russian CR929 Has Room for High-tech Input from the West. [online]. Available on the internet: <https://www.ainonline.com/aviation-news/air-transport/2019-06-14/sino-russian-cr929-has-room-high-tech-input-west>. [cit. 2022-03-28]

[65] ВЕЛИЧКО, А. 2017. Кто будет играть первую скрипку в проекте ШФДМС. [online]. Available on the internet: <http://aviation21.ru/kto-budet-igrat-pervuyu-skripku-v-proekte-shfdms/>. [cit. 2022-03-28]

[66] GOH, B. 2017. China, Russia set up wide-body jet firm in new challenge to Boeing, Airbus. [online]. Available on the internet: <https://www.reuters.com/article/us-china-comac-russia-idUSKBN18I0KZ>. [cit. 2022-02-27; 2022-03-27]

[67] REUTERS. 2021. China's home-grown C919 aircraft hit by tough US export controls, limiting threat to Airbus and Boeing. In South China Morning Post. [online]. 2021. Available on the internet: <https://www.scmp.com/economy/china-economy/article/3150240/chinas-home-grown-c919-aircraft-hit-tough-us-export-controls>. [cit. 2022-03-09]

[68] BOEING. 2020. The Boeing Company 2019 Annual Report. [online]. Available on the internet: <https://s2.q4cdn.com/661678649/files/doc_financials/2019/ar/2019_Boeing_Annual_Report.pdf>. [cit. 2022-03-18]

[69] AIRFRAMER. Aircraft program directory. [online]. Available on the internet: https://www.airframer.com/aircraft_front.html#tabs

[70] BADÁNIK, B., ČERVINKA, M. 2015. Marketing leteckých spoločností a letísk. 1. vyd. Bratislava : DOLIS, 2015. 152 s. ISBN 978-80-8181-024-4.

https://doi.org/10.26552/ pas.Z.2022.2.09

SELECTION OF THE APPROPRIATE TYPE OF HEMS HELICOPTER FOR THE SLOVAK REPUBLIC

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Abstract

The diploma thesis deals with the issue of choosing the appropriate type of helicopter for the implementation of the Helicopter Emergency Medical Service (HEMS) for the Slovak Republic. Currently, the Helicopter Emergency Medical Service is operated by a private company Air Transport Europe, Ltd., based at Poprad-Tatry Airport. The fleet of helicopters for rescue missions consists of three types helicopters. The oldest helicopter is the Agusta A109K2, then BELL 429 since 2013 and Eurocopter EC 135 T2+/P2+ since 2019. The aim of this thesis is to create an analysis of the current state, review affecting parameters such as operator options and possibilities, operating costs, maintenance costs, use due to the geographic features of the Slovak Republic and use of the helicopters for transporting patients with Covid-19 and other highly contagious diseases. The result will be the selection of the appropriate type of helicopter of the Helicopter Emergency Medical Service to be used under the conditions of the Slovak Republic.

Keywords

helicopter, Helicopter Emergency Medical Service

1. I NTRODUCTION

Today, helicopters are an integral part of air traffic. Thanks to their flight characteristics and a wide range of applications, they have also been used in the air rescue service. Here it has become an almost irreplaceable means of saving lives, a means of evacuation in the event of natural disasters and, last but not least, in transports between medical specialized workplaces. This is mainly due to the flight characteristics of the helicopter, the ability to hang over one place, perform technical interventions in inaccessible terrain, use the suspension and the possibility of vertical takeoff and landing on a relatively limited area, as close as possible to the place of need. As primary interventions in unavailable terrain are very often performed in Slovakia at present, it is necessary to ensure the highest possible level of safety for the crew, patient and third parties. Despite the fact that there are strict regulations and strict procedures for the operation of the Helicopter Rescue Medical Service (HEMS), we still face various helicopter accidents, which could be prevented by taking adequate measures. One of them was the fall of the Agusta A109K2 helicopter in the area Pod Kláštornou roklinou - Slovenský Raj, in which a four-member crew perished. The accident was caused by direct contact of the helicopter with the wires of the power line. It was the equipment of the helicopter with the WSPS (Wire Strike Protection System) system that could help avert the catastrophe and save the precious lives of the crew. The main reason for choosing a specific topic is the effort to increase the quality of the helicopter rescue medical service, which is already at a high level in the Slovak Republic. This is evidenced by the successful expansion of the operator Air Transport Europe, Ltd. to the territory of the Czech Republic, where it provides VZZS at two stations in Ostrava and Olomouc. The aim of the diploma thesis is to analyze the currently used VZZS helicopters and then prepare the basis for technical possible unification of the fleet to one type of helicopter, which will be the most suitable for the operation of helicopter rescue medical service in Slovakia. Due to the current pandemic situation associated with the COVID-19 disease in 2019-2022, the secondary goal of the diploma thesis is to include the transport of patients with highly contagious diseases among the frequent uses of VZZS. Therefore, this parameter is important when selecting the appropriate helicopter type.

2. SELECTION OF APPROPRIATE HELICOPTERS ON THE BASIS OF ESTABLISHED TECHNICAL AND OPERATING REQUIREMENTS FOR THE SLOVAK REPUBLIC

The choice of a suitable type of helicopter for the Helicopter Rescue Medical Service for the Slovak Republic is influenced by a large number of criteria and factors. Therefore, the selection is difficult and it is not possible to clearly identify one type of helicopter. An important factor in the selection is the cost of operation. As this is sensitive data that the author did not have available when writing the work, this factor will take into account and the design of a suitable type will be oriented to the price category of currently operated helicopters.

The following criteria and factors were taken into account in the selection:

1. Current fleet of the operator
2. Geographical conditions of the Slovak Republic
3. Maintenance
4. Performance and technical parameters
5. Construction and interior construction of HEMS
6. Avionics

3. BELL 429

The Bell 429 is a multi-purpose helicopter that has excellent flight characteristics, thanks to which it achieves high flight speed, high seeding performance and improved safety systems. The interior is equipped with a digital cockpit, best-in-class WAAS navigation and IFR-compatible dual control. [1]

The Bell 429 provides much more space in the cabin than helicopters of the same class. The flat floor and 159cm wide side doors provide enough space to perform the most complex actions. [1]

The Bell 429 provides increased security by integrating redundant systems into avionics, hydraulics and electronics systems. The result is greater stability of the helicopter in each phase of flight. The helicopter meets category "A" and complies with EU-OPS regulations. In addition, the automatic flight control system reduces the pilot's workload on IFR flights, which increases the level of safety. [1]

The Bell 429 is compatible and certified to current impact and damage resistance standards. The configuration includes integrated avionics with BasiX-ProT flight control, which is designed specifically for the needs of twin-engine helicopters. [1]

The Bell 429 is the first helicopter in its class to use the same maintenance process as commercial airlines to maintain airworthiness. This process is led by a steering group composed of representatives of BELL, regulators and operators. This approach improves safety by addressing the maintenance of significant components at the system level by zone, instead of the individual component level. The goal is to maintain the highest level of security and reliability while maintaining lower costs. [1]

The Bell 429 is designed in the HEMS version with regard to the current needs of the Helicopter Rescue Medical Service. The floor height and stretcher attachment are designed to be handled by one person, through a side or optional rear door. The design of the cabin allows the crew to access the entire patient's body, thus optimizing patient care. [1]

The Bell 429 is available in two major versions with the option of additional configuration according to the purpose and action it will perform. [1]

- Bell 429 with ski chassis
- Bell 429WLG with variably retractable, wheeled chassis

4. EUROCOPTER EC135

The Eurocopter EC 135 helicopter is a light twin-engine, multi-purpose helicopter. Underlining its versatility, the helicopter can be delivered in a controlled configuration for one or two pilots with IFR flights. The helicopter combines the latest Eurocopter technologies, such as advanced cockpit design, modern avionics, Fenestrone - the balancing rotor technical solution and the all-composite main rotor bearing system, which makes the helicopter excellently manoeuvrable. The optimized main rotor blades with advanced geometry in combination with fenestrone with uneven blade spacing make the EC 135 the quietest helicopter in its class, while its noise level is well below the strict ICAO limit. The built-in anti-resonance insulation system filters vibrations caused by the rotor and thus increases in-flight comfort to the maximum. The result is minimal vibration during all phases of flight, emphasizing during hanging. [2]

Thanks to the simple design of the rotor system with the highest safety standard, the level of maintenance is significantly simplified. The first scheduled maintenance is an intermediate inspection after 400 flight hours. Thanks to its simple design, the rotor system together with the gearbox has a long service life. [2]

Depending on the operator's requirements, it can be equipped with a Turbomeca Arrius 2B2 or Pratt & Whitney PW206B2 power unit, both power units are controlled by the FADEC system. These powerful and reliable propulsion units, together with the helicopter design, provide excellent performance during all phases of flight and critical power reserves in crisis situations. The reliability of the powertrains is complemented by a tandem hydraulic and dual electrical system, as well as a redundant main transmission lubrication and cooling system. Other safety aspects of the EC 135 are components such as the energy-absorbing fuselage and seats and the impact-resistant fuel system. [2]

The Eurocopter EC 135 helicopter has a wide range of quick-change options, such as emergency floats, a hoist, a SX16 searchlight, a simple or expensive suspension, ski accessories for landing on snow and softer surfaces and much more. [2]

4.1. Agusta A109 Trekker

The Agusta AW109 Trekker is a lightweight twin-engine, multi-purpose helicopter that can be supplied with a skid-on skid version or with a three-point, variable wheeled landing gear. The Agusta AW109 Trekker can be configured with one or two IFR pilots. The helicopter combines the latest technologies, excellent flight characteristics, excellent maneuverability and a high level of active and passive safety. The result of these features is a universal helicopter suitable for performing the Helicopter Rescue Medical Service. [3]

The Agusta AW109 Trekker has been designed to provide a solution for the most demanding tasks in various sectors. The Agusta AW109 Trekker has excellent performance with sufficient reserves for the most demanding technical interventions. The cabin is characterized by its spaciousness and intuitive layout of equipment. [3]

The Agusta AW109 Trekker is equipped with a Pratt & Whitney PW207C power unit. These powerful and reliable propulsion units, together with the helicopter design, provide excellent performance during all phases of flight and critical power reserves in crisis situations. Energy-absorbing seats are important safety features of the Agusta AW109 Trekker. [3]

The Agusta AW109 Trekker has a wide range of quick-change options such as emergency floats, a hoist, a searchlight, a simple or cargo suspension, ski accessories for landing on snow and softer surfaces, wheel accessories for landing on snow and softer surfaces and much more.

5. SELECTION OF THE APPROPRIATE TYPE OF HEMS HELICOPTER FOR THE SLOVAK REPUBLIC

After careful consideration of the results of the comparison, the most suitable type of helicopter is Bell 429 for the performance of the Helicopter Rescue Medical Service for the Slovak Republic.

Rationale for choosing a Bell 429 helicopter:

1. It has been actively used in the Slovak Republic since 2013.
2. It is appropriate for all geographical conditions located in the Slovak Republic.
3. Maintenance is performed at the Poprad-Tatry home airport. The operator Air Transport Europe, Ltd. has its own maintenance division with the Bell 429 license.
4. Unification of the operator's fleet - unification of operations for one type of helicopter for the Slovak Republic. As a result, helicopters can be exchanged between operating sites without additional staff training.
5. The unified fleet is more economical in terms of operating costs.
6. It is the largest of the compared types with the size of the cabin.

The final design of the helicopter deployment consists of two versions. The first version is to use the Bell 429 helicopter at all operating sites. In the second version, the Poprad site is complemented by a Bell 429WLG helicopter with a three-point, variable wheeled chassis, which will be specially designed for use in mountain conditions.

Fig. 1. First version of the Helicopter deployment

Bell 429 helicopters are equipped with a winch in mountainous areas with an increased chance of technical interventions. These operating areas include: Trenčín, Žilina, Banská Bystrica and Poprad.

The Bell 429 WLG helicopter is equipped with a winch for the Poprad work area.

The diagrams below show the operating radius in the form of circles with the center at the point of take-off, ie at the operating location.

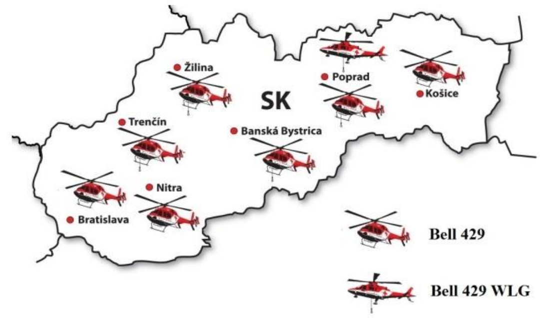

Fig. 2. Second version of the Helicopter deployment

The first diagram shows a circle that has a radius of 50km and the reaction time of the crew from the moment of obtaining information about the intervention is 10 minutes. The calculation is performed with conditions such as ideal weather, standard fuel, helicopter and crew in standard configuration. The cruising speed of the Bell 429 helicopter was set at 240 km / h. When calculating time with respect to distance and speed, we get a time of 12 minutes and 30 seconds. After counting together with the reaction time, the crew is ideally able to arrive from the operating site to the peripheral site of the circle within 23 minutes, which significantly increases the patient's chances of survival and reduces the risk of fatal consequences.

Areas outside the circles are also fully covered by operational sites. The crews will get to these places later than within a radius of 50 km from the operating site, but thanks to the deployment, it is still significantly below the critical value of patient survival - 60 minutes.

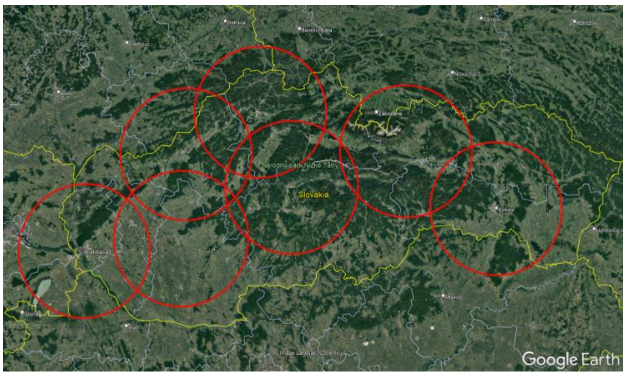

Fig. 3. Scheme of operating circles with a radius of 50km

The second diagram shows a circle that has a radius of 85km and the reaction time of the crew from the moment of obtaining information about the intervention is 10 minutes. The calculation is performed with conditions such as ideal weather, standard fuel, helicopter and crew in standard configuration. In the case of the Krištof 03 Poprad operating site, the radius is set at 50 km due to operation with a lower amount of fuel in the helicopter. This is due to interventions in alpine conditions. The cruising speed of the Bell 429 helicopter was set at 240 km / h. When calculating time with respect to distance and speed, we get a time of 21 minutes and 15 seconds. After counting together with the reaction time, the crew is ideally able to arrive from the operating site to the peripheral site of the circle within

32 minutes, which also significantly increases the patient's chance of survival and reduces the risk of fatal consequences.

Areas outside the circles are eliminated as much as possible. The smaller area of Eastern and Southern Slovakia is beyond the 32-minute operating radius, but due to the minimum distance from the edge of the circles, it is possible to determine an increase in time of the order of a minute. For this reason, the flight time together with the reaction time is significantly below the critical patient survival value of 60 minutes.

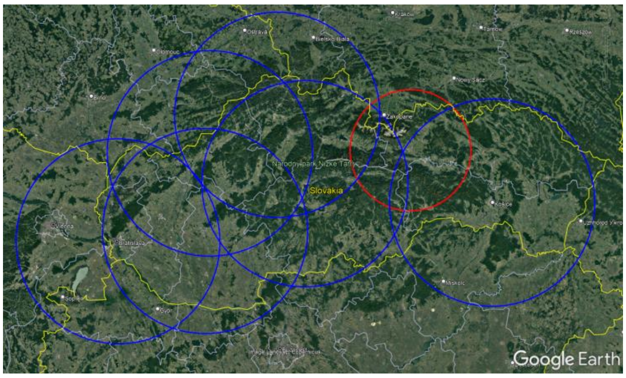

Fig. 4. Scheme of operating circles with a radius of 85km.

6. AIR REQUIREMENTS FOR PATIENTS WITH COVID-19 AND OTHER HIGHLY CONTROLLING DISEASES

Covid-19 has significantly affected the daily lives of all people. From day to day, the life of the entire population changed. The new coronavirus SARS-CoV-2, began to spread in late 2019 in the Chinese city of Wu-chan. From this epicenter in China, the disease has gradually spread throughout the world. A major problem with SARS-CoV-2 is the speed of its spread. The virus has an incubation period of 2 to 14 days, while the infected patient is infectious at all times. There is also a significant risk - the patient may be infected, but he has not yet shown symptoms, but he is still infectious. For this reason, too, measures at airports that helped stop the spread of SARS a few years ago are very problematic and reveal only a fraction of cases. [4]

The virus is transmitted in the classic way of influenza and other diseases, ie in the form of droplet infection. On 28 January 2020, the National Health Commission (NHC) said the virus could also spread through direct contact. However, she did not specify the form of this contact. At the same time, she also stated that all age groups of the population are at potential risk. However, the most serious course of the disease is in the elderly and also in people who already suffer from some disease. [4]

As the virus gained momentum, the use of the Helicopter Rescue Medical Service was increasingly mentioned in connection with the transport of positive patients. As with land transport, the priority in the helicopter was to ensure maximum crew protection against covid-19 infection. Crews, whether ground or air rescue, set out on a daily basis to patients they did not know were infected or not. For this reason, procedures and regulations for the operation of the Helicopter Rescue Medical Service in connection with the new covid-19 have been rapidly established and approved. [4]

The helicopter crews were equipped with full-body suits, had several layers of disposable gloves on their hands, their airways were covered with a respirator, and goggles were worn on their eyes. It was this large amount of protective equipment that restricted the crew in their normal duties. Protective equipment caused major problems, especially for the pilot while piloting the helicopter. Covering the airways with a respirator in combination with safety goggles caused the goggles to mist up and, to a large extent, to complicate the helicopter's view and control. The high summer temperatures only contributed to the discomfort that the crews experienced every day. [4]

The design of the solution comes from the manufacturer EpiGuard in the form of an insulated bed EpiShuttle for adult patients. The EpiShuttle bed isolates the patient from the environment while allowing the doctor to perform most of the necessary procedures with the patient. The EpiShuttle bed has a variable lounger with seat belts. The unit is equipped with a filter device that ensures clean air for the patient inside and, conversely, filters contaminated air from the patient. [5]

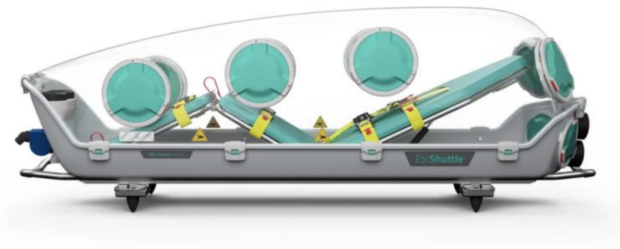

Fig. 5. EpiShuttle insulated bed

The air ventilation system generates more than 15 air changes per hour to ensure maximum patient comfort and safety. Filters and airtight seals ensure that all dirt remains inside the EpiShuttle bed, even in the event of rapid decompression of the aircraft cabin. [5]

The air flow is directed through the inlet filters at the front and passes out through the outlet filters at the bottom. Vacuum and outlet filters prevent contaminated air from escaping from the bed. For optimal handling during transport, the EpiShuttle has eight interchangeable personnel ports integrated in a sturdy case. The ports are located to provide access to all parts of the patient's body, including the airways. This allows for intensive care of the patient with the possibility of angulation such as intubation, infusion or urinary catheter. The ports have internal and external lids, under which there are rubber gloves, a waste bag or a patient service bag. [5]

EpiShuttle is a suitable solution for transporting patients with covid-19 and other highly contagious diseases. The Bell 429 helicopter, which is designed as a suitable type of helicopter for the performance of the Helicopter Rescue Medical Service, is compatible with EpiShuttle and its use in combination with the Bell 429 helicopter is suitable. [5]

EpiShuttle can be used in the Slovak Republic according to two models. The first model proposes equipping the largest medical facilities with EpiShutle beds. If necessary, use the Helicopter Rescue Medical Service for transport, the staff of the medical facility will prepare a bed with a patient, which will then be handed over to the helicopter crew immediately after landing.

This model saves time and shortens transport time between specialized workplaces. [5]

The second model proposes equipping operating sites with EpiShutle beds. In case of need to use the Helicopter Rescue Medical Service for transport, the helicopter crew will fly to a specific medical workplace, where they will hand over the EpiSuttle bed. Subsequently, the patient staff will prepare and hand over the patient for transport. This model is more time consuming and requires a longer deployment of the helicopter for one specific transport between specialized workplaces.

7. CONCLUSION

Helicopters are an integral part of our daily lives. However, this was not always the case. In the past, rescue services relied solely on the use of available technology. Only the gradual development in our country and in the world offered the use of more effective means, thanks to which the Helicopter Rescue Medical Service is at a very well-functioning level today. At present, the Helicopter Rescue Medical Service in Slovakia is operated at seven operating sites 24 hours a day, 365 days a year. The tactical deployment ensures that crews are ready to provide effective pre-hospital care within one hour of reporting to the operations center. This significantly increases the patient's chances of survival.

The content of my work can be divided into four parts. The first part is dedicated to the Helicopter Rescue Medical Service from its beginnings to the present. The first attempts at air rescue in Slovakia date back to 1962. The use of an available Mi-4 helicopter at the time opened up completely new possibilities in the field of saving human lives using a helicopter. Especially thanks to the courage and determination of the pilots and members of the Mountain Service at that time, today the Helicopter Rescue Medical Service is at such a high level as we know it.

The second part is devoted to helicopter accidents of the Helicopter Rescue Medical Service. In the past, several helicopter accidents occurred in Slovakia during rescue operations. In recent history, we find in 2006 an accident of the Agusta A109K2 OM-ATC helicopter near the village of Jánova Lehota. During the night flight to the medical facility, the helicopter crashed after contact with the treetops. Another tragic accident occurred in 2015. The Agusta A109K2 OM-ATC helicopter crashed into power lines as it approached its final location and subsequently crashed. The last tragic accident occurred in 2016, when the Bell 429 OM-ATR helicopter crashed into treetops in the early summer shortly after takeoff, resulting in the crash and death of the crew and patient. All three accidents ended tragically and none of the participants survived. Appropriate selection of a helicopter with sufficient equipment for rescue flights can eliminate the risk of further helicopter accidents of the Helicopter Rescue Medical Service.

The third part is devoted to the selection of a suitable helicopter in the Helicopter Rescue Medical Service for the Slovak Republic. At present, the helicopter fleet consists of three types: Agusta A109K2, Bell 429 and Eurocopter EC135. The aim of the work is to compare suitable candidates and select a suitable type of helicopter, which would lead to unification and modernization of the operator's fleet. The result of the comparison and selection is the Bell 429 helicopter. Ideally, the use of the Bell 429 helicopter at all operating sites and the use of the Bell 429 helicopter in the Bell 429WLG configuration with variable three-point wheel chassis in the High Tatras are proposed.

The last part is devoted to the requirements for the transport of patients with Covid-19 and other highly contagious diseases. The current situation associated with the new coronavirus pandemic has also affected the operation of the Helicopter Rescue Medical Service. It is important to use all available systems and means to ensure the highest possible level of safety for the crew and patient against coronavirus infection. A suitable system is the EpiShuttle insulated bed, which provides perfect isolation of the patient from the surrounding environment in the cabin and at the same time does not restrict the doctor in performing all important medical procedures.

It is necessary to keep in mind that this is only a design of a suitable type of helicopter for the Helicopter Rescue Medical Service. The comparison and selection was created from the materials that the author had at his disposal at the time of writing the thesis.

REFERENCES

[1] Bell Textron inc. 2018. Bell 429 Product Specification. https://b2baviatrading.com.ua/files/mro/Bell-429-Product-Specifications.pdf

[2] Eurocopter Technical Data. https://exclusiveaircraft.co.uk/sites/default/files/brochure/Eurocopter-EC135-Brochure_0.pdf

[3] Leonardo Helicopters, AgustaWestland AW109 Trekker. https://www.sloanehelicopters.com/_/uploads/body_BROCHURE_AW109Trekker_1.pdf

[4] Informácieo ochorení COVID-19. https://www.health.gov.sk/Clanok?Hlavna-sprava-COVID-19

[5] EpiGuard, EpiShuttle. https://www.epiguard.com/epishuttle

[6] BUGAJ, M. 2015. Aeromechanika 1: základy aerodynamiky. Bratislava : DOLIS, 2015. - 208 s., ilustr. - ISBN 978-80-970419-3-9.

[7] BUGAJ, M., NOVÁK, A. 2010. Všeobecné znalosti o lietadle : drak a systémy, elektrický systém. - 1. vyd. - Žilina : Žilinská univerzita, 2004. - 247 s. - ISBN 80-8070-210-1.

[8] BUGAJ, M., URMINSKÝ, T., ROSTÁŠ, J., PECHO, P. 2019. Aircraft maintenance reserves - New approach to optimization. Transportation Research Procedia, 2019, 43, pp. 31–40. ISSN 23521457.

[9] NOVÁK, A., NOVÁK SEDLACKOVÁ, A., KANDERA, B., LUSIAK, T. 2020. Flight inspection with unmanned aircraft. Transport Means - Proceedings of the International Conference, 2020, 2020-September, pp. 589–593. ISSN 1822296X.

https://doi.org/10.26552/ pas.Z.2022.2.10

ANALYSIS OF TRENDS AND POSSIBILITIES OF REDUCING WASTE PRODUCTION ON BOARD OF AIRCRAFT AND INOVATIVE SYSTEMS FOR ITS ASSESSING

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Abstract

A major trend in the 21st century is the protection of the environment from a global perspective, which is associated with reducing emissions and reducing waste production. Therefore, we try to apply the same trends in aviation. With the help of progressive technologies, we ensure the reduction of emissions. However, the issue of waste generated on board of aircraft during the flight is not comprehensively identified. This diploma thesis deals with the topic of reducing waste production on board. The main goal of this work is to analyze the current state of the problem and the subsequent creation of innovative solutions in the form of operating procedures for organizations operating in aviation. The laws and directives valid in the territory of the Slovak Republic in the application of relevant regulations and other EU legislation were used to prepare the work. Articles, studies and methodologies of foreign authors have contributed appropriately to the completion of the theoretical part of the thesis and to a better understanding of the issue. The first chapter presents the current situation and legislative requirements in the field of waste generated on board aircraft. The second chapter describes waste recovery processes and related processes such as landfilling, incineration and recycling. The possibilities of using alternative materials and the application of optimal recycling technologies are described in the third chapter. The practical part of the work was the creation of progressive procedures on board aircraft and in handling or catering companies. At the end of the work, the impact of the created procedures on the environmental, socioeconomic, and operational environment is described.

Keywords

environment, legislation, waste, recycling, operation procedures

1. INTRODUCTION

One of the most actual issues in recent years is ecology and global warming. Many know that while this topic may not be relevant to us right now, our behavior today may affect future generations. For this reason, we are already trying to make effort to prevent environmental disasters, precisely mitigate the environmental impact of human activities.

Awareness of the waste problem is slowly increasing not only on the ground but also on board of the aircraft. In recent years, some airlines, airports and their contractors have begun to turn their attention to waste. In air transport, finances are the most important condition, often preventing companies from breaking away from traditional practices. Government restrictions and the growing awareness of the public are slowly but surely pushing airlines to take action to improve the environment not only by reducing emissions but also by reducing the production of waste on board aircraft.

This diploma thesis focuses on the problem not only with plastic, but also other types of waste. Specifically, it describes the ways in which procedures can be implemented to achieve a better and cleaner future. The aim of the thesis is to create a proposal for new operating procedures focused on separating waste on board and evaluating the impact of the use of alternative products. We will also mention the possibilities of waste utilization and disposal and look at ways of recovering waste that are more environmentally friendly. In the diploma thesis we will talk about the issue of waste on board of aircraft, and we will try to suggest the best way to reduce them. Based on the performed analyzes, we will determine the advantages and disadvantages of the established procedures and provide alternative approaches.

2. CURRENT LEGISLATIVE REQUIREMENT AND THE STATE OF THE PROBLEM

Each country, not just the Slovak Republic, has its own law on waste and its treatment. Act no. 79/2015 on waste, which regulates the competence of state administration bodies and municipalities, the rights, and obligations of persons in prevention waste management and liability and breach of liability in the field of waste management. This law contains definitions such as waste, by-product, biodegradable waste, hazardous waste. [2]

Waste management deals with activities that prevent the generation of waste and its harmful impact on the environment. These activities are waste collection, transport, sorting and disposal and supervision of individual activities. The order of priorities, i.e., what constitutes the best environmental choice under the legislation, is defined by the waste hierarchy: [2]

1. waste prevention,
2. preparation for re-use,
3. recycling (waste recovery operation by which waste is processed into products of the original or new purpose),
4. other recovery; and
5. disposal.

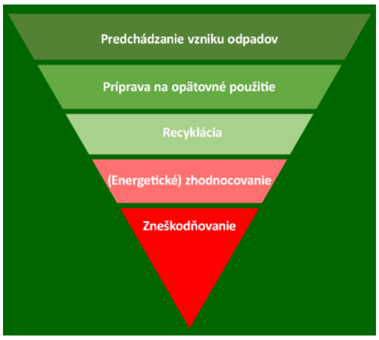

Figure 1: Waste management hierarchy

2.1. Directive on the reduction of the impact of certain plastic products

The Directive of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment states that an endless increase in the generation of plastic waste and its negative impact on the environment needs to be addressed. A European strategy for plastics should achieve a circular economy that considers the recycling, reuse and processing of plastics and plastic products. This decision would help to use easily accessible and sustainable alternatives or innovative solutions focusing on more sustainable business models, reusable options and material substitution. [3]

2.2. PET bottles

According to statistics, 1 billion plastic bottles are launched on the Slovak market every year. The Act no. 302/2019 states that the machines for collecting refundable bottles will be mandatory in all stores with a store area of 300 m2 and more. All other bottles purchased abroad and without the Z mark, as we well know, should be disposed of in yellow plastic containers. Until 30.6.2022, non-refundable bottles can still be found in stores. [4]

2.3. Glass

Glass is a substance made of silica sand (70%), dolomite (14%), soda (14%) and clarifiers (2%). Glass is fully recyclable and can be reshaped and reused without compromising quality. Glass recycling is environmentally friendly, energy-efficient with low CO_2 emissions. [7]

2.4. BRO – biodegradable waste

Biodegradable waste (BRO) is all types of waste that are classified in group 20 according to the Waste Catalog defined in Waste Act No. 75/2015. These include biodegradable kitchen and restaurant waste, including edible oils and fats, which can also be identified as waste on board aircraft. [8]

Due to the specific conditions in the case of the production of such waste on board aircraft, we propose to ensure separate collection and management of biodegradable waste: [8]

a) by introducing special containers for separate collection

b) for catering partners by providing contractual partners for waste collection

(c) informing passengers of such a procedure, including public relations

Sustainable waste management refers to the collection, transport, recovery and disposal of various types of waste in a way that does not endanger the environment, human health and future generations. It covers all processes from production to final processing. In our case, from the food packaging production process, through on-board service to waste disposal. The aim is to reduce the use of natural resources in the production of products and instead to re-use materials that have already been involved in the production process. [9]

2.5. waste recovery

Waste recovery means those activities that lead to the use of the physical, chemical and biological properties of the waste.

Not every incineration is an energy recovery of waste. Not all waste can be fuel. Plastics are considered to be almost pure fuel. They have a higher thermal capacity than solid fossil fuels, such as brown coal, which has a thermal value of 8-12 MJ / kg compared to PET with a thermal value of 22 MJ / kg. [10]

2.6. BIOgas

During decompositions and syntheses performed by biochemical routes, a whole range of gaseous compounds is formed. Biogas is then used as a source for combined heat and power.

Recently, biodegradable waste accounts for almost half of mixed waste from aircraft decks. Although the sorting of bio-waste is more complicated, such procedures can be implemented on board aircraft relatively easily and at minimal investment and operating costs. [11]

2.7. Recycling

After meeting the requirements of the STN ISO15270 standard, the district environmental authorities can be assigned activity code R3. Code R3 indicates material recovery using one of the following methods: [12]

(a) mechanical recycling

b) raw material (chemical) recycling

c) biological (organic) recycling

Mechanical recycling is the creation of a secondary raw material by processing plastic waste without significantly changing the chemical structure. Mechanical recycling takes place in several steps, which gradually prepare the recycled during the production process: [12]

collection → identification → sorting → crushing → washing → drying → sorting → agglomeration → extrusion or preparation of mixtures → granulation.

Raw material (chemical) recycling consists in the production of new raw materials by changing the chemical structure by cracking, gasification or depolymerization without energy recovery and incineration. [12]

The term biological recycling refers to a process where organic residues, water and carbon dioxide are the products of aerobic (composting) or anaerobic treatment (digestion) of biodegradable plastic waste in the presence of oxygen. [12]

2.8. Disposal

Society and environmental requirements call for ever-improving incineration, cleaning, and waste management technologies. The requirements are: [13]

a) a smaller volume of waste deposited in landfills,

b) reduction or complete destruction of hazardous and noxious substances from waste and incineration plants,

c) stabilization and reduction of residual waste,

d) minimization of liquid and gaseous emissions during combustion,

e) maximizing the use of energy in the combustion process

In March 1989, the then Czech and Slovak Federal Republic signed the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal. They are all disposal processes which do not result in recovery or reuse of waste and waste products. [14]

2.9. Landfill

A landfill is a place where solid waste is stored. Only authorized landfills are official and legal. Before building a landfill, it is important to assess safety, importance in the region, economic analysis and especially the impact on the environment. This assessment is governed by Act 24/2006 Coll. on environmental assessment environment. [13]

3. OPTIMIZING THE USE OF ALTERNATIVE MATERIALS AND RECYCLING TECHNOLOGIES

There are many alternatives for plastic products. So why do we still use a lot of plastic? In most cases, plastic cups are replaced by paper that is light, does not take up much space, does not burden the environment and is degradable. Plastic cutlery can be replaced with bamboo or wood. However, these are insufficiently strong at lower material thicknesses and often break and produce relatively dangerous sharp chips.

Table 1 shows data on the weight of some kitchen utensils also used on board aircraft. The items were weighed experimentally on a kitchen scale. The measured objects were not specifically from aircraft, but their size is close to those used on board aircraft.

The weight of these 6 items from column no. 2 together is 516g. If we take into account the flight on a Boeing 737-800 aircraft in the basic configuration of the cabin with 189 seats and for each passenger a dish with this weight would be prepared on board, the total weight will reach 97.52 kg if we do not count the crew and the journey from destinations back. In the case of fuel consumption and weight, 100 kg is a negligible weight, on the other hand, with increasing weight respect the MTOW and this may in certain cases limit the amount of fuel filled. It is for these reasons that materials such as glass, porcelain and metal are not used for all passengers.

One alternative is bamboo cutlery and paper cups. After calculating the weights, the result weight is 43.6 g per passenger and 8.24 kg for a full cabin for the same type of aircraft as in the previous case. In the case of bioplastic PLA cutlery and cups, the weight is 35 g per passenger and 6.52 kg per fully occupied aircraft. It only depends on the company's decision which alternative they choose.

Table 1: Comparison of weights of kitchen utensils (https://markbal.sk/155-pribory)

item	material	weight	material	weight	material	weight
little spoon	steel	19g	bambus	2,3g	bioplastic PLA	4g
spoon	steel	19g	bambus	3,4g	bioplastic PLA	5,6g
knife	steel	38g	bambus	4g	bioplastic PLA	4,6g
fork	steel	19g	bambus	3,9g	bioplastic PLA	4,8g
mug	porcelain	229g	paper	15g	bioplastic PLA	8g
glass	glass	192g	paper	15g	bioplastic PLA	8g
together		516g		43,6g		35g

Many studies indicate that more than half of aircraft cabin waste could be recycled. On-board recycling has already been introduced by some companies. Recycling can also reduce waste disposal costs. There are various obstacles to the recycling of waste on board: [1] [17]

- space and time pressure on the crew during the collection and separation of materials,
- a different understanding of what can be recycled
- lack of recycling facilities at airports,
- crew involvement and development of new procedures,
- involvement of cleaning staff and insufficient requirements in cleaning contracts.

3.1. Case study Air New Zealand

In 2017, Air New Zealand worked with other partners on the "Project Green" waste management project. This project required changes in the airline's processes, in which flight crews played an important role in the proper storage and separation of materials. During 2017, the waste management project enabled the exchange and retraining of 40 products so that they could be reused the next flight if they had not been opened and used before. [18]

3.2. Airport Waste Management

Vienna Airport is an example of how to dispose of waste properly and ecologically. Vienna Airport Eco-Model focuses on waste prevention, reduction and recycling. The less waste is produced, the less it must be separated and disposed of.

3.3. ReTrolley

The European aircraft manufacturer has launched a new concept of boarding trolleys called ReTrolley. This is a trolley designed for efficient recycling directly on board. The innovative trolley allows the crew to collect and separate waste in one. It contains the containers for collecting liquids and space for stacking plastic cups and separate sections for recycling paper, plastics, and other municipal waste. [21]

4. DESIGNING PROGRESSIVE PROCEDURES ON BOARD OF AIRCRAFT AND AT HANDLING PROVIDERS

To implement, compare and evaluate new operating procedures involving on-board waste separation, it is necessary to identify the current operating procedures of the companies involved in this process.

The standard procedure is the sale of on-board refreshments such as baguettes, drinks, sweet and savory delicacies, alcohol, etc. Cabin crew go through the cabin with a snack cart and sell goods to passengers according to the offer. Free water is offered after the sale. Immediately afterwards, the waste from the on-board service is collected in empty trolleys with a plastic bag intended for waste. The cleaning company picks up garbage bags from bins and carts and throws them in one container after the flight. Currently, all generated waste is considered municipal, although some components could be recycled.

Content of trolleys:

- half trolley: 24 bottles of still water
- full trolley (BOB): cans of carbonated drinks 26x, cans of beer 10x, miniatures of alcoholic beverages 33x, snacks 26x, bottles of water and juices 30x

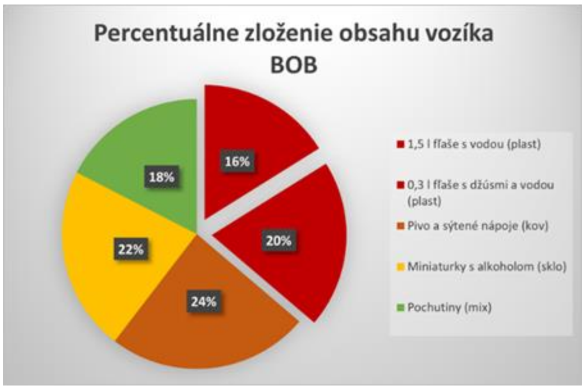

Figure 2: percentage composition of the contents of the trolley BOB

Of the total content of trolleys with snacks and drinks, 82% of the material can be recycled. The quantities of the individual trolleys vary depending on the operation. It can also be seen from the graph that 60% of the material in the form of plastic bottles and cans is refundable. The deposit for them is valid only if they are properly marked.

When separating, storage space for waste from different materials is important. There are designated waste areas in the galley, namely fixed waste bins. The trolleys are constructed as standard in two sizes, a long trolley and a half-size trolley. The responsibility for the trolleys lies with the airline and thus the crew during the flight, after the flight the trolleys are taken from the aircraft by the catering, which then exchanges and replenishes the items needed for the next flight and the trolleys return to the aircraft.

5. ENVIRONMENTAL, SOCIO-ECONOMIC AND OPERATIONAL EVALUATION OF THE INTRODUCTION OF NEW APPROACHES

5.1. Ecological impact

Waste management contributes to climate change and air pollution and directly affects many ecosystems and species. Landfills are considered a last resort in the waste hierarchy, releasing methane, a harmful greenhouse gas associated with climate change. Currently, waste from the aircraft is treated as one component. Whether it is plastic, glass or paper, all types of waste are disposed of together in one container and then sent to the incinerator.

The introduction of new on-board separation procedures will reduce the environmental impact of waste. It is clear from the previous chapter that 82% of the waste sold on board can be recycled.

Energy saving by recycling materials: [22]

- plastic → 97%
- aluminum → 95%
- paper → 70%
- glass → 25%

5.2. Economic impact

It is only possible to reduce the amount of waste by reducing the amount of goods offered on board. Since the interest in the offered dining service persists mainly on long flights, this option is impossible.

The question is whether the use of greener alternatives to these products pays off financially. In the following table we compared the prices of plastic, wooden and PLA plastic cutlery. We compared the price for 100 forks.

Table 2 shows that the cheapest fork is made of plastic at a price of € 0.94, wooden fork is up to € 2.40 more expensive and the most expensive is a PLA plastic fork for € 4.50. From these prices, it is clear why many companies prefer plastic cutlery.

Table 2: Fork prices (https://www.h-print.sk/product-category/jednorazovy-riad/jednorazovy-pribor/plastove-pribory/page/2/)

	material	pieces	price
fork	plastic	100 pc	0,94 €
	wood	100 pc	3,34 €
	PLA plastic	100 pc	4,50 €

The airport charges airlines € 11 per service for removing and disposing of aircraft waste that arrived from an EU country. In addition, charges € 3 per 1 kg or € 0.66 for a plastic bag with a special sticker for waste from flights outside the EU.

With the introduction of separation on board, the number of waste bags would increase, but we know that the so-called extended producer responsibility exists and therefore citizens do not pay for separated packaging.

5.3. Sociological impact

Passenger feedback can tell companies what to focus on. The so-called review or feedback from passengers about food, services and the overall feeling of the flight can help the company make decisions in the future. Passengers could answer questions in the questionnaire such as:

a) Were you satisfied with the services on board the aircraft?

b) Was your food delicious? Would you change anything?

c) What dishes would you welcome on board and which ones would you rather exclude from the menu?

In response to the sorting of waste on board the aircraft, the questionnaire could include questions:

d) Do you separate waste in your household?

e) Do you separate waste at your job?

f) Would you welcome the introduction of separated waste on board the aircraft?

g) Do you agree with the introduction of the use of more environmentally friendly alternatives to kitchen utensils?

These questionnaires can be incorporated into the built-in entertainment system, accessible on the company's website, sent by e-mail when purchasing a ticket or in any other form. Improving the passenger experience will result in passengers receiving the food, drinks and products they prefer during the flight, leading to less waste and reduced costs.

5.4. Operational impact

When introducing new procedures, it is necessary to motivate the employees who will execute these procedures in order to ensure the correct performance of these activities. Ways to engage and encourage the crew and cleaning staff can be as follows:

- to understand the barriers to recycling
- identification of triggers to encourage recycling
- precise instructions on which materials to collect
- to explain the contamination and its effects on recycling
- to accept the effects on the time needed to carry out these activities
- to get feedback from the crew
- to provide information on where the separated waste goes and how it is treated
- for financial and other rewards
- on exploiting competitiveness between crews
- to share knowledge with other companies

Airport organizations are often directly responsible for handling and disposing of cabin waste. Recycling facilities can vary considerably between airports, depending on the availability of local recycling and disposal facilities. The availability of separation facilities will affect the degree of effective separation on board during flight. Local regulators have a major influence on waste management, especially international waste, which is considered hazardous waste.

5.5. SWOT analysis

The SWOT analysis serves as a tool for evaluating the current situation and describes the possibilities of development and possible strategy.

Table 3: SWOT analysis

strengths				**weaknesses**			
environmental protection	5	0,4	2	initial investment	4	0,3	1,2
advertisement	4	0,2	0,8	lack of time	3	0,2	0,6
employee bonus	3	0,2	0,6	lack of space	3	0,2	0,6
waste costs	4	0,1	0,4	cabin crew responsibility	5	0,2	1
refundable bottles	4	0,1	0,4	eco cutlery investment	2	0,1	0,2
together		**1**	**4,2**			**1**	**3,6**
opportunities				**threats**			
technologies	2	0,1	0,2	lack of interest of cabin crew	5	0,3	1,5
partnerships	3	0,1	0,3	increasing costs	4	0,1	0,4
implementing procedures to all bases	3	0,2	0,6	jeopardizing flight safety	5	0,4	2
implementing know-how	5	0,3	1,5	expensive flight tickets	2	0,1	0,2
EU grants	4	0,3	1,2	prioritizing waste separation	2	0,1	0,2
together		**1**	**3,8**			**1**	**4,3**

Strengths outweigh weaknesses, which is a good sign that moving ecologically is a good idea. The environmental value associated with advertising is of the utmost value, because if the public learns about the company's greener intentions, interest in their flights may increase.

Among the negative aspects, the initial investment prevails, which we cannot avoid, but in the long run the profits may be higher.

It is clear from Table 3 that threats have the highest value of 4.3, followed by strengths of 4.2, followed by opportunities of 3.8, and weaknesses of 3.6.

Threats have the highest value because nothing is taken lightly in air transport and any change must be approved, either by the national transport authorities or even by higher aviation organizations. It all costs time and money and these facts cannot be changed because safety always comes first.

Opportunities come with time and evolve, so the value we have calculated may change and may not be a decisive factor in adopting a new strategy.

5.6. PESTE analysis

PESTE analysis is used to map the external factors affecting the operation of the company.

Table 4: PESTE analysis

Political	war	0,4	5	2
	pandemic	0,3	3	0,9
	political stability	0,3	4	1,2
Economic	inflation	0,4	3	1,2
	unemployment	0,2	3	0,6
	economic growth	0,4	4	1,6
Sociological	demography	0,3	5	1,5
	ethics and religion	0,2	4	0,8
	state precocity	0,5	4	2
Technological	technological innovations	0,4	5	2
	internet connections	0,2	3	0,6
	cybersecurity	0,4	4	0,8
Environmental	sustainability	0,3	4	1,2
	recycling	0,3	4	1,2
	pollution	0,4	4	1,6

War as a political factor affects both the whole world and the aviation. An example is the current war in Ukraine, which has restricted airspace, airports, and destinations to which it is forbidden to fly. This causes flight cancellations or flight length extensions and therefore higher costs for the company.

The speed of economic growth of the state affects the construction of airports and infrastructure, on which the handling of aircraft depends, the time and quality of service. This means that if there are no separate waste containers at the airport, the airline unnecessarily separates the waste on board.

From a sociological point of view, the state's maturity weighs on society's perceptions of climate change, pollution, and environmental protection in general. If the state's maturity is low, the implementation of separation procedures will be even more difficult to implement.

Technological innovations determine the company's development in the future. Financial support for the development of new technologies helps the company to advance and compete in the market.

Environmental factors have about the same value because when it comes to the environment, all activities to protect it should have the same priority.

6. SUMMARY AND RECOMMENDATIONS

By analyzing the composition of the sales trolley, it is evident that plastic, glass, metal or paper waste is generated on board and other municipal waste generated by food residues and multi-component packaging.

Through a detailed analysis of operating procedures, we have identified that not only airlines, but also airport, catering and handling (and cleaning) companies are involved in reducing waste production in aviation. Their common goal should be to ensure that the operation is more environmentally friendly. If the airline adopts this strategy, it is important that it involves the other companies mentioned in this process, without which it is not possible to make successful progress in this environmental area. The airline itself must assess whether it has sufficient resources for this process, as the implementation of such a process requires significant investment.

External companies can also be included in the strategy, which will contribute to waste reduction and recycling with their knowledge. For example, by working with 3D printing specialists, recycled plastic can be used to make models of airplanes or other goods from which the airline will make profits. Using online questionnaires, the company can evaluate the interest of passengers, their observations, and ideas for waste separation. Later, with the help of modern innovative technologies (e.g. the use of AI), the company can simplify the separation or identification of waste.

Initially, we recommend to the airline to move to a new strategy by small but predefined steps. In the first step, only the backup of plastic bottles and metal cans can be introduced. These would be stored back in the trolleys. In this way, after some time, the company would find out whether the profits from the bottle advances are returning and could proceed with the introduction of further waste separation procedures.

7. CONCLUSION

The issue of sustainability in food waste management cannot be ignored indefinitely.

Nowadays, operating procedures do not consider waste and its impact on the environment. The aim of the diploma thesis was to evaluate the current operating procedures and create an annex including the separation of waste on board. We have found that up to 82% of the total products in the service trolley are recyclable. This is a high percentage of waste that ends up in landfills unnecessarily. In addition, the treatment of unsorted waste consumes a large amount of energy that could be used for other activities. By separating and using waste as a secondary product, we can reduce the extraction of minerals, reduce emissions, and reduce the amount of waste.

Through analyzes, we have found that even though the aviation is highly controlled for safety reasons, at least in small steps the company can gradually improve its efforts to fully achieve waste-free operation.

REFERENCES

[1] SWEET N., a kol. 2017. IATA Cabin Waste Handbook 2019, Banbury, 2017. [online]. Dostupné na internete: https://www.iata.org/contentassets/821b593dd8cd4f4aa33b63ab9e35368b/iata-cabin-waste-handbook---final-resized.pdf

[2] Zákon č. 79/2015 Z. z. o odpadoch a o zmene a doplnení niektorých zákonov. [online]. Dostupné na internete: https://www.zakonypreludi.sk/zz/2015-79.

[3] Smernica Európskeho Parlamentu a Rady (EÚ) 2019/904 o znižovaní vplyvu určitých plastových výrobkov na životné prostredie. [online]. Dostupné na internete: https://eur-lex.europa.eu/legal-content/SK/TXT/HTML/?uri=CELEX:32019L0904&from=SK.

[4] Zákon č. 302/2019 Z. z. o zálohovaní jednorázových obalov na nápoje a o zmene a doplnení niektorých zákonov. [online]. Dostupné na internete: https://www.zakonypreludi.sk/zz/2019-302.

[5] Meet Aluminum - The Miracle Metal. [online]. Dostupné na internete: https://www.aluminum.org/aluminum-miracle-metal.

[6] Food waste depacting & separating. [online]. Dostupné na internete: https://shredding-machine.com/index.php/application/food-waste-depacking/?gclid=Cj0KCQjw3v6SBhCsARIsACyrRAkQY82dTMT3AolrbnffZAup3Bhen77FgRWofCKBSOgx53ffV-hqi7AaAhj7EALw_wcB.

[7] Sklo. [online]. Dostupné na internete: https://www.vetropack.sk/sk/. (citované Marec 2022)

[8] Metodická pomôcka k vypracovaniu všeobecne záväzného nariadenia obce o nakladaní s komunálnymi odpadmi. [online]. Dostupné na internete: https://www.minzp.sk/files/sekcia-enviromentalneho-hodnotenia-riadenia/odpady-a-obaly/registre-a-zoznamy/metodicka-pomocka-20_12_2012-doc-2.pdf. (citované Apríl 2022)

[9] JENNER G., 2021. The sustainability need for airlines to reduce food waste onboard. In World Travel Catering & Onboard Services [online]. 2021, Dostupné na internete: https://insights.worldtravelcateringexpo.com/2021/04/14/airlines-reduce-food-waste-onboard/. (citované Apríl 2022)

[10] GALLOVIČ P., 2020. R1 Využitie najmä ako palivo alebo na získanie energie iným spôsobom. In Praktická príručka o odpadoch a obaloch. [online]. 2020. Dostupné na iternete: https://prirucka-odpadov.dashofer.sk/onb/33/r1-vyuzitie-najma-ako-palivo-alebo-na-ziskanie-energie-inym-sposobom-uniqueidmRRWSbk196FPkyDafLfWAAnlHoBoU9LR7GtKfEIubhtBEPixxe4LAQ/?uri_view_type=35. (citované Apríl 2022).

[11] Bioplynové stanice [online]. Dostupné na internete: http://www.intechenergo.sk/bioplynove-stanice/. (citované Apríl 2022).

[12] ŠČERBÁK J., 2013. Usmernenie k udeleniu kódu činnosti R3 pri odpadoch z plastov [online]. Bratislava. 2013. Dostupné na internete: https://www.minzp.sk/files/sekcia-enviromentalneho-hodnotenia-riadenia/odpady-a-obaly/registre-a-zoznamy/usmernenie-r3-plasty-zmena2.pdf. (citované Apríl 2022).

[13] ŠICULIAK M., 2021. Zneškodňovanie odpadov. In Praktická príručka o odpadoch a obaloch. [online]. 2021. Available: https://prirucka-odpadov.dashofer.sk/onb/33/zneskodnovanie-odpadov-uniqueidmRRWSbk196FPkyDafLfWAAnlHoBoU9LR7GtKfEIubhvJA7w8ixhBUA/?uri_view_type=33. (citované Apríl 2022).

[14] Zákon č. 60/1995 Z. z. Bazilejský dohovor o riadení pohybov nebezpečných odpadov cez hranice štátov a ich zneškodňovaní. [online]. Dostupné na internete: https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/1995/60/. (citované Marec 2022).

[15] GOLDBERGEROVÁ. S., 2018. 6 duvodu proč si zamilujete bambus. [Online]. 2018 Dostupné na internete: https://www.econea.cz/blog/6-duvodu-proc-si-zamilujete-bambus/?a_box=gz7tc655&a_cha=bambusove-pribory. (citované Marec 2022).

[16] Kompostovateľný bioplast. [online]. Dostupné na internete: https://www.tvojekostatus.sk/pla-kompostovatelny-a-biodegradovatelny-plast/. (citované Marec 2022).

[17] Aircraft Cabin Waste Recycling Guide. 2010. [online]. Dostupné na internete: https://www.sustainableaviation.co.uk/wp-content/uploads/2018/06/Aircraft-Cabin-Waste-Recycling-Guide1.pdf. (citované Marec 2022).

[18] BAXTER G., 2020. Sustainable airline waste management: A case study of Air New Zealand´s waste management programs and strategies. In International Journal of Traffic and Transport Engineering. [online]. 2020. Dostupné na internete: http://ijtte.com/uploads/2020-07-26/b2de7b7d-a0c6-385aijtte.2020.10(3).07.pdf. (citované Apríl 2022)

[19] MEHTA P., 2015. Aviation Waste Management: An Insight. In International journal of environmental science. Vol. 5, Jodpur , 2015. ISSN: 0976 – 4402 [online]. Dostupné na internete: https://www.researchgate.net/publication/292970731_Aviation_waste_management_An_Insight. (citované Apríl 2022).

[20] Environmental Protection. [online]. Dostupné na internete: https://www.viennaairport.com/en/company/flughafen_wien_ag/environment__sustainability/environmental_protection. (citované Apríl 2022).

[21] Iacobucci HF Aerospace presents ReTrolley - the revolution in cabin waste management developed in partnership with Airbus. [online]. Dostupné na internete: http://www.ihfelectronics.com/iacobucci/images/stories/news/PRESS_STATEMENT_IACOBUCCI_HF_AEROSPACE_AIX2018.pdf. (citované Apríl 2022).

[22] Recyklácia - materiálové zhodnocovanie odpadov. In BIO magazín. [online]. 2007. Dostupné na internete: http://www.biospotrebitel.sk/clanok/1256-recyklacia-materialove-zhodnocovanie-odpadov.htm. (citované Apríl 2022).

[23] BARTOVIČOVÁ L. – KORČEKOVÁ K., 2010. SWOT analýza. Trnava: Slovenská technická Univerzita v Bratislave, 2010.

30 s. [online]. Dostupné na internete: https://www.euroekonom.sk/wp-content/SWOT-analza-Diplomova-praca-Bartovicova-Korcekova.pdf. (citované Apríl 2022).

[24] PESTLE analýza. [online]. 2015. Dostupné na internete: https://managementmania.com/sk/pestle-analyza. (citované Apríl 2022).

[25] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

https://doi.org/10.26552/ pas.Z.2022.2.11

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IMPACT OF FATIGUE ON PILOT REACTION TIME

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Abstract

The main goal of the diploma thesis is to analyze the impact of fatigue on the reaction time of the pilot, its possib;ilities of elimination and ways of solving the problem, which greatly affects safety in air transport. The measurements took place at different times, in the morning and in the afternoon, on the basis of which we will compare the length of the reaction time to visual stimuli affected by fatigue. We performed measurements for safety reasons on the L-410 simulator. The simulator is equipped with two cameras based on which we will analyze the length of the reaction time.

Keywords

pilot, central nervous system, psychological aspects, reaction time, fatigue.

1. INTRODUCTION

Air transport is currently at a very high level in terms of safety. To transport passengers or cargo safely to their final destination depends on many factors that together make up a very safe mode of transport. These factors are, for example, the sufficient technical condition of the aircraft, security checks when checking passengers who would tend to deliberately endanger the aircraft by their actions. Another factor is the ground crew and staff who control safety when moving on the ground or in the air. However, these are factors that can be observed with sufficient controls. The problem arises, however, in the decision-making of the pilots themselves in a critical situation, who do not have the time to, for example, check the work as they have done it, or, alternatively, to correct mistakes again. In such a situation, the aircraft is very uncompromising and perhaps one wrong decision will trigger a sequence of events where there is no possibility of preventing a disaster. If we compare this with, for example, an aircraft maintenance engineer, after the work has been done, someone else will come to check how he has done it. If the work is not done according to the regulations, the work may be done again or the aircraft may be completely grounded and not allowed to take off until the fault is corrected. If the mechanic is unable to fix something, another qualified professional or team will be called in for advice and given enough time to make a decision. There are most often two pilots in the cockpit, sometimes three, and they have a very short time to choose the solution they think is best at that moment. And it is fatigue that is responsible for many of the bad decisions that pilots have made that have had fatal consequences later on. Therefore, we would like to focus the thesis on this very important topic from a safety point of view and to highlight the negatives caused by the lack of sleep or excessive workload of the pilot at work or before it. Many young people underestimate the fatigue factor and try to compensate for a lack of sleep or rest with various caffeinated drinks or snacks that maintain attention and suppress fatigue, but only for a very short while. However, such a solution is inadequate from a number of points of view, especially in the pilot profession.

2. ANALYSIS OF THE CURRENT SITUATION

In the early days of aviation development, aircraft were primarily used for military purposes and therefore the development emphasized the combat effectiveness of the aircraft, which included range, speed, maneuverability, and firepower. The quality of pilot training and pilot comfort was not greatly addressed. After a number of mistakes made by pilots, an essential component in aviation, namely the human factor, began to develop. It included the overall behaviour of the pilot in the cockpit from a psychological and health point of view. Statistics show that it is the human factor that bears the largest share in aircraft accidents. The material things in the construction of an aircraft are constantly improving with new technology and aircraft are becoming safer and safer. However, these are parts of the aviation industry that undergo a lot of testing and are only put into service after certification. Should any of the technical parts of the aircraft fail, for this reason aircraft are designed so that the systems are redundant, meaning that another system will replace it if it fails and the aircraft will land safely. The human factor is a part of aviation that can be well trained, the crew has flown many hours and accumulated a lot of experience and still make a mistake in a critical situation. Pilots are also just people and not machines, and are affected by the environment such as stress and fatigue. Therefore, new methods of pilot training are continually being improved to ensure that the number of accidents caused by human factors is eliminated. Overall aviation safety is at a high level and the number of accidents has decreased. According to statistics from PlaneCrashinfo.com, the amount of accidents has had a downward curve from 1950 to 2018.

Air transport is gaining more and more demand and is developing. It is particularly advantageous for passengers because of its speed, comfort and safety. The ever-increasing passenger demand for air travel is forcing air carriers to buy more aircraft and provide more flights. There is a very simple direct proportionality, which, however, is causing a shortage of pilots on the market. Boeing can build an aircraft from imported parts in a few days while it takes about 2 years to train a pilot.

With this imbalance, pilots experience a lack of free time and have to spend more time at work. This was especially the case in Asian countries where there was a shortage of pilots and pilots were very busy, which caused some accidents such as Korean Air's Boeing 747-3B5 flight 801 or TransAsia's ATR 72-500 flight 222 when they were extremely busy without enough rest.

In 1986, Braune and Wickens conducted research on reaction time in pilots flying different types of aircraft. After analysing the results, they concluded that the biggest factor affecting reaction time was age. They concluded that after the age of 40, reaction time speed increased and spatial ability decreased in pilots. In 2002, Werner B. and team decided to verify this statement and therefore created a research study focusing on pilots with different ages, flying different types of aircraft and different number of hours flown. According to their conclusion, the initial claim of Braune and Wickens was confirmed and the main factor that influenced the reaction time of the pilots was their age. What type of aircraft the pilot was flying had no effect on his reaction time rate. The experience the pilot had accumulated over his career had a positive effect and reduced reaction time.

Michael Russo and team focused their research on how reaction time can be affected by fatigue. This research concluded that fatigue primarily affects a pilot's visual perception, and during night flights, the ability to respond to visual stimuli is reduced.

Marcela Jančo, who is a forensic expert in road transport, claims that reaction times are deteriorating significantly after 60 years. With increasing age, a person succumbs to fatigue earlier and the ability to react changes.

3. PSYCHOLOGICAL ASPECTS

The main control system in the human body is the nervous system, which allows it to receive information about changes in the internal or external environment of our body. The nervous system sorts this information, processes it and sends a signal that is fed to the major organs such as muscles or glands. The basic cell in the nervous system is a neuron, and the connection between two neurons is called a synapse. Thanks to the nervous system, which has already reached its highest development, we can, for example, perceive emotions, think abstractly or speak.

The basic parts of the nervous system are the brain and the spinal cord. The nervous system provides several functions in the human body. Most of the information that we get from the external environment is through vision and hearing and hence the transmission of information from external stimuli to the brain is obtained from the sensory organs. In addition to the main sense organs mentioned above, we can acquire information by touch or smell. These sense organs use sensitive nerve cells called receptors to transmit information. The brain weighs approximately 1.4 kg and makes up 97% of the entire nervous system. The second part of the nervous system is the spinal cord. The function of the spinal cord is to nervously connect the brain to other parts of the body. Another function provided by the nervous system using muscles is motor control.

The peripheral nervous system consists of a group of special cells that move the information received from the muscles and organs of the body back to the central nervous system via sensory nerves. Another role of this system is to transmit information from the central nervous system to the muscles and organs via motor nerves. In this transmission, it is not necessary for the brain to be involved at all times. This is for example in the reflexive movement of the hand or foot if something hits, burns or stings us. The principle applies that the fewer nerves directly involved in the execution of the action, the faster the reflex.

The autonomic nervous system provides internal control of organs such as glands, autonomic muscles of internal organs and blood vessels. Autonomic nerves connect the ions to the central nervous system. The autonomic nervous system controls all processes automatically and without our knowledge. These are, for example, breathing, sweating, body temperature, pressure in the arteries or processes and movements in the digestive system.

4. SENSORY ORGANS

Not only in aviation, but also in everyday life, sight and hearing can be considered the two most important sensory organs. With these two organs we obtain most information from the external environment. The sense organs allow us to recognise the space around us, to maintain our balance, to smell different aromas, to recognise tastes, etc. Pilots have to undergo annual medical examinations by classified aviation doctors who check whether these sensory organs meet the minimum requirements for pilots. For some deficiencies, an exemption may be granted to the pilot, such as impaired vision due to increasing age, and the pilot is therefore required to wear goggles. However, there is also a condition attached to this whereby a pilot wearing goggles is required to carry a spare pair on board the aircraft.

We use the eye to visually project the space around us. Through this organ we perceive approximately 80% of information. It serves us to perceive and recognize light, colors, shapes of objects. The eye receives electromagnetic waves from the external environment in the visual spectrum and then sends these signals to the brain where we form an image.

When viewing an object that is in motion, it is important that both eyes are aligned together, so the brain controls the eye muscles to ensure that the signals received are the same. With fatigue, this coordination fails and double vision occurs, due to two different signals being received.

The ear performs several functions in the human body. One is the perception of sound, i.e. the reception of vibrations from the air, where we can detect tones, loudness, the direction from which the sound is coming, the pitch of the tone or the intensity of the sound. Sound waves are the impulse for hearing. A sound wave is made up of the longitudinal oscillation of air molecules. The human ear can hear tones from a frequency of 16 Hz to about 20 kHz. The second function it performs is providing balance and detecting acceleration. Pilots use this organ to perceive acoustic stimuli in normal flight, such as in a piston-powered aircraft to listen for the correctness of engine operation or then for safety systems to warn them. They use the function of the ear in terms of balance to orient themselves in space.

Humans have fairly well developed olfactory receptors. We can detect quite a lot of smells and odours, but compared to other mammals, rodents, for example, are better off than humans. But dogs have the best sense of smell. Compared to humans, their receptors are concentrated on one particular smell and its intensity. The reason why some mammals have a better sense of smell is because of the difference in the size of the mucosal surface. Humans have a very small surface, dogs have the largest.

The input sensory organ is the skin, where the sensory cells are located, which are all over the body. Sensory cells can be divided into several types that perform different functions. With the help of sensory cells we perceive heat, cold, pressure touch or pain.

The human body was not adapted to move through the air in three-dimensional space, but only on the ground in two-dimensional space. After advances in technology and inventions in the field of aviation, man could move in the air. However, for this he needed a machine in which there was a need for a certain harmony between the crew and the aircraft. To make everything work properly, psychologist Elwyn Edwards devised a model in 1972 that described the relationship between man and machine. The name of this model was derived from the first letters of the words of which it is composed and therefore with which the human being forms some kind of relationship in the cockpit of the aircraft.

S = Software - software (computer systems, procedures, manuals)

H = Hardware - machine (cockpit instrument layout, aircraft design, controls)

E = Enviroment - environment (temperature, humidity in the cabin, weather on the flight path)

L = Liveware - human (pilot or other person with whom the pilot comes into contact, e.g. air traffic controller)

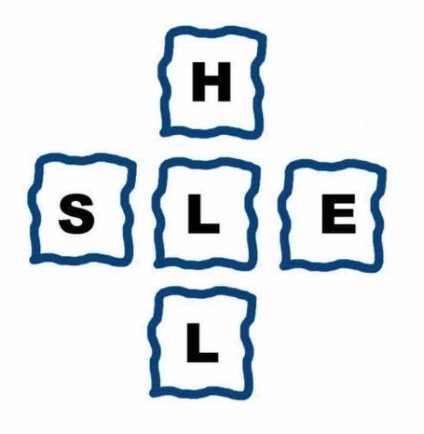


Figure 1 Model Shell

The edges of the individual parts of this model are deliberately irregular, but they must fit together so that if one part fails or fails, it will be able to interlock with other parts and thus not compromise the safety of flight. This is due to factors that affect this such as stress or other potential failure.

Before a person makes a decision, the body goes through a process that begins with a stimulus, i.e., information received that is influenced by attention and perception. Only then do we make either a right or wrong decision. Feedback then occurs, whether in the form of self-control or the reaction of, for example, an aircraft to the instructions we have given.

With aircrew, it is important to make the right decision over a long period of time rather than making a hasty decision without thinking about the consequences. For this reason, each pilot's reaction time is different. The correctness and speed of the decision is primarily influenced by the knowledge and experience of the pilot. The pilot acquires this information by memorising theoretical information about the aircraft and its behaviour in the atmosphere. Another factor that positively influences the amount of information acquired is the number of hours flown. Stress also has a major influence on pilots' decision making. If a crisis situation occurs during a flight, the aircraft should alert the pilot to the error. These indications are divided into visual and acoustic. The most dangerous situations or malfunctions inform the pilot by a combination of both indications.

Stress is a negative situation - a feeling of pressure, tension and negative emotions. From a psychological point of view, stress occurs when a person feels that his or her abilities are not sufficient to perform a desired activity. It has several components and therefore we need to distinguish between stressors and reactions to stress (Ayers, de Visser, 2011). Stress can be caused not only by the current critical situation in the cockpit but also in private life. Stress in combination with fatigue represents a potential risk and is closely related. For the more tired a person is, the more his potential stress and irritability increases.

Stress is beneficial to a person to a certain extent. As the stress load increases, so does our concentration and focus. Optimal performance is at the top of this curve. However, if stress continues to rise and exceeds the optimum, the body is unable to cope with the stress and we slip into anxiety, then into complete helplessness, where we are unable to cope and resolve the situation.

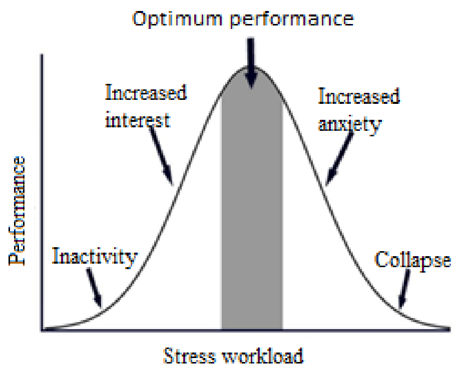


Figure 2 Stress curve

In order to improve safety, aircraft designers are also trying to apply modern technology directly into the cockpit. Air transport is modernising and advancing very rapidly. In the beginning, when airplanes were designed, they were primarily created for military purposes. Because of this, the quality of the aircraft was mainly focused on the combat effectiveness of the aircraft and the welfare of the pilot went by the wayside. Pilots therefore did not feel comfortable, the cockpit was cold or had hard seats and these factors consequently influenced the pilots' decisions. In the past, pilots in particular did not spend long hours in the cockpit as is currently the case for long-haul flights.

Analog instruments are slowly being replaced by modern LCD displays in aircraft cockpits. For new student pilots, this type of instrumentation and its operation is easier than it may be for old pilots who have been piloting airplanes with only analog instruments for three decades.

5. THE EFFECT OF FATIGUE ON THE PILOT

Pilot attention affected by fatigue can be fatal, especially in small one-man crews. With the amount of activities a pilot has to attend to during a flight, it is very difficult to concentrate one hundred percent on all tasks. His reactions are slower and there is therefore a risk of either being diverted from the correct course when his attention is diverted, for example, or focusing his attention purposefully on one particular activity, for example, steering the aircraft correctly on course, while the oil temperature instrument, for example, is soaring.

Piloting large transport aircraft over long distances is a monotonous activity after take-off and when the autopilot is engaged. Flying for five hours, for example, and only checking the instruments is exhausting for pilots. Fatigue can be divided into mental and physical fatigue. Mental is caused by the monotony of the flight and physical is caused by prolonged sitting when some parts of the body are not well blooded. In smaller general aviation aircraft, fatigue is caused by the exhaustion of a long flight when the pilot has to manually control the aircraft while still checking the heading, comparing the approximate location with the chart, communicating with air traffic control, recording the times when passing the turn point and then calculating the approximate time of arrival at the next turn point.

Short-term fatigue is a state of exhaustion caused by insufficient rest. It occurs when sleep is short, the body is taxed by strenuous exertion, a long work shift or when flying through several time zones. Short-term fatigue is quite easy to detect and easy to eliminate. All a pilot needs to do is rest and sleep well for a few days.

Long-term fatigue is a type of fatigue is harder to recognize. The pilot is also negatively affected by situations that do not only happen at work, i.e. during flight planning or the actual execution of the flight, but long-term fatigue can be caused by long-term exposure to stress, such as problems at home, in a marriage, health problems of a loved one or financial problems. With this type of fatigue, it depends on the personality of each individual individually, because someone can withstand such situations for much longer than a person who is very sensitive. If a pilot suffers from long-term fatigue, he should stop flying for some time.

The feeling of fatigue should be detected and evaluated by the pilot in the first place and it is best to cancel the flight completely if this condition is felt before the flight. Unfortunately, we are in a time when pilots are afraid of sanctions and subsequent termination of employment and therefore prefer to board the aircraft tired and hope that fatigue will not adversely affect the safety of the flight. In pilot training, in turn, students are afraid to tell instructors that they will not fly in the morning if they are not sufficiently rested and sleepy due to social activities the night before. The feeling of fatigue manifests itself in various ways, namely: lack of attention, impaired motor skills, narrowed eyes, head dropping, impaired focus, slower reactions, memory problems, sudden mood changes, an increase in errors while piloting, or tunnel concentration - paying attention to only one problem and not noticing others.

Sleep is a basic physiological need of humans. When there is insufficient rest and sleep, this deficiency begins to affect the human body through stress, nervousness, anxiety, poor memory, impaired concentration, slowed metabolism, or a weakening of the entire immune system. From this point of view, it is important to have a good quality sleep so that we can work, react or make decisions the next day without any feelings that could interfere with these activities.

In a profession such as being an airline pilot, it can be very challenging at first to get used to the variable working hours and especially the rest time between flights. If a pilot takes a night flight he comes to his room in the morning and goes to sleep. This changes his biological rhythm. The human body is a diurnal mammal and therefore our bodies are set up so that we should be asleep at night and awake during the day, which is why some pilots may have trouble falling asleep even when they are tired.

External factors that cause sleep problems are such as taking medications, noise from outside or surrounding rooms, phone calls, electromagnetic appliances near the body, or the negative feeling of a temporary apartment room.

Air transport is unique and the most widely used, mainly because of the fast transportation of passengers or cargo over long distances. The longest flights pass through several time zones which can cause sleep problems for the crew and consequently health problems with stomach disorders called jet lag or circadian dysrhythmia. Flying eastward makes acclimatisation and adjustment to the current local time worse. This effect is mainly related to the production of melatonin, which is produced in the brain during the night and then gives us information about when we should go to sleep.

Determining the cause of a civil aircraft accident is very important for the analysis of accidents from a safety point of view, on the basis of which new regulations, guidelines and recommendations are established to prevent similar accidents in the future.

Caffeine is a xanthine alkaloid that is found in commonly available plants such as coffee and cocoa beans, tea leaves, kola nuts or in guarana berries. Caffeine can be called a drug that is not only allowed in air travel but also in other modes of transport. It is mainly used in the form of liquid products for consumption, such as coffee or energy drinks, which are popular all over the world, but it also finds use in pharmaceuticals. Caffeine specifically stimulates adenosine receptors in nervous tissues and the brain. This achieves a state of alertness and activity. Adenosine is a substance found in the human body that regulates the brain activity of wakefulness and sleep.

Caffeine intake does not have a negative effect on a healthy human body, just the opposite is true and according to recent studies caffeine has a positive effect on the human body when consumed in smaller amounts. For more caffeine-sensitive individuals, there is a risk if the daily dose exceeds 300 mg. According to medical studies and research, caffeine causes a risk of minor heart attacks in these people. Younger people or people who are not used to ingesting larger amounts of caffeine may experience short-term behavioural changes such as irritability, anger, nervousness, anxiety or excessive activity.

The right amount of caffeine ingested into the human body has a positive effect that improves the alertness, mind and coordination of the body. It is approximately 100-600 mg of caffeine. However, there is a risk where even a small amount of caffeine can affect even a healthy body's fine motor skills or concentration. When ingested in excess, caffeine causes insomnia, rapid breathing or induces shivering. With regular intake of this substance, the body builds up a tolerance to the negative effects. Caffeine also exacerbates the release of adrenaline and cortisol, causing blood pressure to rise and the heart to beat faster. It causes a feeling of need to urinate, relaxes the bronchial tubes, speeds up metabolism and increases the production of digestive juices.

Energy drinks are a recent trend, especially among young people, and form an almost daily part of their lives. We can already see these drinks in primary school children, where it can have the greatest negative impact on their attention and behaviour. They are also being used in motoring by drivers who are tired when driving for long periods of time. The two main substances that make up these drinks are sugar and caffeine. Sugar is supposed to provide energy and caffeine to suppress fatigue. A normal 250ml can of an energy drink such as Redbull contains 80mg of caffeine, that's the equivalent of almost two coffees, which suggests that there is not much risk in consuming one can. The problem can arise if more than one can is consumed in a short period of time or when combined with alcohol. Excessive consumption can cause insomnia, contribute to obesity caused by the high sugar content of unhealthy lifestyles and low levels of exercise, depression, cardiac arrhythmia or the increase in blood pressure caused by the substances taurine, guarana, various plant extracts or B vitamins that are added to energy drinks.

6. REACTION TIME

There is a period of time from when the pilot notices the stimulus, recognizes it, to when he performs an action. But reaction time can be affected in terms of not only how quickly the pilot executes his decision but whether he executes it correctly. The reaction time may therefore be longer before the pilot recognises the impulse and then makes a decision, which he must first think about and also consider the consequences it may cause.

Attention is the ability of a person to focus on one or more events or objects at the same time. The role of attention is to send only a certain amount of information to consciousness. It has a protective function, so that the brain is not overwhelmed by a lot of information, but concentrates only on the significant ones. We can divide it into active, which is purposely focused on an object, and passive, which draws our attention.

We divide the factors that influence attention either positively or negatively into external and internal. External factors include those that pull our unintentional attention such as: stimulus length, size, strength, non-anticipation of the stimulus, and so on. Internal factors include the overall mental and physical state, i.e., mood, interests, expectations, and so on.

Selective attention is a type of attention in which a person tries to focus on one particular action or object. With this type, there is an advantage that the pilot would be able to fully devote himself to one task. He does not perceive the other information that is happening in his surroundings so he loses track of the things and events that are happening in his surroundings. Selective attention is therefore not used in the aircraft, but on the contrary, it can cause a dangerous situation. Such attention occurs when the pilot concentrates on one activity, for example, steering the aircraft on the correct course according to the instruments, but does not perceive what is happening around the aircraft or on the instruments on the dashboard.

Pilots use this type of attention to pilot the aircraft correctly and safely. It is attention that is divided over several events or objects at the same time. During flight, the pilot receives a great deal of information from different quarters, which he must process and evaluate. Although full concentration on one particular action or object decreases with diffuse attention, it is essential for the pilot. An example of diffuse attention is flight, where the pilot manually controls the aircraft while having to communicate with air traffic control, adjust and check instruments, record time data, and much more. If he gets stuck at some point and goes into selective attention where all his attention is only on that problem, there is a problem with other events such as deviation from the correct course, altitude change, etc.

A type of remembering information and storing it in long-term memory is intended for later use of that information. Storing or encoding information is forever, but sometimes there may be a problem with recalling it due to prolonged unusability. Therefore, information should be continuously refreshed and recalled. If we refresh it regularly, we will remember it more quickly. Information is better and more quickly stored in our memory if it has some connection to information we have already acquired, or if we can make that connection, for example with foreign words that are harder to remember.

Civilian aircraft are predominantly piloted by a crew of two, i.e. a commander and a co-pilot. Before the flight, they determine which pilot will be the flying pilot and the other will be the monitoring pilot and will also communicate with the air traffic controller. Therefore, in order to improve the safety of air travel, NASA devised a concept in 1979 to help reduce the accident rate of transport aircraft. They called this concept CRM - Crew Resource Management. It is the precise division of cockpit activities between pilots, mutual cooperation and control. Currently, there is a lot of emphasis on this type of crew training. If a pilot shows signs of fatigue, with this model the co-crew member could be able to detect pilot fatigue, for example by long response reactions.

7. RESEARCH METHODOLOGY

The aim of the practical part of the thesis is to find out how much fatigue can affect the reaction time to visual cues from the instruments on the cockpit dashboard. From a safety and financial point of view, it is not possible to perform these experimental flights in a real aircraft, but only on the cockpit simulator of a Flight L-410 Turbojet.

The measurements were carried out on the L-410 UVP-E20 simulator operated by the Training and Education Centre of the University of Žilina in Žilina at the airport in Dolný Hričov. The simulator has a fully controllable glass cockpit for a two-person crew and a control centre for simulating various situations, through which we will change the visual cues to the pilots. The simulator is an exact replica of the real cockpit of the Flight L-410 UVP Turbolet and therefore in 1:1 scale. The simulator has a simulation of two turboprop engines, their control with the possibility of reverse thrust. This simulator is certified and complies with all EASA regulations applicable in the Slovak Republic.

A total of 8 pilots with varying numbers of flight hours participated in the measurement. All of them are students in training. Most of them have already graduated by instrument flying. They have flown between 95 and 210 flight hours. The age range is from 21 to 26 years old. It is important to note, however, that none of the pilots have an official rating or professional training in that type of aircraft.

TABLE I. INFORMATION ABOUT TESTED PILOTS

Pilot	**Age**	**Number of hours flown**
1.	23	170
2.	23	175
3.	22	170
4.	21	210
5.	26	95
6.	25	215
7.	24	100
8.	25	200

After informing the test pilots prior to the flight, it was agreed that if they detected any visual warning or instrumentation change on the dashboard, they would point the finger at the fault. This agreement facilitates the subsequent analysis of the videos from the two cameras located in the simulator. These cameras are located at the top of the cockpit and facing each other. One records the general movement and behavior of the pilots and the other is pointed at the entire instrument panel. These cameras do not have an audio recorder. Therefore, a method of finger pointing to a given instrument or alert has been agreed with the pilots.

The video will be analysed in the Sony Vegas computer program, which will provide us with a timeline below the visual preview of the video, which can be used to accurately determine the length of the reaction time. The video will be easily comparable to the timeline as the program can accurately compare the video frames to the timeline. The second method was used directly during the conduct of the research in question by using stopwatch measurements, but after subsequent analysis of the data, this method was judged to be insufficient.

We selected indications for visual cues from different parts of the dashboard to gauge the test pilot's attention and insight. We first illuminated the pilot with the battery overheating indication. This indication is located on the left side of the instrument panel, is lit red, and consists of a pair of rectangular indicator lights. Second, we illuminated the pilots with the right engine low oil pressure indication, which glows amber and is located in the upper right portion of the instrument panel. Third, we deactivated the left engine torque needle indicator, which manifested itself by the needle in the instrument dropping to zero or showing no value. The detailed layout is shown in the following figure.

Figure 3 Cockpit

8. RESULTS

The first measurement was taken in the morning, at approximately 8:30. The pilots tried one short flight around the circuit to get familiar with the simulator controls. Then their reaction time measurements started. Pilots 6 and 7 had slept for 5 hours and the others stated that they had slept for approximately 8 hours. According to the measured values, we can see that the pilots had the biggest problem in the morning to detect the problem of the needle instrument indication, or they did not pay attention to the needle instruments at all.

TABLE II. MEASURED TIME IN THE MORNING

Pilot	**Overheating of batteries** [s]	**Decrease in pressure** [s]	**Torque** [s]	**Length of sleep** [h]
1.	0:19	0:02	0:04	8
2.	1:32	0:23	0:05	8
3.	0:03	0:06	0:04	8
4.	0:04	0:01	0:02	8
5.	0:05	0:06	0:04	8
6.	0:02	0:02	0:04	5
7.	0:03	0:45	1:14	5
8.	0:10	0:18	0:56	8

The second measurement was carried out in the afternoon when the pilots were fed after lunch.

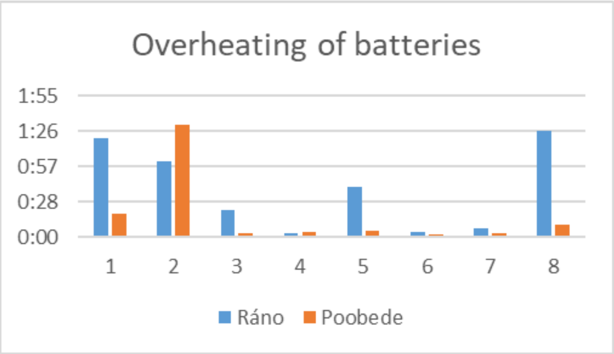
TABLE III. MEASURED TIME IN THE AFTERNOON

Pilot	**Overheating of batteries** [s]	**Decrease in pressure** [s]	**Torque** [s]	**Length of sleep** [h]
1.	1:21	0:02	1:11	8
2.	0:02	0:35	1:44	8
3.	0:22	1:34	2:19	8
4.	0:03	0:17	0:22	8
5.	0:41	0:02	0:04	8
6.	0:04	0:03	0:03	5
7.	0:07	0:10	2:42	5
8.	1:27	0:02	2:35	8

Comparison of the results shows that in the second measurement, although the pilots may have been more fatigued, their reaction time was more consistent and faster, especially when checking the needle instruments. Another possibility is that the pilots may even have been more tired in the morning than in the afternoon, which is due to the body not being sufficiently awake from sleep, and this is what prolonged their reaction time. Ignorance of the instruments and poor cockpit orientation had a big influence on the measurements. On the second measurement the pilots knew what to expect and this may have been what helped them to reduce their reaction time so much on some indications compared to the first measurement.

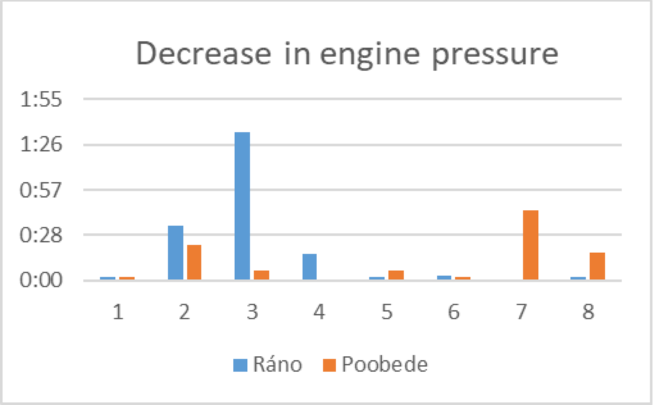
During the measurements we also noticed one shortcoming that the pilot made and that was that the pilot did not detect the wrong values of the given indicator even after visual checking.Perhaps this reaction of the pilot was also caused by fatigue, when the pilot checked the instruments by just looking at them, but did not think about them at all. Alternatively, other factors associated with fatigue, as mentioned in the theory (tunnel vision, distraction, etc.), may have contributed to his error rate.

Each of the simulated errors was specific. The first one was red and in the pilot's field of view, so it should have caught his attention earlier. However, according to the following graph, we can analyse that the simulated fault that had an orange indication attracted the pilots' attention faster, even though it was out of their field of view. The high values for the simulated battery overheating fault in the morning hours are due to the fact that pilots are not used to this kind of fault and therefore did not even notice the red-light indication.



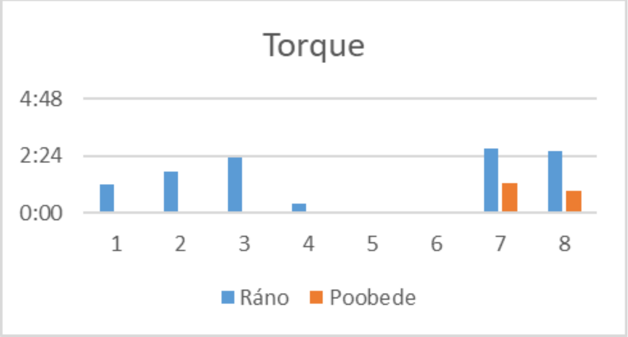
Graph 1. Overheating of batteries

The error that was associated with the amber warning light caught the attention of the pilots the fastest, which is why we can see such fast reaction times on the graph for almost all of the pilots tested. Pilots 7 and 8 may have started to experience tunnel vision in the afternoon, which is caused by fatigue.



Graph 2. Decrease in engine pressure

Thus, the attention reaction time graph for a malfunction where the pilot received no colour alert lasted considerably longer. Unlike the previous indications, no colour is used and therefore it is more difficult for pilots to get their attention. However, the pilot should continuously check all the instruments and the readings on their indications so that his attention is evenly distributed. In this case in particular, the pilots' reaction time was longer compared to previous errors, which may cause considerable problems in the future. Therefore, pilots should focus on the correct distribution of attention and regularly monitor all instruments.



Graph 3. Torque

The combination of inadequate training with fatigue can result in excessively long reaction times, which in some cases can lead to tragic consequences.

9. CONCLUSION

In the thesis we tried to find out to what extent fatigue can affect the reaction time of a pilot. It all depended on attention, which is what fatigue affects the most.

In the beginning, we focused on the current situation in terms of aviation safety, where we analyzed the decreasing accident rate caused by pilot error. We also analysed research by other experts on the same topic. They concluded that reaction time speed increases approximately and spatial orientation decreases after the age of 40.

In the chapter on psychological aspects, the human nervous system is described, which is the control system of the entire organism of the human calf and thus transfers stimuli received from the external environment by means of the sensory organs to the brain. From this point of view the different sense organs are explained in detail. Sensory organs like sight and hearing are indispensable for piloting a transport aircraft and therefore pilots must be in hundred percent health both physically and mentally. In order to make the harmony work between the human factors with each other and with the machine, which in our case is the aircraft, the SHELL model was invented and put into practice. The decision-making process is influenced by various factors such as attention, stress, knowledge, experience or, for example, increasing age. In this chapter we have tried to summarize the whole process of decision making, from the initial impulse the pilot receives to some of his reactions, whether right or wrong. Cockpit ergonomics is developing and moving forward very rapidly in the aviation industry. Outdated instrument panels with analog instrumentation are slowly disappearing and being replaced by modern electronic screens. Pilots must therefore adapt to these changes and undergo new training on these new systems on board transport aircraft.

Fatigue is one of the factors that negatively affects air transport safety, especially for pilots. For this reason we have chosen this topic, which some pilots underestimate and overestimate their strength. If a pilot is tired and makes a bad decision in the simulator, nothing will happen to anyone, he will only be warned and he will be careful the second time, but if he makes a mistake during the flight when he is in a single-pilot aircraft, i.e. alone, it can have fatal consequences. He may harm not only himself and possibly some passengers he has on board, but also the people on the ground. Quality sleep or sufficient rest is essential. The pilot should enter the cockpit of the aircraft for the intended flight rested. Fatigue is a feeling of exhaustion and lack of rest that is difficult to detect by another person if they have only interacted with the pilot for a short time. He or she would have to spend more time with him or her and notice a yawn, subtly impaired body motor skills, or reduced attention when communicating together, for example. Caffeine provides a supportive substance that has the ability to suppress the feeling of fatigue and provide energy for a certain period of time. Its positive and negative effects are discussed in the next section of the thesis. The analysis and investigation of fatal accidents where pilot fatigue was part of the cause of the accident is important to prevent similar disasters in the future. In this thesis we have mentioned 3 transport aircraft accidents. Legal regulations are also broken down, giving the exact maximum time a pilot can spend at work, or the minimum amount of rest a pilot must take.

In the fourth chapter we have broken down information about reaction time and the difference between short-term and long-term memory. Also important is the cooperation between pilots and the exact division of the tasks to be performed so that there is no chaos between pilots. This cooperation between pilots is called CRM.

The measurements were carried out on a Flight L-410 Turbolet simulator from a safety point of view. During the measurements and their evaluation we came to the conclusion that creating conditions like in a real aircraft and then measuring the reaction time affected by fatigue is not as easy as it may seem at the beginning. This was influenced by factors such as the pilot's not being very familiar with the aircraft itself and the cockpit indications, the limited time for the research between 8 am and 4 pm. It is at night that fatigue affects pilots' attention and reaction time the most. Also, the pilots were not as tired in a few hours in the simulator as they would have been if they had been piloting the aircraft for, say, six hours, but even the repeated indication of a given error reduced their reaction time quite a lot, as they knew what was coming and were not caught off guard and surprised as they would be during a normal flight when it might occur.

As a recommendation, we would therefore suggest that pilots get sufficient rest and thorough preparation before the planned flight and do not overestimate their strength. In particular, a good quality and especially regular pilot training, where pilots regularly repeat and practice their knowledge and experience, has a positive effect on reaction time and decision making.

REFERENCESS

[1] Air Accident Statistics [online]. Available on the Internet: http://planecrashinfo.com/cause.htm

[2] WERNER, B. a kol. 2002. Rate of information processing and reaction time of aircraft pilots and non-pilots [online]. Available on the Internet: https://www.researchgate.net/publication/47739375_Rate_of_information_processing_and_reaction_time_of_aircraft_pilots_and_non-pilots

[3] RUSSO, M. a kol. Únava a vyčerpanie pilotov [online]. Available on the Internet: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.215.465&rep=rep1&type=pdf

[4] JANCO, M: Reakčná doba vodiča. 2018 [online]. Available on the Internet: https://marceljanco.sk/reakcna-doba-vodica/

[5] Human factor [online]. Available on the Internet: https://e.dennikn.sk/82487/ktora-cast-letu-je-rizikova-co-sposobi-najviac-nehod-pozrite-si-cisla/

[6] KŘÍŽ, J a kol. 2001. Ľudská výkonnosť a jej obmedzenia: Žilinská univerzita v Žiline: Veda, 2001 212 s. ISBN 80-8070-215-2

[7] NEJEZCHLEB, M. a kol. 2016. Učebnice pilota 2016. Cheb : Veda, 2016. 408 s. ISBN 978-80-87567-89-0

[8] HANTABÁLOVÁ, I. a kol. 2001. Prírodopis pre 7. ročník základných škôl. Bratislava: Veda, 2001. 91 – 98 s. [online]. Available on the Internet: https://oskole.detiamy.sk/clanok/zmyslove-organy-zrakovy-organ

[9] Sensory organs - ear. [online]. Available on the Internet: https://biopedia.sk/clovek/zmyslove-organy

[10] Sensory organs - ear. [online]. Available on the Internet: https://www.medel.com/sk/anatomy-of-the-ear/

[11] [FANČOVIČOVÁ, J. – Prokop, P. 2010. Biológia človeka pre učiteľské kombinácie s biológiou. Trnava : Veda, 2010 112 – 136 s. ISBN 978-80-8082-398-6

[12] AYERS, S. – DE VISSER, R. 2011. Psychology for Medicine. Londýn : Veda, 2011. 568 s. ISBN 978-1-4129-4691-9

[13] Stress load [online]. Available on the Internet: https://charitatt.sk/wp-

content/uploads/2020/05/psychologicke-intervencie-NSSDR.pdf

[14] Stress. [online]. Available on the Internet: https://dennikn.sk/1174977/neurovedkyna-o-strese-kedysi-nas-nahanal-mamut-dnes-nas-nahanaju-deadliny/

[15] POSPÍŠILOVÁ, J. 2014. Stres u vojenského personálu vrtulníkové základny: diplomová práca. Olomouc: Univerzita Palackého v Olomouci, 2014. 189 s.

[16] FUJAČKOVÁ. H. 2017. Analýza obvyklé doby pozorování specifických objektů řidičem: diplomová práca. Brno: Vysoké učení technické v Brně, 2017. 94 s.

[17] Sleep. [online]. Available on the Internet: https://www.vyspimesa.sk/article/sk/poznate-vsetky-fazy-spanku

[18] Jet-Lag [online]. Available on the Internet: https://www.dlr.de/me/en/desktopdefault.aspx/tabid-2023/2958_read-4535/

[19] Circadian rhythms [online]. Available on the Internet: https://fns.uniba.sk/fileadmin/prif/biol/kzf/media/2019/Moje_Zdravie_10_2019_CIRKADIANNE_RYTMY_profesor_Zeman.new.pdf

[20] Flight duty period [online]. Available on the Internet: https://www.easa.europa.eu/sites/default/files/dfu/EASA_2012_00120001_SK_TRA.pdf

[21] Flight duty period [online]. Available on the Internet: https://understandingeasa2016ftl.wordpress.com/easa-ftl/oro-ftl/oro-ftl-205-flight-duty-period-fdp/

[22] Flight duty period [online]. Available on the Internet: https://luftfartstilsynet.no/globalassets/dokumenter/regelverk/ftl-consolidated.pdf

[23] Flight duty period [online]. Available on the Internet: https://www.transportstyrelsen.se/globalassets/global/luftfart/flygoperativt/fc-am-seminarium-2010/max-fdp-tabeller.pdf

[24] Rest time [online]. Available on the Internet: https://far117understanding.com/tag/wocl/

[25] Caffeine [online]. Available on the Internet: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5788283/

[26] Caffeine [online]. Available on the Internet: https://www.zdravie.sk/clanok/44590/kofein-zdravy-alebo-skodlivy-pre-nase-zdravie

[27] Energy drinks. [online]. Available on the Internet: https://hnonline.sk/prakticke-hn/849109-test-energetickych-napojov

[28] Energy drinks. [online]. Available on the Internet: https://www.redbull.com/sk-sk/energydrink/red-bull-energy-drink-prisady

[29] JAKUBEKOVÁ, I. 2014. Pozornosť. [online]. Available on the Internet: https://www.mentem.sk/blog/pozornost/

[30] CRM training [online]. Available on the Internet: https://imagelab.sk/riesenia-pre-vas/unikatne-produkty/crew-resource-management/

[31] Univerzitný vedecký park Žilinskej univerzity v Žiline – Simulátor leteckej dopravy

[32] NOVÁK SEDLÁČKOVÁ, A., PITOR, J., MRÁZOVÁ, M. 2015. Crisis management in aviation. 1. vyd. - Bratislava : DOLIS, 2015. - 152 s., ilustr. - ISBN 978-80-8181-000-8.

[33] NOVÁK, A., TOPOĽČÁNY, R., BRACINÍK, T. 2009. Výcvik leteckých posádok s využitím nových technológií. Žilinská univerzita, Fakulta prevádzky a ekonomiky dopravy a spojov, 2009. - 94 s. ISBN 978-80-554-0108-9.

[34] AŽALTOVIC, V., ŠKVAREKOVÁ, I., PECHO, P., KANDERA, B. 2020. The correctness and reaction time of piloting the unmanned aerial vehicle. Transportation Research Procedia, 2020, 51, pp. 342–348. ISNN 23521457.

[35] ROSTAS, J., KOVACIKOVA, M., KANDERA, B. 2021. Use of a simulator for practical training of pilots of unmanned aerial vehicles in the Slovak Republic. ICETA 2021 - 19th IEEE International Conference on Emerging eLearning Technologies and Applications, Proceedings, 2021, pp. 313–319. ISBN 978-166542102-7.

https://doi.org/10.26552/ pas.Z.2022.2.12

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DESIGN AND IMPLEMENTATION OF THE AEROBATIC FUEL SYSTEM OF THE M60 ENGINE

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Abstract

The paper deals with the specific modification of the M60 two-stroke engine so that the engine can be used in aerobatic conditions. In the introduction of the paper, the basic theory concerning piston two-stroke engines, the principle of operation of this engine, and the analysis of individual fuel systems is first discussed, with a focus on fuel injection systems and their components. Furthermore, the preparation of the fuel mixture is characterized together with the factors affecting it and also the basic characteristics of the engine control unit. In this way, the reader will gain the knowledge necessary for a better understanding of the following chapters. The motivation is to find a way to modify the non-aerobatic engine for the needs of aerobatic flight, and this modification includes a number of important advantages over the original fuel system design mentioned in the paper. At the core of the paper, we discuss the design of the fuel system, including important modifications, and also the practical implementation of this fuel system on the engine mentioned above. At the end of the paper, we evaluate the results of the work achieved by changing and modifying the fuel system on the M60 engine, including the achievement of the set objectives.

Keywords

Piston engine, Carburettor, Direct injection, Indirect injection, Mixture preparation, Two-stroke engine, Intake manifold, Fuel system,

1. INTRODUCTION

Technical developments have enabled advances in all areas of aviation, leading to developments in reciprocating internal combustion engines as well. The high demands associated with aerobatics have also been transferred to the technical advances in aircraft engine fuel systems. It is this topic that is addressed in our paper, which aims to design and implement an aerobatic fuel system for the M60 engine.

In addition to the main objectives, sub-objectives are also elaborated in the paper, which enables progress towards the fulfilment of the main objectives. Motivation for us is the work on the piston engine, the practical implementation including the design and the possibility of creative thinking. The aim of the work is to rebuild the original fuel system, which did not meet the requirements for aerobatic flight, and to design a new one that would meet the requirements.

The paper discusses the problems of individual fuel systems, including important components. Attention is also given to the preparation of the fuel mixture and the factors affecting it. The described issues are important for further elaboration of the work. The main part of the work consists of the preparation of the design of the aerobatic fuel system as well as the actual practical implementation of the M60 engine. The paper describes the solution of problems and complications that occurred during the implementation.

2. OPERATING PRINCIPLE OF A TWO-STROKE ENGINE

More four-stroke engines than two-stroke engines can be found in today's aircraft piston engines. This does not mean that two-stroke piston engines have disappeared completely. The choice of the four-stroke engine in the aviation sphere is linked to the advantages such an engine brings. Considering the objectives and the nature of this paper, it is the issue of two-stroke engines that will be discussed in this chapter.

2.1. Two-stroke engine cycle

The two-stroke piston engine, as the name implies, operates in two periods, so the piston performs exactly two strokes. Unlike a four-stroke engine, the entire working cycle is completed in one turn of the crankshaft, but the cycle is still made up of intake, compression, ignition combined with expansion and finally exhaust. These four processes happen in just two strokes of the piston. [1]

2.2. Basic characteristics of the M60 engine

The M60 engine was designed and manufactured in the 1990s by Aeromot Brno. It is a reciprocating two-stroke four-cylinder engine with opposed cylinders with a power of 58 kW (kilowatt), i.e. 80 HP (horsepower). The fuel system consists of a pair of diaphragm pumps that provide fuel delivery from the tank. The pumps supply fuel to two float carburettors which are mounted on top of the engine near the diaphragm pumps. Each carburettor delivers fuel through a common intake manifold to the two cylinders. There are a total of two throttle valves in both intake manifolds below the carburettors, which are operated manually by means of a common throttle rod. Flushing and filling of the cylinders are handled by a sleeve valve through the inlet and exhaust ports. With a power output of 58 kW, the engine operates at 2250 rpm (revolutions per minute) - propeller speed. However, the recommended cruise power is 40 kW and 2000 rpm. [2]

3. FUEL SYSTEMS

Fuel systems are a complex system of delivering fuel from the tank to the engine cylinder so that the engine runs continuously and efficiently over a specified speed range. Efficient engine operation depends on the proper preparation of the fuel mixture. [3]

The preparation of the fuel mixture is provided by special equipment. With these devices, the required amount of air and fuel is supplied to the cylinder so that the engine runs continuously under specified conditions. There are several types of fuel mixture preparation equipment, which we will describe next. [3]

3.1. Carburettor

A carburettor is a device for preparing a mixture of air and fuel. It is an evolutionarily older type of mixture preparation device that is less frequently used nowadays and is being replaced by more modern injection devices. However, the carburettor still appears in small engines with lower power outputs as it is a cheaper and simpler mixture preparation device. [4]

3.1.1. Diaphragm carburettor

In principle, the diaphragm carburettor is no different from other carburettors. The difference lies only in the mechanism for maintaining the fuel level in the fuel chamber by means of a diaphragm. This diaphragm is flexible and folds due to the pressure difference. The diaphragm is connected to the needle valve by a lever mechanism. In the event of a vacuum in the fuel chamber caused by the fuel being drawn into the mixing chamber, the diaphragm will fold to the fuel chamber side due to the pressure difference in the fuel and air chambers. The deflection of the diaphragm is transmitted via a lever mechanism to the needle valve which begins to discharge fuel into the fuel chamber. This causes the pressure in the fuel chamber to rise, the chamber pressures equalize, the diaphragm returns to its neutral position and the needle valve closes due to the action of the spring. When the carburettor is working, the diaphragm is continually moving, and the valve accordingly lets through the necessary amount of fuel. [5]

Such a diaphragm carburettor can also be used for aerobatic purposes, however, it is not used much nowadays. It can still be found on older aerobatic aircraft. Thanks to the diaphragm mechanism, the fuel supply to the fuel chamber and the operation of the carburettor are ensured, independently of the engine or carburettor position. [6]

3.2. Fuel injection system

Due to the more demanding requirements placed on engine economy, fuel injection is nowadays used, which allows for more even fuel dispersion, a more homogeneous mixture, better fuel metering and reduced fuel consumption. There is also no need to worry about carburettor priming and the necessary carburettor heating. The injection also puts less strain on the environment, as combustion is more perfect, resulting in less harmful substances in the exhaust gases. [1, 7]

As we focus on aircraft piston engines, it is important for us to ensure smooth operation of the engine, even when changing its position. However, this requirement cannot be met in piston engines with a conventional float carburettor (the exception is the use of a diaphragm carburettor). On the contrary, the fuel injection system allows the engine to run continuously even when the engine is repositioned, but there are other conditions that must be met. [6]

3.2.1. Direct fuel injection

If the fuel is injected directly into the cylinder, we speak of direct injection. This solution is very efficient in terms of performance as the fuel is sprayed directly into the combustion chamber and there are no hydraulic losses. On the other hand, direct injection requires an elaborate system to inject the fuel under high pressure. This pressure is needed to best disperse the fuel in the air in the combustion chamber. However, such a solution is considerably expensive and difficult to maintain. [7, 8, 9]

3.2.2. Single-point fuel injection

Single point fuel injection is the first option to inject fuel into the intake manifold. Fuel is injected into the intake manifold from a single point via an injection nozzle. The location of the injection nozzle corresponds to the location of the carburettor, which means that the fuel is injected upstream of the throttle body into the air stream, with the injection nozzle positioned perpendicular to the base of the throttle body. The fuel is injected intermittently based on engine speed and pressure in the intake manifold downstream of the throttle body. In addition to these two quantities, other quantities such as the amount of air intake and the position of the throttle valve may be used. The amount of fuel injected is controlled by the time the injection nozzle is open and also by the fuel pressure. The fuel pressure supplied by the fuel pump must be constant. [9, 10]

The prepared fuel/air mixture flows through the throttle valve through the intake manifold to the intake valve. The intake valve then passes this mixture into the combustion chamber. On two-stroke engines, the prepared mixture enters the crankcase via a check valve in the intake manifold. As the name implies, this type of fuel injection means that the mixture is prepared equally for all cylinders with one common intake manifold. [1]

3.2.3. Multi-point fuel injection

The second option for indirect injection is multipoint fuel injection. This type is slightly more complex compared to single-point injection because each cylinder has one injection nozzle. The difference also lies in the location of the injection nozzles, which inject the fuel in front of the intake valve, i.e. behind the throttle body. Also different is the intake manifold, which is branched according to the number of cylinders in the engine and includes a fuel ramp that feeds fuel under pressure towards the injection nozzles that are located on it. The fuel is injected continuously or intermittently. The advantage of this type is better fuel mixture formation and uniform filling of the individual cylinders of the engine. [9]

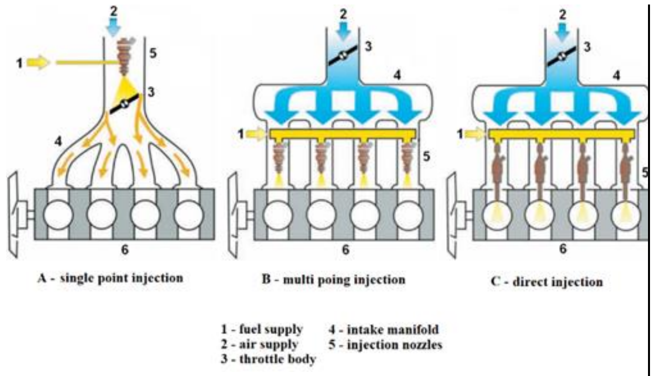

Figure 1: Comparison of different types of injection [11]

Fuel can be injected intermittently, in which case we speak of timed injection or electronically controlled fuel injection. The fuel pump feeds the fuel through a fuel ramp that distributes it to the injection nozzles and creates positive pressure. In this case, however, it is already electromagnetically controlled injection nozzles that can inject a precisely defined amount of fuel at precisely defined time intervals. The instruction to open and close the injection nozzle comes from the engine control unit, based on data such as the pressure in the intake manifold downstream of the throttle body, the engine speed or the intake air temperature. There are three types of timed injection into the intake manifold. Simultaneous, group and sequential injection. [9, 10]

3.2.4. Simultaneous fuel injection

The simultaneous injection is a type of injection where all injection nozzles inject fuel at the same time. Thus, for all cylinders, fuel is injected simultaneously, during each revolution of the crankshaft. Thus, fuel is injected exactly twice in one working cycle, with the injection rate being half of the total amount of fuel required. The injection also takes place when the intake valves are closed. The injected fuel remains in the intake channel until the intake valve is opened. [10]

3.2.5. Group fuel injection

Group injection consists of combining the injection nozzles into two groups. The number of injection nozzles within one group depends on the number of cylinders of the engine. In the case of a four-cylinder engine, there are two groups of two injection nozzles, in the case of a six-cylinder engine there are two groups of three nozzles. The injection nozzles within one group are connected in parallel and therefore open simultaneously. Within one group, fuel is injected into the cylinders whose operating cycles are consecutive. Injection into the intake manifold takes place once per complete working cycle and the injection nozzle opening time corresponds to the required amount of fuel. [9, 10]

3.2.6. Sequential fuel injection

In sequential injection, fuel is injected only into those cylinders which subsequently undergo an intake stroke. The injection nozzles operate individually depending on the position of the crankshaft and camshaft. The crankshaft position signal is not sufficient because the injection is linked to the opening of the intake valve, which opens only once during two turns of the crankshaft. The control unit is, therefore, unable to distinguish whether an intake or an expansion stroke is taking place. For this reason, the position of the camshaft must also be sensed, by which the control unit can already distinguish which stroke is involved. The length of the fuel injection corresponds to the required amount of fuel. Compared to the previous two injection types, this type of injection is the most complex, but at the same time the most sophisticated in terms of mixture formation, performance, consumption and exhaust gas ecology. [10, 12]

3.3. Injection system components

Compared to carburetted piston engines, fuel injected engines are more complex. Whether it's fuel injection into the combustion chamber or the intake manifold, both of these systems require equipment to ensure the continuous operation of the engine. In particular, we are talking about injection nozzles and fuel pumps. [10]

3.3.1. Injection nozzle

The injection nozzle is the end component of injection systems. It may be located in the intake manifold above or below the throttle body or in the immediate vicinity of the combustion chamber. It depends on which injection system it is part of. The closer it is placed to the combustion chamber, the more pressure must be applied to atomise the injected fuel, as it is necessary to form a homogeneous mixture. Control of the injection nozzles can be provided mechanically or electromagnetically. [15]

The mechanically operated injection nozzle is opened and closed by fuel pressure. The fuel pressure is provided by the fuel injection pump. The opening of the nozzle occurs when the fuel pressure causes the spring to be compressed, which extends the nozzle needle and allows fuel injection. The extended needle returns to the nozzle seat when the pressure drops. The mechanically operated injection nozzle can be used for continuous fuel injection. [15]

The electromagnetically actuated injection nozzle is more represented nowadays. Its opening and closing are controlled by the engine control unit by an electrical signal. Structurally, this type of nozzle is more complex than the mechanically actuated injection nozzle. It usually consists of a nozzle body with an internal solenoid winding, an electrical supply and a needle mounted on the seat. Unless an electrical signal is applied to the injection nozzle, the needle remains seated in the seat pressed by a spring and the fuel passage is closed. If an electrical signal is applied to the solenoid winding, the needle is raised and fuel flows through the gap in the seat. [10]

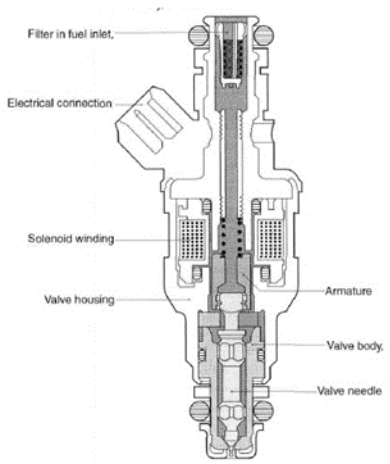

Figure 2: electromagnetically controlled injection nozzle [14]

3.3.2. The fuel pump

Fuel pumps work by delivering fuel from the tanks to the engine. They are therefore a very important part of fuel systems. For piston engines with a carburettor, diaphragm pumps have usually been used. These are pumps with a mechanical drive from the engine itself, which were used to deliver fuel from the tanks to the carburettors. [15]

In addition to mechanical pumps, there are also electric pumps. They differ from each other with regard to the required pressure of the fuel to be supplied and there are therefore several types. Typically, electric pumps are used to supply fuel to indirect injection nozzles. [15]

The design of the electric fuel pump consists of three parts. The connecting lid includes the electrical connection, the check valve and the fuel inlet. The check valve maintains the fuel pressure even after the pump has been switched off. This prevents the formation of bubbles due to increased fuel temperature. The pump's electric motor consists of a system of permanent magnets and armature, which are designed for the required amount of fuel to be conveyed at the specified system pressure. The third part is called the pump part. Both the electric motor and the pump section are housed in a common casing through which the fuel flows. The fuel flow provides their cooling. The main part of the pump section consists of an impeller on the shaft of the electric motor. By rotating the impeller, fuel is drawn from the tank and the necessary pressure is built up. Exceeding the maximum pressure is regulated by a special valve at the pump outlet. [10]

Depending on the type of injection system and its fuel pressure requirement, electric fuel pumps are divided into single-stage or two-stage. Alternatively, two single-stage fuel pumps can be used in succession. The pumps may also differ from each other in their pump section. They are divided into positive displacement and vane pumps. [10]

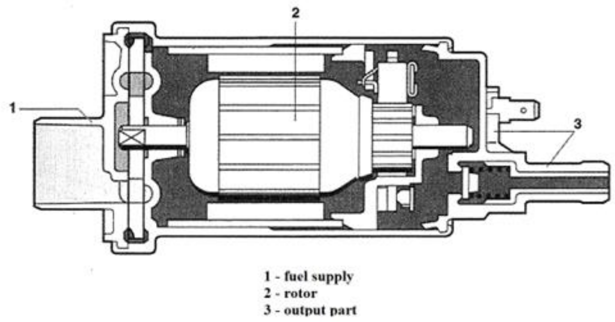

Figure 3: Fuel pump driven by electric motor [10]

4. MIXTURE PREPARATION

In the preparation of the fuel mixture, we start from the basic theory of combustion. During combustion, the chemical energy of the fuel is converted into heat energy. Combustion of the fuel requires oxygen, which is supplied to the combustion chamber in the form of air. This mixture of fuel and air must be in the correct ratio for the fuel to be completely burned. The ratio of air to fuel is determined by calculation, according to the type of fuel that is used. In the case of spark-ignition internal combustion engines, 14,7 kg (kilogram) of air is required to completely burn 1 kg of fuel. Diesel engines are based on a different ratio. [10]

4.1. The stoichiometric mixture

A stoichiometric mixture is a term for a mixture for which a specified ratio is observed. For spark-ignition engines this ratio is 1:14,7. As long as the fuel/air ratio is maintained and the mixture is properly mixed in the combustion chamber, the fuel contained in the mixture can be perfectly burned. During combustion, the hydrocarbons contained in the fuel and the oxygen in the air are converted into carbon dioxide and water vapour. [10]

4.2. Excess air coefficient

The excess air coefficient is used in the preparation of the fuel-air mixture composition. This coefficient expresses the ratio of the amount of air actually supplied to the theoretical amount of air required to burn a certain amount of fuel perfectly. The coefficient is denoted by the Greek letter λ (lambda) and is equal to one for a stoichiometric mixture - $\lambda=1$. It is very important in the preparation of a fuel mixture and by it we can determine whether the prepared mixture is correct, lean or rich. If the mass of air drawn in is greater than the theoretical value, the coefficient of excess air is greater than one ($\lambda>1$). We refer to such a mixture as poor. Conversely, if the mass of entrained air is less than the theoretical value, the air excess coefficient is less than one ($\lambda<1$). We refer to such a mixture as rich because it has excess fuel. [10, 13]

4.3. Measuring the amount of intake air

There are several ways to measure the amount of air intake and this is done with fuel injection systems to create the correct mixture. The amount of air can be measured directly or indirectly. [10]

4.3.1. *Indirect measurement of air quantity*

In indirect air measurement, the amount of air itself is not measured, but is replaced by another parameter that determines the amount of fuel injected. This parameter can be, for example, the position of the throttle valve or the pressure in the intake manifold. In order to achieve the optimum mixture, multiple parameters are sensed. [10, 13]

4.3.2. *Direct measurement of air quantity*

Not only optimisation, but also stringent emission standards have required more precise ways of measuring the amount of air. Direct measurement of air quantity consists of either measuring the volume of air or its mass. Air quantity meters are located in the intake manifold. [10, 13]

4.3.3. *Influence of other parameters on fuel dosage*

Fuel dosing is primarily based on the amount of air. From their ratio the composition of the mixture is determined. However, other parameters such as engine speed, engine temperature or engine load also influence the fuel dosage. These parameters are also taken into account by the engine control unit to ensure optimum engine operation, correct consumption and exhaust emissions. [10, 13]

5. ENGINE CONTROL UNIT

The Engine Control Unit (ECU) is an electronic control unit that represents a complex system for controlling individual components or engine systems. [16]

A. Input data of the engine control unit

- Crankshaft sensor,
- Intake manifold pressure sensor,
- Throttle position sensor,
- Air quantity sensor,
- Lambda sensor and others. [17]

B. Engine control unit functions

- Electronic fuel injection,
- Mixture preparation,
- Ignition system including timing and advance ignition,
- Real-time monitoring and others. [18, 19]

C. ECU MASTER Ignition engine control unit

The MASTER Ignition ECU is a versatile control unit that can be used in several areas. The MAP sensor version of the control unit has an integrated intake manifold pressure sensor. The ECU MASTER unit's ECU functions allow programming of ignition advance control and injection timing for spark ignition engines with both induction and capacitive ignition. The included software program allows real-time monitoring and adjustment of individual engine parameters. We are talking about e.g. engine speed, intake manifold pressure, ignition advance, injection time, measured temperatures and other parameters or values. Adjustment using the software device consists of arbitrary ignition and injection settings The control unit has a number of inputs and outputs that can be used to monitor given parameters and adjust certain functions. [20]

6. OBJECTIVES

A. The main objectives

- Design of aerobatic fuel system for the M60 engine,
- Implementation of an aerobatic fuel system for the M60 engine.

B. Sub-objectives

- A brief introduction to the issue,
- Selection and summary of selected literature sources,
- Analysis of fuel systems,
- Characteristics of individual fuel systems,
- Comparison of selected fuel systems,
- Analysis of factors influencing mixture preparation,
- Characteristics of the engine control unit,
- Elimination of complications arising during implementation,
- Precision during implementation,
- Chronological photo documentation,
- Testing of the new fuel system.

7. DESIGN OF AEROBATIC FUEL SYSTEM FOR THE M60 ENGINE

Since the original fuel system of the M60 engine did not meet the requirement for aerobatic flight, it was necessary and our goal to design a new fuel system for this engine so that the requirement mentioned above was met.

7.1. Fuel system diagram

The fuel system is the supply of fuel from external tanks located e.g. in the wings towards the engine. It consists not only of the tanks themselves, but also of the pipe system through which the fuel flows towards the fuel injection pump. Usually the fuel system is also made up of a number of valves which provide, for example, venting or defueling. The requirement for fuel purity is also very important. For this reason, the fuel system also includes the fuel filter itself, or a system of several fuel filters, which trap unwanted impurities in the fuel as it travels to the combustion chamber. In particular, the injection nozzles of not only direct injection but also indirect injection are susceptible to fuel purity. [4]

7.2. The principle of operation

Such a theoretical design represents fuel delivery from two fuel tanks located in the wings of the aircraft. From these tanks the fuel is conveyed to the central fuel tank using a pair of diaphragm pumps, which originally served to supply fuel to the carburettors. Each diaphragm pump would draw fuel from its own tank. Before entering these pumps, the fuel would be filtered through a fuel filter so as not to damage the diaphragm pump itself and at the same time not to clog the lines or the central fuel tank. The central fuel tank would contain the fuel injection pump itself, or its suction basket, which would be located exactly in the centre of this tank. This would ensure the condition of continuous refuelling even when the position of this tank is changed. The fuel injection pump would supply fuel under pressure to the fuel ramp. Prior to entering the fuel ramp, the fuel would be filtered in a fuel filter so as not to clog the injection nozzles. Injection nozzles mounted in the fuel ramp would inject the required amount of fuel into the intake manifold ahead of the throttle body, based on instructions from the control unit. A mixture of fuel and air would be formed in the intake manifold. This mixture would enter through the intake duct towards the crankcase of the piston engine. The engine control unit is also an important part of this design. Although the control unit is not a direct part of the fuel system, it is essential to its operation. This control unit makes it possible to control the fuel injection electronically through the injection nozzles, based on the vacuum in the intake manifold and the engine speed.

7.3. Central fuel tank

The central fuel tank is a very important component of the aerobatic fuel system because it allows fuel to be pumped into the engine even when the engine position is changed.

A suitable option for us was a plastic round tank often used in the automotive industry as an expansion tank for the coolant mixture.

7.4. Fuel injection pump

The fuel injection pump is an important part of the aerobatic fuel system. It allows fuel to be pumped from the central fuel tank to the fuel ramp. In addition, it delivers fuel to the injection nozzles at a certain pressure so that this fuel can then be sprayed through the injection nozzles.

7.5. Indirect injection design for the M60 engine

The design of the fuel injection system was first created in AutoCad Inventor. AutoCad Inventor allowed us to create a 3D design of the fuel injection system, which made it easier to make further decisions before we made a non-reversible practical implementation.

7.5.1. Intake manifold design

For further use of the engine we count with the original throttle bodies. Based on the given dimensions and shape of the throttle body, we have designed an intake manifold consisting of a base of the same shape as the throttle body and a circular line. The intake manifold was shaped as follows (Figure 4), with the inlet portion being the fresh air drawn in from the propeller as shown by the arrows in the figures. The inlet duct situated in this way was a suitable option for us, especially because of the direct inlet of fresh air.

Figure 4: Intake manifold design

7.5.2. Fuel injection design

The next stage was the design of the injection system. This consisted of a single point injection system consisting of a pair of injection nozzles mounted in the intake manifold on one side and in the fuel ramp on the other side.

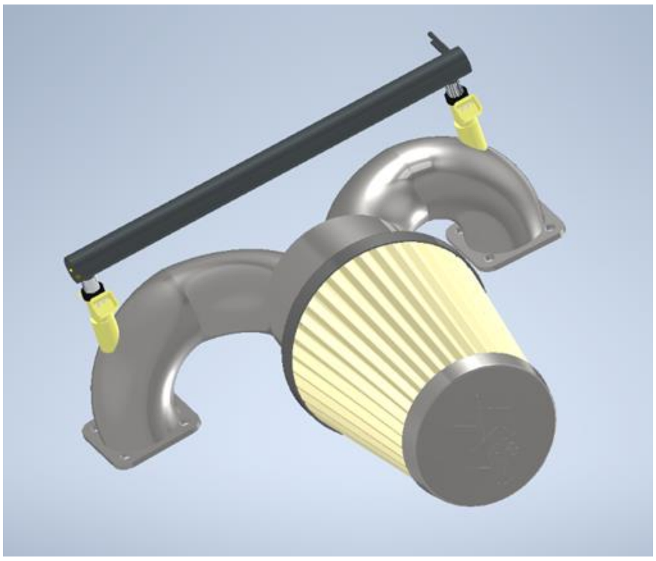

Figure 5: Design of the fuel ramp and injection nozzles in the intake manifold - front view [author]

8. IMPLEMENTATION OF THE FUEL SYSTEM

After a thorough elaboration of the design of the new fuel system, we started the actual practical implementation of the individual parts of the fuel system. Thus, we started from the design itself, which is described in the previous chapter. During the practical implementation, we encountered a number of complications that we had to resolve over time so that specific problems did not cause further problems, e.g. in the assembly of the individual components of the fuel system. The complications that arose during the implementation are described in the individual subchapters to which they relate. The manufacture of the components and the implementation of the fuel system is described chronologically, as we actually proceeded, step by step:

- Production of the intake manifold,
- Choosing the right material for the intake manifold,
- Production of the intake manifold base,

- Connection of the base to the knee pipe

Figure 6: manufactured intake manifold [author]

8.1. Installation of the intake manifold and subsequent modification of the design

We mounted the fabricated pair of intake manifolds on the throttle bodies instead of the carburettors. This was just a test fitting without the correct gaskets, so that we could assess whether the proposed alternative would be correct. However, this step showed us that the original design would have to be partially modified. Although the direction of the intake manifolds was suitable and had no obstruction, the intake basket in the original design would have been too large and could not be fitted, due to the upward protrusion of the propeller reducer. For this reason, the original design had to be modified.

8.2. Modification of the original design

The second alternative was to change the direction of the intake manifold. It was necessary to turn the intake manifold 180°, i.e. backwards. In addition, it was no longer possible to use one common air filter, as the distance between the intake manifold was too great. For this reason, we were inspired by the first alternative, to use just two smaller air filters. This modification of the design also brought one advantage. It was no longer necessary to deal with the complications associated with making a flange to hold the air filter common to both intake manifolds as originally designed.

Figure 7: Modification of the original design associated with a 180° rotation of the intake manifold [author]

8.3. Injection system

The fuel supply and injection into the intake manifold is provided by a number of components. These components did not need to be fabricated, such as the intake manifold, because they are components that we obtained by disassembling some automotive fuel systems. However, it was necessary to adapt them to our M60 engine according to the specified design.

- Fuel ramps and their modifications.

8.4. Injection nozzle inlet modification in the intake manifold

According to the established design, the intake manifold needed to be further modified. This modification consisted the creation of a suitable fitting for the injection nozzle in the intake manifold. Our aim was to create a perpendicular fit to the base of the intake manifold and at the same time to position this fit at the centre of the cross-section of the base so that the injection nozzle could inject fuel directly onto the throttle body. This modification summarized several steps:

- Manufacture of injection nozzle neck,
- Drilling a hole in the intake manifold,
- Inserting the neck into the intake manifold.

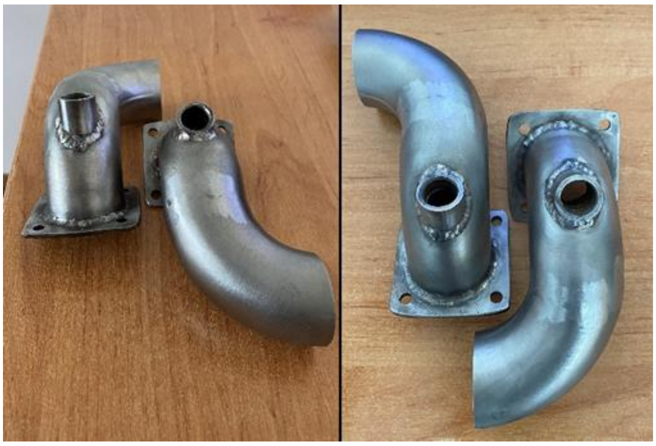

Figure 8: Modified intake manifolds [author]

8.5. Central fuel tank and its modifications

Based on the requirements we had already established for the central fuel tank in the design, we decided to purchase an expansion tank for the refrigerant mixture. When selecting the tank, we made sure that the inlet diameter was large enough so that we could insert the fuel injection pump into the tank and also remove it easily. The expansion tank from the Ford Transit we eventually purchased met these requirements. Along with the tank, a pressure cap was purchased for this tank up to a pressure of 1.45 BAR.

Following modifications:

- Adjustment of the inlet opening,
- Adjustment of the pressure cap.

8.6. Installation of individual fuel system components

The manufactured components were then mounted on the M60 engine. We started with fitting the intake manifolds to the throttle bodies. Because of the good tightness of the joint between these components, we had to use gaskets. The gaskets were made from purchased clingerite with a thickness of 0.5 mm. We cut the exact shape according to the original gasket. The holes were punched using a set of punchers. The intake manifolds were secured against the throttle bodies via 4 bolts along with spring washers and nuts. Air filters were fitted to the inlets of the intake manifolds and secured with clamps.

Injection nozzles were inserted into the throats of the intake manifolds along with a fuel ramp. We decided to use the fuel ramp and injection nozzles from a Fiat Punto. Wiring was run from the engine control unit towards the injection nozzles. The second fuel ramp and its injection nozzles from the Skoda Felicia remain part of the project as a backup component.

The central fuel tank was bolted to the engine stand. In total, this tank has four holes. Two holes of the same diameter are used to feed fuel from a pair of diaphragm pumps via fuel lines. We have not used the third hole yet and have blinded it for tightness. However, it could later be used to accommodate a bleeder valve. The fourth hole is located in the throat of the main bore and was used to create a fuel return line. In the event that the central fuel tank became full, fuel would leak back into the main tank through this hole via the fuel line.

8.7. Testing individual parts of the fuel system

Individual components have been tested and tried to see if they work properly.

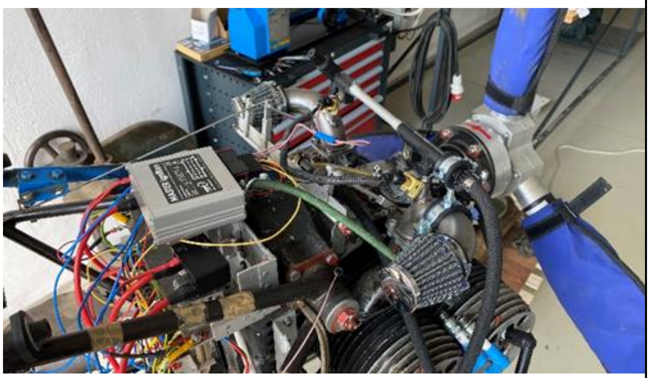

Figure 9: Complete implementation of the fuel system. [author]

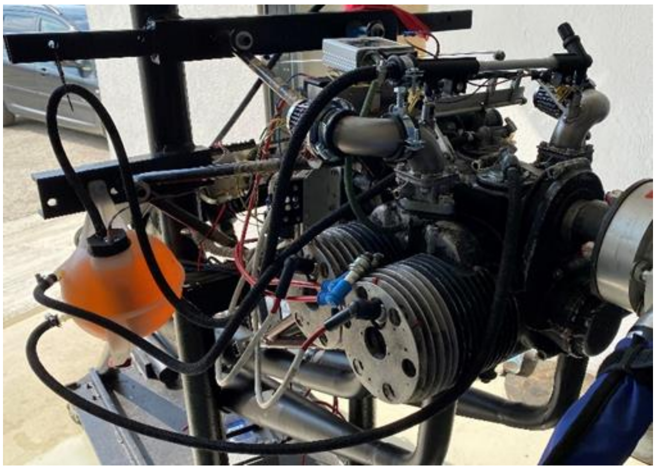

Figure 10: Complete implementation of the fuel system II. [author]

9. CONCLUSION

This paper has dealt with the design and practical implementation of an aerobatic fuel system for the M60 engine. The practical implementation was based on the developed design. In the theoretical part of the paper the problems of individual fuel systems were described, as well as the individual components of these systems.

In the introductory chapters, the basic characteristics of two-stroke engines were treated, including a brief description of the M60 engine. Subsequently, the issue of fuel systems, their distribution and comparison was treated. The mentioned fuel systems were discussed in detail and compared with each other by the method of comparison. As part of the treatment of the problem, the individual components of the fuel systems were described, and their various alternatives were considered. The alternatives were processed in the form of description, characterization and comparison. Attention was paid to the preparation of the fuel mixture. The factors influencing the formation of the fuel-air mixture and the possibilities of forming the fuel-air mixture have been discussed. The various methods have been described and categorized within the chapter. The theoretical part included the treatment of the characteristics of the engine control unit. The functions, advantages and disadvantages that the engine control unit brings were described. At the end of the chapter, the purchased engine control unit ECU MASTER was described.

The practical part was implemented on two levels. The first part was devoted to the design of the acrobatic fuel system. Within the design, the fuel system was described, including a schematic that discusses the fuel delivery from the tanks to the combustion chamber. Furthermore, the individual components that form part of the new fuel system were described. The design of the injection system was created in the software program AUTOCAD Inventor, which allowed the visualisation of the individual components of the fuel system. The created design became a necessary basis for further continuation in the practical part. The second part of the practical part consisted of the actual implementation of the fuel system. The realisation consisted of the creation of the individual components of the fuel system. The formation, modifications and complications that occurred during the practical part have been described within the chapters to which they relate. The manufactured, modified or purchased components were then fitted to the engine in the correct design. At the end of the practical part, the testing of the individual components was described. This established the functionality of both the individual components and the entire fuel system of the M60 engine.

We can consider that the task, together with the main objectives set, has been fulfilled. In the same way, we managed to meet the sub-objectives and respond to the complications that arose during the practical part. The incorporation of the new fuel system together with the engine control unit creates new space for its possible optimization or suggestions for additional components that would improve the engine's performance.

ACKNOWLEDGMENT

This paper is an output of the project of the Ministry of Education, Science, Research and Sport of the Slovak Republic KEGA No. 048ŽU-4/2020 "Increasing key competences in aircraft maintenance technology by transferring progressive methods to the learning process".

REFERENCES

[1] WILD, T. – KROES, M. 2013. Aircraft powerplants. 8th edit. USA : Quad/Graphics, 2013. 768 s. ISBN 978-0-07-179913-3.

[2] JAROŠ, K. 1992. Technická zpráva. Brno : Aeromot Brno, 1992. 4 s.

[3] KŘÍŽ, J. 2004. Lietadlové pohonné jednotky. Žilina : Žilinská univerzita, 2004. 264 s. ISBN 80-8070-342-6.

[4] KOCÁB, J. – ADAMEC, J. 1991. Letadlové pohonné jednotky. 2. vyd. Praha : Nadas, 1991. 380 s. ISBN 80-7030-103-1.

[5] Web Reference: How Does a Diaphragm Carburetor Work?. Available online: https://www.reference.com/world-view/diaphragm-carburetor-work-f076f980d4c045e9 (cit. 2022-03-20)

[6] MAKSAJ, A. – POLANSKIJ, H. 1957. Teorie leteckých pístových motorů. Praha : Naše vojsko, 1957. 288 s.

[7] MACKERLE, J. 1980. Motory závodních automobilů. Praha : Alfa, 1980. 196 s.

[8] GROHE, H. 1981. Benzínové a naftové motory. Bratislava : Alfa, 1981. 192 s.

[9] VLK, F. : PŘÍMÉ VSTŘIKOVÁNÍ BENZINU. Available online: http://www.sinz.cz/archiv/docs/si-2004-01-67-71.pdf (cit. 2022-04-10 až 2022-04-15)

[10] FERENC, B. 2006. Spalovací motory. Karburátory a vstřikování paliva. Brno : Computer Press, 2006. 388 s. ISBN 80-251-0207-6

[11] Figure 11 source: https://www.autolexicon.net/sk/articles/mpi-multi-point-injection/

[12] Technologie oprav 1 : T 16 Palivové soustavy zážehových motorů se vstřikováním paliva. Available online: https://publi.cz/books/160/16.html (cit. 2022-04-20)

[13] FERENC, B. : Elektronika a zážehové motory. Available online: https://www.mjauto.cz/newdocs/ferenc/n2_mot/n2.htm#davkovani (cit. 2022-04-18 až 2022-04-23)

[14] Figure 12 source: http://howcarpartswork.blogspot.com/2016/03/l-jetronic-fuel-injection-system.html

[15] Technologie oprav 1 : T 15 Doprava paliva u zážehových motorů, čističe vzduchu, palivové soustavy zážehových motorů s karburátorem. Available online: https://publi.cz/books/160/15.html (cit. 2022-04-25)

[16] Web Denso: A history of Engine Management Systems according to DENSO. Available online: https://www.denso-am.eu/news/march-2017-newsletter-a-history-of-engine-management-systems-according-to-denso (cit. 2022-03-20)

[17] Web Wikipedia: Riadiaca jednotka motora. Available online: https://sk.wikipedia.org/wiki/Riadiaca_jednotka_motora (cit. 2022-03-20)

[18] Web Student lesson: Understanding the working of automobile brainbox. Available online: https://studentlesson.com/automobile-brainbox-definition-applications-working/#Advantages (cit. 2022-03-20)

[19] JANCO, M. : Riadiaca jednotka (ECU) – poruchy a kabeláž vozidla. Available online: http://www.autorubik.sk/clanky/co-je-to-riadiaca-jednotka-motora-alebo-motor-manazment/ (cit. 2022-03-20)

[20] Web Imfsoft : ECU MASTER - MAP sensor. Available online: https://imfsoft.com/kategorie-ridici-jednotky/ecu-master-map-sensor#toc-specification (cit. 2022-04-26)

[21] ČERŇAN, J., HOCKO, M. 2020. Turbínový motor I. 1. vyd. Žilina : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 335 s.ISBN 978-80-554-1673-1.

[22] BUGAJ, M., NOVÁK, A. 2010. Všeobecné znalosti o lietadle : drak a systémy, elektrický systém. - 1. vyd. - Žilina : Žilinská univerzita, 2004. - 247 s. - ISBN 80-8070-210-1.

[23] BUGAJ, M., URMINSKÝ, T., ROSTÁŠ, J., PECHO, P. 2019. Aircraft maintenance reserves - New approach to optimization. Transportation Research Procedia, 2019, 43, pp. 31–40. ISSN 23521457.

[24] ČERNAN, J., ŠKULTÉTY, F. Design of the air velocity measuring inlet channel for the small jet engine. Transport Means - Proceedings of the International Conference, 2020, 2020-September, pp. 942–945. ISSN 1822296X.

https://doi.org/10.26552/ pas.Z.2022.2.13

IMPACT OF COVID-19 PANDEMIC ON PILOT TRAINING

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Abstract

The COVID-19 pandemic had a negative impact on all areas of human development. The air transport industry has been forced to adopt virtually all of its activities to meet rapidly changing travel regulations and requirements. The main goal of this paper was to identify the impact of the pandemic on pilot training. For this purpose, an analysis of many aspects were carried out, such as, for example, the impact of the pandemic and related restrictions on the psychological state, physical health, and the very quality of education in these difficult times. The paper also contains information about the pandemic's impact on aviation in general and active pilots, and about how the pandemic affected them.

Keywords

Pandemic, Training, COVID-19, Impact, Pilot.

1. INTRODUCTION

The coronavirus pandemic, named "COVID-19" can be called a serious global problem. This pandemic has become one of the most significant challenges of the 21st century. The consequences of a coronavirus pandemic are a phenomenon that has many aspects. In addition to affecting almost all areas of human life, the pandemic has affected complex social, economic, cultural, organizational, and managerial aspects of society as a whole.

Air traffic fell to record levels worldwide during the pandemic. This type of transport was most affected during the pandemic. The crisis has also affected airline employees - pilots, flight attendants, technicians, and so on.

Education has also undergone several changes during the pandemic period. Secondary, general, vocational, higher, and supplementary education systems have moved to an online format using distance learning technologies.

The transition to the distance form requires all participants in this process the ability to adapt quickly, to find suitable ways and approaches in teaching, to work on the efficient use of time, and increased responsibility for their results. The difficult pandemic situation and the constant changes in the form of education could worsen the mental state of the students.

2. IMPACT OF THE PANDEMIC ON PILOT TRAINING

The year 2020 brought surprises and challenges around the world. Many countries have begun to implement strict anti-pandemic measures, including lockdowns and the temporary closure of borders.

Due to the COVID-19 pandemic, we all had to change our usual approach to work, study, and everyday life, to relationships with colleagues, friends, and loved ones. For this reason, most educational institutions have begun to implement a safe model of organizing the educational process for students and teachers following the necessary hygienic and pandemic requirements. It was also necessary to adapt the educational process and scientific activities, limit personal communication between students and teachers, and prevent the spread of the virus. It was necessary to increase the use of digital technologies, develop new methods of distance learning, and at the same time maintain high quality, in the shortest possible time.

With the transition of universities to online education, most of them have strengthened cooperation between themselves, national education authorities, educational platforms, and international organizations.

As it is very important to monitor physical health, mental health and the consequences of the coronavirus crisis, universities and research organizations have conducted studies around the world, analysing the impact of the COVID-19 pandemic on the population. The results of studies focused on students of universities of various disciplines will be presented, as there is very little information concerning only pilots. The first step for a large part of future pilots starting their path into the world of aviation and a professional pilot is integrated training, which is often completed at the university that offers the field, which means that the information provided will also cover pilot training.

Can we claim the modular course students were not affected? This is not entirely true. Due to strict anti-pandemic measures, such as the temporary closure of businesses, shops, but also educational institutions, the lockdown has also been applied in most countries, which severely restricts mobility and leads to self-study or distance learning and may lead to the consequences mentioned below. When the government of the countries started to ease the anti-pandemic measures, the situation changed for the better, but the pandemic left traces and the probability that we will return to the period before the pandemic and forget about the virus is quite small.

According to FlightLogger, at the beginning of the pandemic, a significant decrease (above 40%) in the average activity of pilots in training was recorded (see Fig. 1). This decline shows the impact of pandemics and anti-pandemic measures on pilot training. As already mentioned, aviation schools were forced to adapt to new conditions and situations, to implement a new approach to the organization of the educational process. After the release of some measures and the organization of all training processes, the activity of students also increased. We can see an improvement in the situation at the time, but the data show that the average number of active pilots per training organization is still lower than before the pandemic. [1] [2]

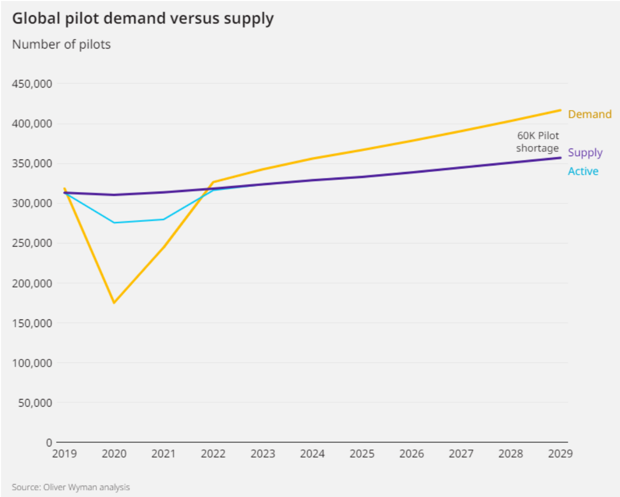

Fig. 1. Average active students per Pilot Academy

2.1. Implementation of distance education and its impact

The field of higher education can easily be called one of those on which the pandemic has had the greatest impact worldwide. In addition, the education sector has become one less ready to move most of its processes online. Many students initially like to switch to this form of education because in this case, they can spend more time at home, but in fact, it's not everything as good as it might seem at first glance. Of course, there are benefits. For example, it saves time, which is reflected in the absence of the need to go to university, including travel time, which means that the morning routine ends at the computer, but also the use of multiple Internet resources to study better and more thoroughly study information and much more. It should be noted that almost all resources are aimed at improving the quality of education and assimilation of information, but their excessive amount can adversely affect the state of students.

The psychological burden on students and teachers is increasing in connection with the transfer of many educational and administrative realities online. Due to the close dependence on tackling the problems of effective education, many universities are experiencing problems faced by educational organizations in the transition to the distance format of work. This challenge requires adequate preventive measures of a regulatory and organizational nature on the part of universities. [3]

During the first wave of the COVID-19 pandemic, the quality of distance education depended on services related to administration (speed of response of management of educational facilities to problems), technical support (speed of provision of all necessary technical means and especially services that would be suitable for online education), the active role of teachers in the online learning process and their response and timely feedback, and the overall quality of the system with the way it is procured by IT infrastructure. Students' digital competencies and online interactions with colleagues and teachers are slightly less important factors, but they are still statistically significant. The influence of quality on students' performance also depends on the students themselves it depends on their satisfaction with online teaching, so it is important to monitor and analyse their satisfaction and the factors that affected student performance after the rapid introduction of e-learning. This can be important for decision-makers and anyone involved in implementing any new measures in the future. Investment in the development of digital competencies for both students and academics should also be supported, together with initiatives to support research and interdisciplinary innovation collaboration in various aspects of higher education online to increase its quality. [3]

The process of distance education depends on the attitude of teachers and students. Students' attitudes towards distance education are twofold and ambiguous. On the one hand, they understand its advantages and, on the other hand, they are still a little worried that the quality of the acquired knowledge will be lost, influenced by the lack of personal contact with the teacher. At the same time, it is clear that the right explanatory and marketing activities of educational institutions, as well as a well-established distance learning system (using the latest technological advances, sophisticated methodological basis, interactive interaction, etc.), can significantly increase the weight of distance learning.

Until two years ago, no one could have imagined that for almost two years, students around the world would study distance learning. In any case, the current situation in the world has given us a lot of experience. And now we can be sure that no matter the circumstances, there will always be an opportunity to gain quality education and skills, even at home. It can also be assumed that in the future it is possible to expect the introduction of a distance or combined method of education instead of the traditional one.

2.2. Impact of the COVID-19 pandemic on mental health

During the COVID-19 crisis, there was no direct contact between students. Communication was possible mostly through social networks, or via other applications and platforms that were designed for the exchange of information. As students in almost every country in the world have spent most of their time in isolation over the last two years, the pandemic has not only disrupted their normal way of life but also could endanger their mental health.

However, studying at university usually means a new chapter in life - the transition to adulthood and independence. In 2020, students did not experience this new life because they were deprived of social contacts, extracurricular activities, and brigades and many had to return home when they had previously been in dormitories, a place where student and social life is very active. The radical changes caused by the pandemic affected all students in some way. The most influenced were first-year students who had just started studying, the process of adapting to university life was especially challenging for them.

The psychological state of society is determined in terms of the mental and emotional well-being of people and is considered by taking into account objective indicators and subjective evaluations. The World Health Organization has defined mental health as "a state of well-being in which an individual can exercise his or her abilities, cope with the stresses of everyday life, to be able to work productively, and can contribute to the life of society." [4]

Since the beginning of the pandemic, several studies have been conducted on its impact on society.

Researchers from the University of Applied Sciences in Zurich conducted a study where they monitored the mental health of university students. 2437 respondents took part in the survey. The average age of the participants was 25 years. The baseline survey was conducted from 3 to 14 April 2020. [5]

The most widely used measure of anxiety, which has also been used by Swiss researchers, used in clinical practice as well as in research to screen, diagnose and assess the severity of anxiety disorders is GAD-7 (Generalized Anxiety Disorder 7). GAD-7 is a personality questionnaire for assessing anxiety levels and screening for generalized anxiety disorder. In addition, it can be used to screen for panic disorder, social phobia, and post-traumatic stress disorder. The questionnaire consists of 7 test questions, each of which offers four possible answers. The points are awarded for each response, based on the sum of which concludes with the level of anxiety, the presence of symptoms of generalized anxiety disorder, and other anxiety disorders. Questions need to be answered based on the respondent’s feelings over the past 14 days. [5] [6]

Analyses suggest that COVID-19 specific factors are related to student anxiety and anxiety prevalence. Depending on the latent group, some students perceived a strong impact on well-being and daily life and the level of anxiety approached the binding limit, but most students perceived a medium or even small impact of the pandemic. [5]

The research shows that students from the medical fields showed significantly less anxiety compared to students of management and law, biology, or linguistics. [5]

The data suggest that some students are better able to cope with the dramatic changes they have experienced, such as medical students, and younger and wealthier students. Others are doing worse and, with future measures in mind. Their needs should be addressed by public health and educational institutions. [5]

Researchers from Kazan Federal University together with colleagues from Moscow State University and the Psychological Institute of the Russian Academy of Sciences conducted a study on student mental health, which took place from April 9 to April 20, 2020. Students from several universities in Russia's eight federal districts took part in the online study. The total number of respondents was more than 3,000, students, most of whom were women. The average age of the respondents is 21 years. The results of studies conducted earlier by researchers during a large-scale research project on the study of students' mental health in the period 2018-2019 from 5 March to 23 March 2020 were compared. [7]

The main focus of the new study by Russian scientists is to identify stress levels in three different periods: long before the start of the pandemic (period 1); in the first days of the spread of COVID-19 in Russia, but before the introduction of measures (period 2); in taking tough measures to curb the first wave of the pandemic (period 3). The researchers were interested in how anxiety increased and what factors contributed to increasing or decreasing the level of anxiety. [7]

In general, the available data allowed the researchers to conclude that no differences in mental well-being were found in the first period. The second and third periods were characterized by the highest rates of depression, anxiety, and stress. [7]

The results of the study also show that in a situation where the uncertainty caused by the pandemic was high, there was a significant deterioration in the mental health of male students. Thus, it can be assumed that pandemics, restrictions, and lifestyle changes had a stronger impact on men than on women. [7]

In this study, students' mental health indicators are significantly better than before the COVID-19 pandemic. The deterioration occurred when the pandemic was reported and the epidemiological situation in Russia and the world continued to deteriorate. And after weeks of anti-pandemic measures, the level of stress and anxiety began to decline. The data suggest that Russian students have been able to adapt quickly to change and the level of uncertainty in the situation has decreased. [7]

A study involving 3,490 respondents in Slovakia showed that "a combination of social isolation, insecure news and confusing information from school often led to states of anxiety, stress, and loneliness". 74% of respondents did not have a problem with a lack of communication and socialization within the possibility caused by the situation. Less than half of the students had excessive stress from school, almost 40% felt little to do anything and about 27% of students felt lonely. More serious manifestations, such as depression and anxiety, were felt by fewer people, 29% and 33%, still being a disproportionate part of the population. [8]

From the point of view of future pilots, the crisis in aviation caused by a pandemic can also cause feelings of anxiety and depression. There could be less interest in new pilots and thus less probability of employment after training and obtaining the necessary licenses and qualifications.

The increased anxiety observed among students at the onset of the pandemic subsided over time. Anxiety declined as people got used to the new way of life and the virus itself was no longer acute. However, depressive disorder is not so much related to general concerns as to feelings of isolation, lack of support, and drastic lifestyle changes. The psychological support offered by universities also helped the students.

2.3. Impact of the COVID-19 pandemic on physical health

Coronavirus has a detrimental effect not only on the lungs but also on other human organs. Attempts to systematize this process based on data obtained from physicians have been made by the American edition of Science.

Upon entering the human body through the nasopharynx, the virus begins to multiply and spread in new cells. If the immune system cannot stop it, the virus enters the trachea and lungs, which is especially dangerous. As a result of the immune system's fight against it, the body's oxygen supply is disrupted.

Infection with pneumonia and acute respiratory distress syndrome is also possible with the infection. People infected with the virus are seriously ill and do not even die from the coronavirus but from the action of their immune system. The immune system sometimes works so fast and hard, trying to fight the virus that in some cases it destroys its own body. [9]

Experts believe that COVID-19 poses a threat to the brain and central nervous system. According to experts, patients may lose consciousness. A symptom such as olfactory loss is quite common. A cytokine storm can lead to brain edema and stroke due to increased blood clotting. The publication says that an objective picture of the effect of coronavirus on the human body can be obtained only after serious long-term studies. [9]

In addition to the impact of the virus itself on the human body, the impact of distance learning and anti-pandemic measures should also be taken into account.

Sight is one of the five major human senses that needs to be protected. While studying at university, eyesight was less stressed: during lectures, students look at the teacher, the notebook, the blackboard, and the moment they move their eyes and focus on other subjects, they relieve eye strain. Working at a computer all day, and during breaks monitoring social networks, which means minimal eye movement from the computer screen to the screen of a mobile phone or tablet can cause visual impairment. To prevent this, it is necessary to shorten the time spent at the computer screen and it is also useful to do exercises or gymnastics for the eyes. The pandemic had a strong impact on human activity, significantly limiting it. The student was still on the move: a trip to the university and back, relocation to other classes between classes, short walks during breaks, and so on. [10]

The new measures have encouraged people around the world not only to reduce physical activity but also to consume more junk food that can be ordered quickly through various services and applications. Remarkably, eating junk food is closely related to a mental condition that worsened for many during the quarantine period, and could have changed sleep patterns. Therefore, even those who have never experienced anything like this before had problems with overeating and being overweight. The pandemic has forced us to look at the problem of overweight (obese people are more at risk and harder to bear the virus). [10]

Distance learning also affects students' postures. Students often sit in pour postures, which can cause serious illnesses, such as scoliosis, osteochondritis, and other diseases. [10]

It is important for pilots, whether in training or already working, to monitor their health. This is because their state of health depends on the possibility to work. At least once a year, the transport pilot should have a medical examination and, upon successful completion, obtain a medical certificate. In case of any deviation of their medical condition that could affect air safety, the medical officer shall no longer issue a medical certificate and the applicant should undergo further examination and treatment, but there may be a possibility that the problem will not be resolved what can mean the end of a career.

We can therefore conclude that this form of education, like any other, has its advantages, but also significant disadvantages. In addition, they significantly affect the health of students, but with a little effort and it would be possible to minimize the damage of a pandemic. However, it should be noted that during a pandemic, distance learning is to some extent a lucrative solution.

2.4. Degradation of pilot skills

The pandemic could also have a negative impact on aviation safety. Civil aviation pilots could mak mistakes at work due to a lack of experience, fears, lack of professional skills, self-confidence, or simply forgetfulness which can lead to tragedy. Some airlines provide pilots with adequate refresher training after a break. Others, however, offer only the bare minimum or offer nothing. According to a publication in the Global Journal of Engineering and Technology Advances, the aerospace industry, as a highly technical and inherently risky area, is largely dependent on the ability of pilots to reduce operational risks to the lowest possible level. However, the competence of the pilot depends to a large extent on how often pilots train the most important skills associated with safe flight. [11]

The paper describes an experiment conducted by Ammons et al. to evaluate pilots' ability to retain skills due to a long period of lack of expertise, and a general decline or trend in declining practical knowledge was observed. [11]

The experiment involved training participants eight hours a day to gain the necessary knowledge and perform a specific flight task. The training was stopped at intervals of 24 hours to two years and then the skills were reassessed. The result of this experiment showed that the longer the skill was not practiced, the lower the corresponding skill. [11]

In a similar experiment conducted by Fleisman and Parker, were also reported similar observations, and there was also a reduction in pilot skills because of the lack of practice during pauses. When the refresher course or training was completed, the skill level returned to 75%. The same problem prevailed among private pilots who did not regularly perform critical flight maneuvers and emergency procedures after an eight-month test flight. [11]

A significant increase in the number of major accidents has not yet been observed. According to the Aviation Safety Network, there were eight major commercial aircraft accidents in the world in 2020, 20 in 2021, which is not a very high difference compared to previous years, for example in 2019 there were 23 and in 2018 there were 18. So it means that the pandemic has not had a major impact on flight safety, but it is still always better if pilots have the opportunity to undergo not only basic training to maintain a license during major breaks [12]

During the period of quarantine and suspension of air traffic, the issue of the validity of the pilot's license became topical. Airplanes and pilots do not fly. As a result of the COVID-19 pandemic, airlines around the world have sharply reduced flights since March 2020.

Most of the aircraft remained on the ground, and the pilots who were forced to leave the cockpit only have to come to terms with the rare simulator training needed to maintain their professional skills. At the same time, according to the rules in force in the EU, civil aviation pilots must complete at least three take-offs and landings in 90 days in order not to lose their type rating.

Full Flight Simulator became almost the only opportunity to practice the professional skills of a pilot when there was no opportunity to be in the cockpit of a real aircraft. Training on such a simulator is equal to the actual flight and is calculated when the license is renewed. The problem is that due to the coronavirus pandemic, many centres with simulators have been closed. Another problem was maintaining the validity of licenses and clauses for pilots who had not yet worked before the pandemic or lost their jobs because of it. Maintaining valid qualifications is an expensive affair, considering that it is sufficient to complete the necessary tasks on the simulator, not to mention flying on an airplane. The airline could pay the employed pilots or at least help with it financially, but the unemployed must pay for everything themselves. And, despite the financial difficulties of many airlines, it was clear that firing pilots would not be the best decision.

2.5. Forecasts

The aviation and aerospace industries have already experienced historical turbulence and major impacts, such as the aftermath of 11 September 2001 in America, the SARS pandemic of 2002-2004, and the disruption of air traffic caused by the eruption of Eyjafjallajökull in Iceland in 2010 and others. However, the consequences of the COVID-19 pandemic were very different.

At the beginning of the pandemic, the aviation industry saw a record decline in the number of flights, now, as the pandemic situation around the world improves, we see a recovery in demand. With the opening of borders and the lifting of travel restrictions in most countries in Europe and other parts of the world, airlines are moving closer to pre-pandemic flight indicators. History shows that after all the crises, the aviation industry as well as other industries are returning to pre-crisis indicators and increasing over time, and only the speed of the process differed. [13]

According to the IATA forecast, the Aviation industry should return to pre-pandemic indicators by 2020. Despite the rapid spread of the omikron variant, people want to travel. In 2021, the total number of passengers was 47% of passengers carried in 2019. It is expected to improve to 83% in 2022, 94% in 2023, 103% in 2024 and 111% in 2025. However, these optimistic prognoses may be influenced again by the spread of SARS-CoV-2, its most widely used variant, omicron. But the possibility of virus mutation cannot be ruled out. The growth of the civil aviation market may also be affected by the ongoing military conflict between Russia and Ukraine. As a result of the war, significant increases in the prices of fuel and raw materials used in the manufacture of aircraft and others can be expected, which may be reflected in ticket prices. [14]

The big question facing the aviation industry is when demand will return. Regarding the resumption of passenger transport, estimates range from early 2022 to 2024 and beyond. In the case of pilots, however, demand depends on the use of aircraft, which in turn depends on the number of potential passengers. As the civil aviation market recovers from the effects of the pandemic, recruitment and quality training continue to play a key role in ensuring flight safety. Before the pandemic, airlines offered more options and benefits for pilot training, mainly to help with training funding. When the rapid spread of the virus began and the costs outweighed the profits, these benefits and assistance were limited or cancelled. Some banks, which offered loans to students to pay for training, also reassessed the risks involved and severely limited the process.

According to Oliver Wyman, 25,000 to 30,000 current and future pilots may choose alternative career paths due to the pandemic. According to a scenario by Oliver Wyman, there will be a shortage of pilots in some regions by 2023 at the latest, but a faster increase in demand must also be considered. According to the scenario, there will be a shortage of 34,000 pilots by 2025 and 60,000 by 2029 (see Figure 2). The recovery is not expected to be identical worldwide. According to the company's analysis, North America, the Asia-Pacific region and the Middle East are likely to face the largest deficits, while Europe, Africa, and Latin America will remain closer to balancing demand and supply. [15]

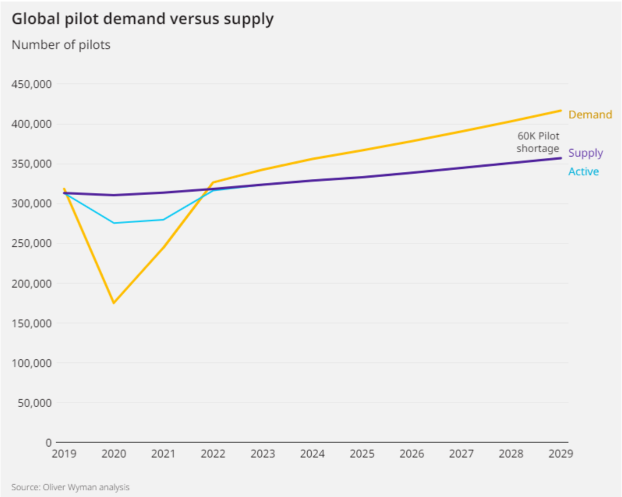

Fig. 2. Global pilot demand versus supply

Boeing analysts expect more than 2.1 million new aircraft and technicians to operate a global fleet of civilian aircraft over the next 20 years. Of which - 612 thousand pilots, 626 thousand mechanics, and 886 thousand flight attendants. Demand for 115,000 new pilots in Europe is expected over the next 20 years. [16]

3. EVALUATION OF RESULTS

Global crises always contribute not only to technological progress but also to their widespread implementation in society in ways that were previously considered impossible. The global pandemic has confirmed that online learning is essential in such crises, and all educational institutions should spend the necessary time and money on developing and improving it to be prepared for similar situations in the future.

Even before the pandemic, there were experiments with the introduction of distance education. More often only in the form of courses, but implementation was slow. COVID-19 has certainly brought a breakthrough, with most universities around the world making a relatively rapid shift towards distance learning.

Over time, a large number of analysts, university leaders, educators, and students themselves began to realize that the pandemic brought not only disasters for them and their universities, but also unexpected positive effects. The main benefits of distance learning include reduced study costs, greater mobility, and the availability of a wealth of information and resources. The main disadvantage was the lack of socialization among students, they were forced to live in isolation for a long time and there was a lack of direct interaction with teachers and classmates and the problems associated with it. Problems can be called reduced physical activity, increased stress, and anxiety at the beginning of a pandemic, which subsided over time as students got used to the conditions.

In this article, we pointed out the effects of the COVID-19 pandemic on pilot training. We found that the pandemic had the greatest impact on pilots in training during the first waves of the SARS-CoV-2 virus when national governments introduced anti-pandemic measures and educational institutions switched to distance learning, according to the response of approved training organizations. However, the pandemic also had a major impact on active pilots, some of whom eventually had to find employment opportunities in other sectors. We can judge that thanks to the coordinated cooperation, the process of adaptation proceeded at a sufficiently fast pace, and over time, the students also got used to studying in the new conditions. The licensing authorities have also set up the aviation licensing process relatively quickly.

4. CONCLUSION

The pandemic has thus become a new serious challenge for civil aviation, which is radically changing established trends in the aviation industry. At present, there are no individual measures that could reduce all risks to air transport. However, the solution of all strategic tasks is possible only with the consolidation of the efforts of all parties and with the active involvement of the state, as its tasks also include the provision of comfortable business conditions.

The COVID-19 pandemic has also challenged the education sector, changed the lives of students and their families and creating wider societal challenges. Countries and universities that faced the same challenges responded to them at different speeds. The most sensitive was the provision of up-to-date information to students and applicants about the situation at universities. The impact of the COVID-19 pandemic on pilot training cannot be called long-term, thanks to the rapid adaptation of all training processes, and the impact also varies from region to region.

All countries will have to mitigate the effects of the pandemic, but based on the available materials, it can be concluded that the trend of digitalisation of education and academic exchanges will continue. Countries and universities will develop new forms of cooperation with academic and non-academic organizations. Countries and universities will review the experience gained and use it in further work.

REFERENCES

[1] About FlightLogger. [online]. [Cit. 2022-03-04]. Available: <https://flightlogger.net/about-us-history/>.

[2] COVID-19 Update. 2021. [online]. [Cit. 2022-03-04]. Available: <https://flightlogger.net/2021/12/02/covid-19-update/>.

[3] Keržič, D. et al. 2021. Academic student satisfaction and perceived performance in the e-learning environment during the COVID-19 pandemic: Evidence across ten countries. [online]. PLoS ONE, 2021. [Cit. 2022-03-10]. Available: <https://doi.org/10.1371/journal.pone.0258807>.

[4] Mental health: strengthening our response. [online]. [Cit. 2022-03-12]. Available: <https://www.who.int/news-room/fact-sheets/detail/mental-health-strengthening-our-response>.

[5] DRATVA, J. et al. 2020. Swiss University Students' Risk Perception and General Anxiety during the COVID-19 Pandemic. [online]. International Journal of Environmental Research and Public Health. 2020. [Cit. 2022-03-12]. Available: <https://doi.org/10.3390/ijerph17207433>.

[6] Generalised Anxiety Disorder Assessment (GAD-7). [online]. [Cit. 2022-03-12]. Available: <https://www.corc.uk.net/outcome-experience-measures/generalised-anxiety-disorder-assessment-gad-7/>.

[7] ZINCHENKO, Y. et al. 2021. The Spread of COVID-19 in Russia: Immediate Impact on Mental Health of University Students. In Psychological Studies. [online]. 2021, vol. 66, pages. 291–302. [Cit. 2022-02-17]. Available: <https://doi.org/10.1007/s12646-021-00610-1>.

[8] The Slovak Accreditation Agency for Higher Education – The Student Council of Higher Education. 2020. Impact of COVID-19 on students. 2020. [online] [Cit. 2022-02-18]. Available: <https://saavs.sk/sk/dopad-covid-19-na-studentov-hlavne-zistenia-a-zavery/>.

[9] WADMAN, M. ae al. 2020. A Rampage Through The Body. In Science. 2020. [online] [Cit. 2022-01-03]. Available: <https://doi.org/10.1126/science.abc3208>.

[10] ZAKORKINA, N.A. Impact of distance learning on health of university students. In Social aspects of population health. 2021. [online] [Cit. 2022-02-05]. Available: <http://vestnik.mednet.ru/content/view/1269/30/lang,ru/)>.

[11] OLAGANATHAN, R – AMIHAN, R. 2021. Impact of COVID - 19 on Pilot Proficiency – A Risk Analysis. In Global Journal of Engineering and Technology Advances. 2021. [online]. [Cit. 2022-03-09]. Available: <https://doi.org/10.30574/gjeta.2021.6.3.0023>.

[12] ASN Accident Statistics Highlight Need for More Work on Runway Excursions, Conflict Zones. 2021. [online]. [Cit. 2022-03-09]. Available: <https://news.aviation-safety.net/2021/01/06/asn-accident-statistics-highlight-need-for-more-work-on-runway-excursions-conflict-zones/>.

[13] The impact of the financial crisis on labour in the civil aviation industry. [online]. [Cit. 2022-03-31]. Available: <https://www.ilo.org/sector/activities/topics/crisis-recovery/WCMS_161566/lang--en/index.htm>.

[14] Air Passenger Numbers to Recover in 2024. 2022. [online]. [Cit. 2022-04-01]. Available: <https://www.iata.org/en/pressroom/2022-releases/2022-03-01-01/>.

[15] After COVID-19, Aviation Faces A Pilot Shortage. [online]. [Cit. 2022-04-01]. Available: <https://www.oliverwyman.com/our-expertise/insights/2021/mar/after-covid-19-aviation-faces-a-pilot-shortage.html>.

[16] Pilot and Technician Outlook 2021–2040. 2021. [online]. [Cit. 2022-04-01]. Available: <https://www.boeing.com/commercial/market/pilot-technician-outlook/>.

[17] NOVÁK SEDLÁČKOVÁ, A., PITOR, J., MRÁZOVÁ, M. 2015. Crisis management in aviation. 1. vyd. - Bratislava : DOLIS, 2015. - 152 s., ilustr. - ISBN 978-80-8181-000-8.

[18] NOVÁK, A., TOPOĽČÁNY, R., BRACINÍK, T. 2009. Výcvik leteckých posádok s využitím nových technológií. Žilinská univerzita, Fakulta prevádzky a ekonomiky dopravy a spojov, 2009. - 94 s. ISBN 978-80-554-0108-9.

[19] AŽALTOVIC, V., ŠKVAREKOVÁ, I., PECHO, P., KANDERA, B. 2020. The correctness and reaction time of piloting the unmanned aerial vehicle. Transportation Research Procedia, 2020, 51, pp. 342–348. ISNN 23521457.

https://doi.org/10.26552/ pas.Z.2022.2.14

DIGITALIZATION OF THE MAINTENANCE PROCESS FOR THE NEEDS OF THE CAO ORGANIZATION

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Abstract

Digitalization and automation are unstoppable processes that are linked to the present and have a significant impact on the efficiency of the work carried out in aviation or any other industry. The aim of this article is to create a digital maintenance environment for the needs of the Combined Airworthiness organisation (CAO), which is part of the Air Training and Education Centre of the University of Žilina. Such software would unify and facilitate the overall maintenance process performed by the CAO. In this article we have evaluate the requirements of the CAO organisation and the legislation in force. During the development process, we communicated extensively with both the experts and the maintenance staff for whom we were developing the program. Then, based on what we learned, we created a basic structure of the required software and hardware needed to create a digital maintenance environment and started building it. We have then described all the processes involved in the program and its components to the extent that this article can partially serve as a guide for the creation of such a program. Methods of drawing on software and hardware resources have been purposely limited in the article to free products or to those, that are commonly available in price. The work has resulted in functional software that contains all the necessary documents, job cards and forms to carry out maintenance and substantially replaces the more paper-intensive form of data entry and storage.

Keywords

Digitalization. Maintenance. CAO. LVVC ŽU. Server. Software. Linux.

1. INTRODUCTION

In today's modern age, technology and the digital environment impacts our daily activities without us realising it. We live in an era of unlimited digital possibilities and innovations that are advancing rapidly. These innovations have been adopted by many industries in recent years, including aviation. Aviation is widely known to be a conservative industry. Rapid change and the rapid emergence of new standards are not typical of aviation. This is because of caution and safety, as the latter is paramount in aviation. This also applies, for example, to the introduction of electronic software for maintenance-related records. Due to the level of security and their complexity, these software are often unaffordable. Although these software are currently on the rise, the cost of operating and licensing them is often beyond the budget of smaller maintenance organisations. The CAO associated with the University of Žilina's Aviation Training and Education Centre is no exception, and this motivated us to come up with the idea of creating our own software, using our own resources and capabilities, that would be inexpensive to operate.

After consulting with the maintenance staff and CAO leaders, we started building and putting ideas on paper. In this thesis, we analyse the necessary legislation that is integral knowledge for further development and integration of applications and programs into the CAO environment. We then present our design for the digital interface of the proposed software and continue with a detailed description of building the foundation for the entire software. The goal of this thesis was to produce a foundation for building CAO digitization software that would be easy to use and contain all known elements such as currently used job cards and other documents.

2. BACKGROUND

In today's technological era, it is no surprise that digital transformation is one of the most fundamental drivers of change and presents a unique opportunity to shape the future. For this reason, much of the aerospace industry is looking to digitise its technical documentation and maintenance operations to facilitate document management. However, the digital revolution, particularly in maintenance, repair and overhaul (MRO), has been slow to take off for a number of reasons like the complexity and size of manuals, older data standards such as ATA iSpec 2200 or different rules in member states regarding digital practices.

2.1. Current PC programmes in use

The maintenance process in the CAO organisation at the Air Training and Education Centre of the University of Žilina, hereinafter referred to as LVVC ŽU, is currently partially digitised by means of commonly available software from the Microsoft package such as MS Office, MS Excel, MS Access. These software packages are simple and can be used by any member of the maintenance staff. The administrators of these software are the manager of the Combined Airworthiness Organisation (CAO) and the Director of LVVC.

During the last years, the maintenance staff has been working within its own resources and capabilities to create electronic databases that would facilitate the work with the technical records of the aircraft operated at LVVC ŽU. This work has resulted in the creation of Microsoft Excel and Microsoft Access spreadsheets containing the following service information.

- Life Limited Parts and Special inspection list;
- Recurring Service Bulletins (SB) and Airworthiness Directives (AD);
- Communication and Navigation (COM/NAV) equuipment list;
- SB, Information Service Bulletines (ISB), Service Letters (SL), AD;
- SB, SL, Service Instruction (SI), AD for propeller;
- SB, SL, SI, AD for engine;
- Status of changes, repairs and damage;
- Accident record;
- Weight and Balance (W&B) change record;
- Instructions for continuing airworthiness (ICA);
- Maintenance order;
- Maintenance work order;
- Job cards;
- Finding report;
- Certificate of Release to Service (CRS).

2.2. The contribution of digitalisation in the CAO organisation

For the CAO organisation, digitisation can help create faster and more efficient ways of checking maintenance records. The main reasons for digitization are:

- Reducing risk of human error;
- Reducing security risks;
- Improving maintenance delays;
- Improving the flow of information between maintenance technicians and organisation managers.

Paper documents are often complex files, especially when considering the long maintenance history of older aircraft. It is highly likely that the maintenance history may not be complete, as over time paper documentation may be lost or degraded when files are transferred or moved from one organization to another, or when the organization changes office space. As more operators become involved over time, the risk of missing documents can increase - but digitising records could significantly mitigate this risk.

There is no doubt that updating the current culture of technical documentation is a multi-layered and complex challenge. Many things currently stand in its way, such as various organisational and regulatory processes. However, it is up to the aerospace industry, from aerospace engineers and company executives to manufacturers, suppliers and regulators, to come together to address this challenge in the interest of a more standardised global industry. Such shared responsibility would ensure that important technical and maintenance documentation poses less of a safety risk [1].

2.3. Information on available applications

Currently, there are many forms of applications that would meet the requirements of the CAO organization under the LVVC ŽU. Some of the available applications on the market that could meet the needs of a CAO organization were developed in the framework of the master thesis by Ing. Dominik Mikulec, who compared Flight Office, SAM and Envision. He compared the programs in terms of content and benefits, but from the analysis he concluded that only Flight Office is suitable, as this program is the most affordable and contains all the necessary attributes for the operation of CAO records. The cost of running such an application would be approximately EUR 1400 in the first year and approximately EUR 480 annually thereafter [2].

2.4. Electronic aircraft maintenance records

The current ICAO provisions on aircraft maintenance records and continuing airworthiness records describe the use of both paper and electronic formats. Currently, aircraft maintenance records are mostly kept in paper form. However, aircraft operators, aircraft manufacturers and maintenance organisations are steadily moving towards the use of electronic aircraft maintenance records (EAMRs) and continuing airworthiness records and digitally supported aircraft maintenance information. This includes electronic maintenance records and continuing airworthiness records for aircraft, engines, propellers and related parts. Some States have already published advisory material on the use of EAMR and continuing airworthiness information, already allowing aircraft operators, aircraft manufacturers and maintenance organisations to use EAMR and digitally supported aircraft maintenance information [3].

Guidance material on EAMR and continuing airworthiness records has been included in the unmodified edition of the Airworthiness Manual - Doc. 9760 approved in July 2020. At present, the Slovak Republic does not have any guidance material of its own in relation to EAMR.

2.5. Assesnebt of the regulatory base

The CAO is required to have all the records mentioned above and is also required to archive them accordingly. This means that this information is currently recorded in partially digitised databases created in MS Excel, which has made it much easier to find the necessary documents and increase their clarity. However, there is still a lot of documentation that is archived in purely paper form, which represents a large number of records after years of aircraft operation. These quantities of records could be rapidly reduced by a process of digitisation of the maintenance environment, including the digitisation of all aircraft records. However, the Slovak legislation is currently not set up and fully prepared for such a form of digital records as well as their control, therefore it is still necessary to print and store these documents in case of an external audit. These are mainly output documents related to the airworthiness of aircraft.

However, for the internal needs of the CAO, such fully digital records may be maintained in parallel with paper documentation. The introduction of a digital maintenance environment together with digital record keeping would prepare the CAO for the future transition to a fully digitalised EAMR environment as presented by ICAO in document 9760.

3. DESIGN AND STRUCTURE OF THE DIGITALIZATION PROGRAMME

The aim, is to design and create the basis of a digital maintenance environment for the technical staff of a CAO organization. It also includes the design of a simple maintenance order entry system along with the design of digital job cards. These designs are based on the basis of currently used documents and forms.

3.1. Design of the logical process structure

In the following sections, we present the design of the individual logical process structures. These processes build on each other and all the interconnections are explained in the individual subsections.

3.1.1. Login

The interface of the application, whether on a fixed or portable device, should have uniform basic attributes, which may differ in graphical representation depending on the device on which the application is used, but their essence and meaning must remain the same.

In the case of the application login process, it is necessary to select which person with which authority wants to log in to the program. There are two options to choose from: Administrator and Worker. The login can be made up of the person's last name and first name or an identification number or license number. The user password should be strong enough. It should be formed by a personal identification number or PIN, a cryptographic key or by attaching a card to a reader. In the future, two-factor authentication of the user's identity could be added to the password.

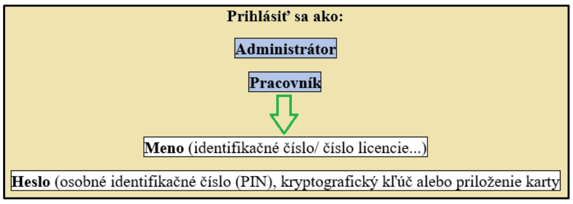

Fig. 1. Application login window design

3.1.2. Basic interface

After logging into the application, the basic interface is displayed to the user. This is made up of a list of actions that can be performed. The available actions vary based on the user account through which the user has logged in.

3.1.3. Admin interface

This interface has more items available than the maintenance worker interface. There are action items "Fleet, Enter Maintenance Order, End Maintenance Order, Maintenance Database, Update, Ongoing Maintenance" and the interface can be extended with other actions. The "Fleet" item will list the aircraft with the number of hours flown and hours remaining until inspections. Through the "Enter Maintenance Order" command, the administrator will be able to assign tasks to be performed by individual maintenance personnel. For a quick overview of how maintenance is progressing on the aircraft, there may be an option to view the maintenance in progress, where it will be written which worker is working on which jobs and how they are progressing. The "Maintenance Database" item will contain a long term database of all inspections performed on the aircraft, which will also be backed up on another disk. The administrator should have the possibility to additionally add or delete information via the action item "Update".

3.1.4. Maintenance worker interface

The interface that is displayed to maintenance personnel has fewer responsibilities than the admin interface. This type of interface includes the actions "Fleet, New Maintenance Order, Maintenance in Progress, Maintenance Database, Current Information, Search" and a place to add additional actions. When an Administrator enters a new maintenance order, after logging into the worker's account, the worker to whom the order was entered will see a notification on the "New Maintenance Order" item. The worker will then complete and execute each procedure according to the maintenance type. "Current Information" contains any changes/updates that the administrator has made.

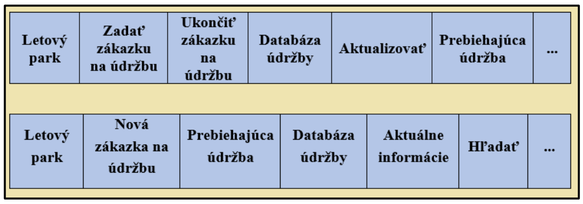

Fig. 2. Application interface design for administrator (top) and maintenance worker (bottom)

3.1.5. Flight fleet

The action item "Flight Park" is common to both the administrator and maintenance worker accounts. When clicked, a list of aircraft maintained in the CAO managed environment, including the LVVC ŽU fleet, will be displayed. It should be possible to add additional aircraft to the application as the CAO is authorized to maintain aircraft outside of their fleet.

The list of aircraft is created via a scrolling window with an alphabetical list of aircraft matriculation marks (Figure 3. shows a generic list). After selecting an aircraft by matriculation mark, a background with the selected aircraft is displayed. The aircraft type is displayed with basic data (Serial Number (S/N), Flight Hours, Hobbs (motor hours), Number of Landings, Hours to Next Inspection, etc.).

Also, an algorithm can be set up to colour-code the need to prepare the aircraft for the next inspection according to the number of hours remaining and the current use of the aircraft (green- inspection is still "far away", yellow- inspection will come in "n" hours or in "n" days (for the current use of the aircraft), red- aircraft needs to be withdrawn from service), similarly to the document of parts with a limited service life and the list of special inspections.

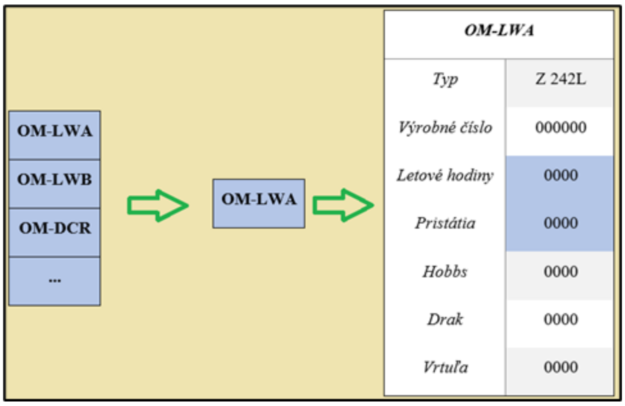

Fig. 3. Proposed structure for displaying the list of aircraft and consequently their basic information

3.1.6. Maintenance order

At the heart of the entire program is the ability for the administrator to enter a maintenance contract to the maintenance technicians using the "Enter Maintenance Contract" action item. If an aircraft needs to be inspected, the administrator selects from the list of aircraft (the same as in the "Fleet" item) the specific aircraft on which maintenance needs to be performed and what type of maintenance needs to be performed.

- The administrator selects the aircraft to be maintained from the list.
- The administrator shall select from the list the type of maintenance to be performed.
- The administrator shall select the maintenance personnel to carry out the maintenance.
- The administrator confirms the selection of the aircraft, type of maintenance and maintenance personnel and submits the order.

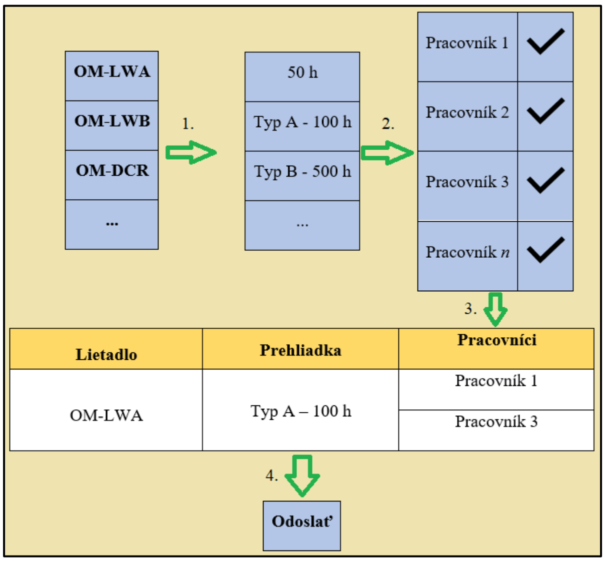

Fig. 4. Proposal of the principle of a logical contracting structure

4. ESTABLISHING THE BASIS FOR A DIGITAL MAINTENANCE ENVIROMENT IN CAO

The aim, is to create a digital maintenance environment for the needs of a CAO organization. Digitizing the maintenance process in a CAO organization is a time consuming and complicated challenge, therefore it should be created and implemented in a phased manner. As mentioned earlier, there are currently many functional and available applications and software for maintenance organizations. However, these software are costly to operate and a small organization such as the CAO at LVVC ŽU cannot afford to fund such a program at this time. Therefore, the idea of developing such software using own resources was conceived.

The problem of designing an electronic aircraft maintenance planning system for ATO needs was dealt with by Ing. Dominik Mikulec. In his work he created a proposal for the structure of the aircraft planning system and the interconnection of the information flow between the ATO and the maintenance organisation. In this thesis, we deal with the design of the digital maintenance environment and its creation.

4.1. Hardware selection

Firstly, it is necessary to select the appropriate hardware that will serve as a server and ensure the smooth operation of the application and information flow. The following factors need to be taken into consideration when selecting the hardware:

- Dimensions
- Processor
- Operating memory (RAM)
- Storage

For example, a server where documents and folders will be stored needs a less demanding processor, so we can save on energy, but on the other hand it needs a much larger storage for data processing. A web server needs a larger amount of RAM than a document server, this depends on how many users we intend to connect to the server. The dimensions of the server are important when choosing where we want to store it. The server should generally be stored in a well-cooled, dark room with air conditioning to ensure that the heat produced by the internal parts of the server is dissipated and new, cool air is brought in.

As a basis, we have chosen a desktop computer (PC) with classical dimensions with an Intel Core 2 Quad Q 6600 processor, a Samsung 80 GB SATA HDD and 3.24 GB RAM. For the initial start-up and setup of the server, a monitor is also required along with a keyboard.

4.2. Software selection

The original operating system on the PC was Windows XP Professional, Version 2002. However, for our server's operating system, we selected Linux Ubuntu 20.04, which is an open-source operating system that provides a five-year warranty of software support and security in regular updates. This operating system is very stable and therefore suitable for building structured applications or setting up a server.

4.3. Software setup

After successfully installing the server on our PC, we need to set up the root account. The root account is unavailable after installation for security reasons, as we can use root commands to change basic settings and access all commands as an administrator. For our server's needs, we will access root using the command: sudo passw root and type the password for root in the next line. The password for the root administrator is never the same as the password to access the server, so you must enter a different one.

Continue by installing net tools. Net tools is an important toolkit in Ubuntu for controlling the network subsystem of the Linux kernel. These include arp, ifconfig, route, rarp, nameif, and netstat. In addition, this package contains tools related to specific types of network hardware and advanced Internet Protocol (IP) configuration options [4].

For remote server administration, port 22 , which is required for Secure Shell (SSH) communication, must be enabled. This port itself is not secure and poses a potential risk of unauthorized access to the server. Therefore, when enabling port 22, it is necessary to have a password set on the server.

To enable port 22, use the ufw allow 22/tcp command. The abbreviation UFW stands for uncomplicated firewall. This is used to manage the Linux firewall and aims to provide a simple interface to the user [5].

A port is generally used to let the computer know what type of data is being received from or sent to the computer over a similar network connection. Each port is assigned a different function and number. A port is a virtual numeric address that is used as an endpoint to communicate with various protocols [6].

From this point on, we could control our server via remote access, using the PuTTY software. PuTTY is a client of SSH and other protocols (Telnet, rlogin, TCP and terminal) for serial port connections.

Next, we downloaded the Snappy software. Snap is a package of applications and dependencies that works without modification on various Linux distributions. It works as a superstructure to simplify the control of web services and evaluates what the server needs to download (e.g. PHP, SQL, Apache) Snappy can be found and installed from the Snap Store or by using the terminal command sudo apt install snap. After entering this command, a password was required. Along with snap, we also installed Wget, which is software for reading the contents of files from various web servers, using the sudo apt-get install wget command. Wget stands for world wide web get and supports downloading via FTP, SFTP, HTTP and HTTPS.

4.4. Establishing the basis for a digital enviroment

The output of this is to create the basis of a digital maintenance environment for the CAO organisation. In the previous chapters we described how we proceeded to create the foundation-a server that will be used to store all maintenance information. In order to work with the server and use its full potential, we needed to install the Nextcloud software.

Nextcloud is a client-server software package for creating and using file hosting services. It is ready to be used in enterprises with comprehensive support options. As it is free and open source software, anyone can install and run it on private devices. Nextcloud is functionally similar to Dropbox, Office 365 or Google Drive when used with the integrated office suite solutions of Collabora Online or OnlyOffice. It can be hosted in the cloud or in an on-premises environment. It is scalable from home office solutions to full-fledged data centre solutions used by millions of users [7].

To install the Nextcloud software, we used the following sudo snap install nextcloud command to install it on our server. For the software to work properly, we needed to enable ports 80 HTTP and 443 HTTPS using the ufw allow 80/tcp and ufw allow 443/tcp commands. This allowed our server to communicate with the network using these protocols. Port 80, is only opened when the security certificate is verified.

By default, port 80 is used for HTTP connections. It is a popular and widely used port on all over the world. A user can use this port to connect to websites available on the Internet. This means that unencrypted data is exchanged between the user's browser and the server using this port. On the other hand, the secure version of HTTP is HTTPS, which uses port number 443. This port establishes a secure connection between the website and the browser. The main difference between port 80 and 443 is strong security. Port 443 allows data to be transferred over a secure network, while port 80 allows data to be transferred in plain text. Therefore, when accessing an insecure site that does not have HTTPS, the user receives a security warning [23].

After enabling the ports, and installing the Nextcloud software on our server, we proceeded by logging into Nextcloud on the other machine. We again typed the IP address of the server into the browser in the following format: http://10.10.10.116 and connected to the web interface of the Nextcloud site. First, we then created an administrator account, from which we created the entire digital environment on the site.

First, we used the admin account to create the admin interface. Through the add files item, we created a group of files representing our proposed look and feel for the admin interface. We then uploaded the relevant documents to the individual folders.

Subsequently, for the purposes of this thesis, and to validate the functionality of client-server communication, we created fictitious users to represent the maintenance staff. In the application, we created 4 accounts for the maintenance technicians, and one for the maintenance manager. For their accounts, we had to create email addresses with which the server would be able to contact them. We created these addresses using Gmail accounts, and we set up the server's e-mail on the Centrum.sk web.

Using the maintenance supervisor account, we created an event in the calendar, with a description of the inspection, the aircraft type, and assigned several maintenance workers to it. Once the data was saved, the server automatically contacted the required maintenance personnel via their email. Emails from the server appeared on the maintenance workers' accounts, with an invitation to the event. The event description contained the exact information entered by the administrator. After the maintenance workers accepted or declined the invitation, the maintenance manager's account showed a confirmation for the event.

5. CONCLUSION

In this thesis we have dealt with the development and building of software for the CAO organization, which is part of the Aeronautical Training and Education Centre of the University of Žilina. First of all, we analysed the current state of the problem in detail. The current state of slow digitalization in smaller maintenance organizations is often due to the high price of software, which these organizations cannot afford. Another problem is that outdated standards are currently being used and are only slowly being replaced by new, compatible standards. The lack of national legislation on this issue is only contributing to the slower uptake of the digitisation of maintenance processes.

Therefore, we decided to create a set of information and available legislation on the subject. In this way we can help the CAO to better prepare for future changes in national legislation that will result from the new European standards and regulations. In this paper we describe in detail the current technologies and procedures used in carrying out maintenance, most of which are in paper form. Furthermore, we present the design of a digital maintenance environment that is simple, clear and structurally contains all current procedures.

The output of this thesis is a working software that serves as a basis for the future building of the digitalization of the maintenance process. We have described its construction and development in detail in the core of the thesis, explaining the individual steps. The built server forms the basis on which the CAO organization can further build its digital interface. The server can use simple software to send emails and alert maintenance staff of incoming inspections or other important information. This server can store data related to maintenance in the CAO.

Creating comprehensive software that can match current licensed software is a complex and time-consuming task. Therefore, the created server can also serve as a good basis for further bachelor and diploma theses, which would further build individual parts of the maintenance digitalization software on its basis.

REFERENCES

[1] HERBERT, I. 2020. Why MROs should go digital with technical documentation. [online]. [cit. 2022.03.06]. Dostupné na internete: <https://resources.vistair.com/articles/why-mros-should-go-digital-with-technical-documentation>.

[2] MIKULEC, D. 2021. Návrh elektronického systému plánovania údržby lietadiel pre potreby ATO. Diplomová práca. Žilina : Žilinská univerzita v Žiline, 2021. 72 s.

[3] ICAO. 2021. Electronic Aircraft Maintenance Records (EAMR) and Continuing Airworthiness Records. [online]. [cit. 2022.03.09]. Dostupné na internete: <https://www.icao.int/safety/airnavigation/OPS/airworthiness/Pages/EAMR.aspx>.

[4] UBUNTU. 2022. Binary package „net-tools“ in ubuntu bionic [online]. [cit. 2022.04.09]. Dostupné na internete: <https://launchpad.net/ubuntu/bionic/+package/net-tools>.

[5] nixCraft. 2021. How to open ssh 22/TCP port using ufw on Ubuntu Linux [online]. [cit. 2022.04.09]. Dostupné na internete: <https://www.cyberciti.biz/faq/ufw-allow-incoming-ssh-connections-from-a-specific-ip-address-subnet-on-ubuntu-debian>.

[6] LINUX JOURNAL. 2008. Graphic Administration with Webmin [online]. [cit. 2022.04.09]. Dostupné na internete: <https://www.linuxjournal.com/magazine/graphic-administration-webmin>.

[7] 9TO5LINUX. 2021. Canonical, Collabora, and Nextcloud Deliver Work From Home Solution to Raspberry Pi Users [online]. [cit. 2022.04.09]. Dostupné na internete: <https://9to5linux.com/canonical-collabora-and-nextcloud-deliver-work-from-home-solution-to-raspberry-pi-users>.

[8] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

[9] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

https://doi.org/10.26552/ pas.Z.2022.2.15

THE ISSUE OF GLYCAEMIA AND HEART RATE VARIABILITY OF FLIGHT CREW DURING EMERGENCY SITUATIONS USING HRV CORSENSE ELITE

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Abstract

The purpose of this article is to research the issue of glycaemia and heart rate variability (HRV) of flight crew, while these physiological processes are investigated during emergency and abnormal situations on the flight simulator. Stressful situations, which pose dangerous emergency situations for pilots during the flight, raise blood sugar level to ensure the brain has enough glucose during stressful situations. The attention is also given to assessing the effect of fasting blood glucose on flight crew performance, stress and heart rate variability. We try to focus on the overall evaluation of the impact of the above physiological processes during flights in which selected emergencies occurred in order to increase the level of stress hormone – cortisol, which is produced during workload and stress. The autonomic nervous system and its parasympathetic and sympathetic branches affect the heart functioning and its activity. The methods used to measure blood glucose and heart rate variability are non-invasive methods of measurement. The survey compares the results of measurements from samples of ten pilots studying the field of professional pilot. As proper eating habits are important for safe flight, we are trying to find out how the absence of food for at least 12 hours can affect pilot's performance as well as heart rate variability in the research.

Keywords

anatomy and physiology, diabetes mellitus, glycaemia, flight simulator, nervous system, emergency situations, workload

1. INTRODUCTION

Flight crew members work under immense pressure and demands placed on them by airlines, which can ultimately be the cause of potential negative events, including aviation accidents or incidents. With the ever-increasing trend in the introduction of innovative systems into aircraft, aviation technology professionals are striving to take as much of the burden off the pilot as possible when performing flight-related tasks in order to achieve the highest possible level of safety in the aviation sphere. The pilot, as a key link in the whole aviation industry, is affected by a wide range of physiological, psychological and physical characteristics and, insofar as they can affect the overall performance of the flight crew, they have by their nature a direct impact on the safety of air operations. Safety in aviation is a much debated concept today. Due to its demanding nature, the profession of pilot is one of those professions, in which it is essential to be in perfect physical and mental condition. If we looked back to the not-so-distant in the past, we would found out there were regulations which prohibit pilots from practising this type of profession in the event of a serious illness, such as diabetes mellitus.

Since the issue of glycaemia in flight crew is not a much researched area, for this reason we decided to go deeper into the above mentioned issue and try to explore the area of human performance from multiple perspectives. In aviation research, heart rate monitoring of flight crew members provides an overall index of the workload on pilot. It is with heart rate variability, also known by the acronym HRV, as a promising measure, that we decided to turn out the attention to this important factor as well. Based on a review of the available literature and the research conducted dealing with these two fundamental facts, we decided to set as the subject of our investigation the issue of glycaemia and heart rate variability in pilots during abnormal and emergency situations. The primary objective of the research was to investigate the effect of glycaemia on heart rate variability, and we also wanted to observe how these two parameters behave under the influence of different types of emergency and abnormal situations during flight on the flight simulator. However, it is important to note that we focused our attention to measurements when pilots were in a fasted state, and the time between the last meal consumption and the test flight had to be at least 12 hours.

2. DIABETES MELLITUS AS A HORMONAL AND METABOLIC DISORDER

Humanity has been plagued by diabetes, as a type of hormonal and metabolic disease, practically since time immemorial, for more than 3,000 years. With its unfortunately adverse and unpleasant effects, it particularly affects the daily life of several social segments of the world; the affliction of diabetes mellitus in flight crew is no exception, while the prevalence of the disease in pilots has been a subject of controversy for many years on the ground of inconsistent legislation in different parts of the world. In not so distant times, in aviation all over the world, the diabetic pilot was considered as an oxymoron, because the pilot profession is conditioned by perfect health corresponding to the requirements. When diabetes mellitus occurs in applicants for this type of profession and in pilots who hold an ATPL or other licence, the pilot's medical condition is closely examined by medical supervision, and various restrictions are placed on the issue and granting of restricted certificates to fly. A huge controversy in the field of diabetes diagnosis in insulin-treated pilots has been caused by the potential value of the performance required of pilots to carry out the profession with the utmost professionalism, as there is no space for human error in aviation [1] [2] [3].

To the above characterized multifactorial disease, which affects the human individual throughout life, we could add attributes such as the most economically costly, medically most serious chronic and often disabling disease, limiting all activities of persons with diabetes mellitus, based on its impact and severity [4].

For specific profession of diabetics, a cumulative assessment of exposure to various forms of stress and stressful situations is essential, and the profession of pilot belong among the extremely difficult jobs by virtue of its demanding nature, both physically and mentally. In particular, newly recruited transport pilots who are new to their field are under more stress than pilots who have been with the airline for some time. When a pilot who has been employed by an airline for a short period of time is treated by insulin for diabetes mellitus, he or she may experience fluctuations in glycemic levels due to exposure to a variety of stressors. The general recommendation for such a matter is to change from a job with too much stress to a less stressful type of job, after mutual agreement with a certified aviation doctor [4].

2.1. Metabolic basis

Carbohydrate metabolism in organisms, which biochemically include monosaccharides such as fructose, galactose, and the essential glucose, is characterized by a complex interplay of interactions between certain disorders and enzymatic pathways. Searching for the best definition of diabetes mellitus in relation to the metabolic processes typical for the disease, we came across the definition of the general meaning of the medical term "diabetes mellitus" by the Portuguese Society of Diabetology (PSD). The PSD generally states that it is a dysfunction with multiple aetiologies, in which chronic hyperglycaemia with metabolic disturbances is the typical presenting symptom of the disease. The aforementioned hyperglycaemic symptom is caused by insufficient secretion or even insufficient action of insulin, and if these defective processes continue for a prolonged period of time, degenerative processes occur in the organs, namely the brain, eyes, heart, blood vessels and kidneys, or even organ failures, which, if diabetes mellitus is inadequately, improperly and especially in the absence of treatment, can lead to the extinction of human life [1] [2] [5].

Glucose, serving as an essential and indispensable fuel for the major part of human body processes, is taken in the form of complex carbohydrates contained in the consumed food. Into the vital fluid represented in our bodies and in the bodies of animals by the blood, glucose enters by release as a result of the process of digestion, which is transported with the aid of the blood to the end organs of the body, in which it represents a function as a source of necessary fuel. In order to avoid the adverse and severe consequences of unusually low or unusually high blood sugar in living organisms, the healthy body of an individual can normally maintain relatively tight control over the level of glucose found in the blood. The dietary intake of living individuals should be at certain regular intervals, but there are also periods of fasting which human beings have established between regular intervals of eating. But since the human body can adapt itself relatively quickly to the varied external conditions found in the environment, the body of the individual has also been able to adapt itself to this existing fact over the course of several generations. In general, it can be argued that hormone production is dependent on the unit of time, which means that hormones are produced at different times during the day to lower blood glucose levels and to promote the storage of this monosaccharide after the consumption of food, also to raise blood glucose levels and to release it from the so-called "storage sites" during the aforementioned periods of fasting between meals. If we consider a healthy human individual, i.e. an individual without diabetes mellitus of any type, in the manner described above, his body is able to maintain the functioning of normal carbohydrate metabolism, which is accomplished through the coordinated interaction of glucose and the various controlling hormones, and it is insulin, as a complex molecule, that is one representative of these key regulatory hormones serving for the control and supervision of blood glucose [3].

"The harmonious couple in the house on the island"- insulin and glucagon, as the French physician P. J. Lefèbvre called these hormones, are key and important hormonal factors regulating energy metabolism. The β-cells of the Langerhans islets are the cells responsible for the secretion of insulin, initially a precursor of the hormone proinsulin, which is subsequently hydrolysed to give active insulin and, in addition, a metabolically inactive fragment of C-peptide. The β-cell marks the basis for the act of cleavage of proinsulin into insulin with the C-peptide, where this act, better said cleavage, also takes place. After consuming a diet, a person may notice that he or she has an elevated blood glucose level, which acts as a trigger for the next event, which is the release of insulin from the β-cells of the Langerhans islets [3].

Glucose is released into the blood circulation when blood glucose levels are lower, indicating, for example, a fasting state. The origin of this glucose would be found in the breakdown of glycogen internal reserves and in the increased amount of endogenous glucose production. Author D. G. Newman states in his report that there is even slight evidence to show that the kidneys are equally involved and play a function in glucose metabolism. In carrying out an action such as the reduction of excessive glucose contained in the blood of an individual to values belonging to the normal range, it must be emphasized that the mission of insulin in the metabolic control of glucose is to arrange for the progress of this action. The entire course of this action is accomplished through three specific modes of action [3] [6]:

1. insulin facilitates the transport and uptake of glucose from the blood into skeletal muscle and fat cells;
2. it also suppresses the endogenous production and release of glucose from important storage depots located in the liver;
3. intensifies the rate of glycogen synthesis contained in the liver [3].

The predominant effects of insulin are associated with a state of satiation, i.e. a certain state after the consumption of food by a human or other living creature. In the opposite state to the satiated state, which is the fasting state, the effects of other hormones are applied to promote the release of glucose into the body's bloodstream, thereby achieving a marked reduction in insulin levels. It is the failure of these aforementioned processes of metabolic control that leads to metabolic disorders, and diabetes mellitus is unfortunately the result of this failure [3].

2.2. Acute complication of diabetes mellitus – hypoglycaemia

From the whole range of complications associated with diabetes mellitus, which are usually further divided by experts into acute and chronic complications, we will deal with only one type of complications, namely hypoglycaemia, which, according to V. Bartoš, among other complications, represents acute complications of diabetes mellitus [7]. In general, hypoglycaemia (low blood glucose concentration) can be characterised as an immediate life-threatening complication due to its severity and possible recurrence, often in diabetes mellitus type 1 patients (more than 90%), that develops when insulin is over administered into the blood of a diabetic patient or when treated with a wide range of oral antidiabetic drugs, intended only for patients with DM2 because of their mechanism of action. In terms of the complication of insulin therapy, the term "major complication of insulin therapy" is assigned to it [3].

“Hypoglycaemia is generally understood as a pathological state of reduced glucose concentration associated with clinical and other biochemical manifestations.” Regarding the measurement of glycaemic values, in general, the established limit of hypoglycaemia in capillary plasma according to V. Bartos value of 3.3 mmol/l [7]. Laboratories located in hospitals generally work with a glycaemic value of 3.8 mmol/l as the lower limit [8].

The action of a variety of hormones in an attempt to raise blood glucose levels can cause most of the symptoms associated with hypoglycaemia, as the development of a wide variety of symptoms can be rapid and have too great a negative impact on the brain in particular, and therefore it is imperative to take action in hypoglycaemia and to start the required treatment. If such a situation occurs when the diabetic is alone or when he sleeps during the night hours, the vast majority of all cases associated with hypoglycemic coma can usually be regulated and corrected even without proper treatment. The other part of the symptoms associated with hypoglycaemia is caused by impaired CNS function, which is caused by, or causes, insufficient amounts of a key fuel supplied to the central organ of the NS - the brain. Since this organ, which is considered to be the most complex structure observed in human beings, is directly dependent on continuous glucose doses [3] [7] [9].

Various investigations that have been conducted in a more detailed study in relation to hypoglycemia and visual reaction time have led to the findings that during the state of hypoglycemia, complex decision-making abilities are impaired. The literature suggests that brain dysfunction in diabetic patients is caused by exposure to hypoglycemia, but it is generally argued that it is in the close examination and subsequent understanding of the various effects resulting from hypoglycemia and its effects on brain metabolites that may prove helpful to scientific investigators in developing new approaches needed in hypoglycemia to reduce brain damage [3] [10].

3. HEART RATE VARIABILITY

"During depolarization of the heart muscle (when it is irritated), which gradually spreads through the heart from the atria to the ventricles, certain potential differences are generated, the so-called action currents, which also spread to the surroundings of the heart, which are recorded on the surface of the body with the help of a clinical diagnostic device - a galvanometer" [11]. The ECG, as the electrocardiogram is commonly referred to in the medical profession, serves as a way for us to express a graphical record of the bioelectric action potentials of the heart (the electrical activity of the heart) over a specific time span and is an established routine diagnostic tool for irregular heart activity. Five distinct points can be observed on the ECG, representing positive and negative oscillations [11] [12]:

- P wave;

- QRS complex;

- T wave [12].

The Heart Rate (HR) has been the most widely used method to assess emotional response or stress in an individual and is the most accessible function suitable for us to record a physiological parameter that reflects the autonomic regulation of the human cardiovascular system and in the body as a unified whole [13] [14]. On the other hand, after several investigations have been conducted, it has been shown that the interval between heart beats (RR-interval) is an indicator of the ability to regulate internal and external demands [13] [15].

The promotion of heart rate variability has been that it is a simple, useful and, most importantly, non-invasive measurement method that serves as a general assessment of the influence of ANS on the heart rhythm of an individual and also represents a kind of insight into the overall ability needed to adapt to stimuli occurring in the external environment [16] [17]. Heart rate variability (HRV) provides useful information about certain differences in the length of individual RR intervals not only for medical personnel or researchers, but also for ordinary people [66].

However, the intervals are not constant but vary from heartbeat to heartbeat, the time between each beat of our "life pump" fluctuates slightly and this difference in time is milliseconds [ms]. Simply put, beat-to-beat HRV measures the change, or difference, between two heartbeats compared to two previous heartbeats. By looking at the beat-to-beat intervals, we can see that they are not constant, varying from heartbeat to heartbeat, and if a person has a higher HRV, it only indicates a better overall health, either in terms of physical or mental state [13] [15]. Conversely, if a person or a flight crew member experiences a reduced HRV, we can conclude that the person is more vulnerable to physical and psychological stressors, as well as to various diseases. In general, the effects of stress will result in changes of a different nature, e.g. biochemical or hormonal, which are characterised by their markedness, but even before these changes, changes in the heart rate parameters will first occur in a stressful situation. "HR is most commonly determined by electrocardiac signal with extraction of QRS complexes and duration of RR intervals." [18].

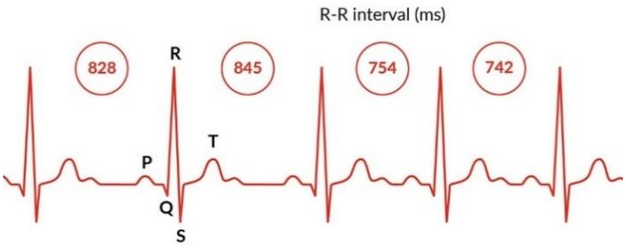


Figure 1 - R-R interval measured in milliseconds as the time between heartbeats that varies from heartbeat to heartbeat [Source: https://www.firstbeat.com/en/blog/what-is-heart-rate-variability-hrv/]

3.1. Heart rate variability and performance of commercial airline pilots during flight simulations

The demands of being a pilot are often closely linked to the stressors that crew members may encounter during the various phases of flight, which can affect pilot performance through their occurrence. A typical stressor in relation to flight performance is the humidity in the cockpit present during the flight, in addition to which fatigue, illness, or death in the pilot's immediate family, as well as many other events, can be a stressor for the pilot. Stress occurring at work, so-called "occupational stress," represents a chronic condition and, together with the workload, can be recognised by various physiological indicators such as salivary cortisol levels, respiratory rate and, for us, the inherently important HRV. In the context of this study, we will encounter the use of HRV to characterize the sympathetic stress response in crew during flight performance [19].

The general assumption for the dependence of HRV on workload in a flight crew member is that the higher the workload, the lower the HRV, or in other words, that the harder the pilot tries, the more regular his heart rate [20]. The participants of the study, conducted from March to May 2017, were active pilots of selected commercial airlines (n = 30 pilots) who voluntarily underwent the subject research. The task of the commercial airline pilots was to perform three flight segments on an A320 flight simulator that was certified by the Federal Aviation Administration (FAA) in the USA. An interesting feature of the study was that in each flight segment, CO2 was present in the cockpit of the flight simulator, the concentration of which varied depending on the flight segment. The research was set up in such a way that pilots had to fly different manoeuvres with varying degrees of difficulty, with the performance of experienced pilots being evaluated by examiners who were pre-determined by the FAA [19].

For the measurement, the authors of the study used the Movisens EcgMove3 sensor, which is a measurement system used for the overall assessment of the ECG and physical activity of a person. The sensor can acquire raw data of single-channel ECG, 3D acceleration, barometric air pressure, as well as temperature, which was then used by the researchers using a software application to calculate HR, HRV, as well as other parameters such as energy expenditure, etc. [19] [21].

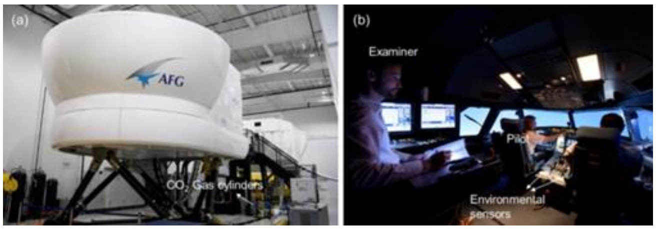


Figure 2 - (a) A320 flight simulator; (b) Flight simulation test [Source:https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6352143/]

4. MEASUREMENT METHODOLOGY

When assessing the appropriate choice of research method to best obtain data relevant to the overall evaluation of the issue under study, we judged that the choice of quantitative and qualitative research would be the most appropriate solution for the area under study, based on the research questions posed in the introduction of the thesis. The basis of the quantitative research in collecting the necessary data in connection with the mentioned issue will be a questionnaire with different types of questions and assessment scales, which we had the pilots fill in before and just after the flight, on the basis of which we were able to assess the psychological state of the participant before and after the flight in the flight simulator. In the case of qualitative research, from a range of choices of research methods in data collection, we use scientific observation, which is characterized by planning the observation some time in advance, systematicity and objectivity, through which the results of the research are not influenced by various subjective factors or factors.

The environment in which the scientific observation was carried out can be described as suitable for conducting the research, since it was a bounded environment or space, which, by its boundedness, is considered to have better conditions that are suitable for the observation process. Although no environment is absolutely perfect in its conditions, we have tried to create as objective as possible conditions suitable for the participants of the research for the undisturbed measurement of the necessary variables. To ensure the overall safety of all research participants, but also from a financial point of view, we conducted observations based on flight simulations and abnormal conditions. For the observations, as one type of the research methods, we used short-term direct observation, which was also carried out with the help of the teaching staff needed to operate the simulator from the instructor's workplace. In the flight simulator, we, as observers, were located at a sufficient distance from the subjects during each measurement due to possible disturbance and influence during the participant's flight activity, which would bias the measurement results.

4.1. Measurement methodolody

For the measurements performed on the flight simulator provided by LVVC, we focused not only on objective but also on subjective measurement methods, the results of which we evaluate and analyse in the following chapter. We decided to use objective (measuring devices, HRV applications) and subjective measurement methods (questionnaire) based on the fact that by obtaining the results of both measurement methods we would obtain comprehensive results that would complement each other, thus also obtaining the pilots' subjective view to assess the possible influence of fasting glycaemia after at least 12 h of fasting and the influence of this measurement parameter on the other measured variables.

Prior to the actual measurements, all participants were briefed and informed about the subject of the investigation. Always the day before the flight simulator measurements, the pilots were instructed when they could take their last meal and from that meal onwards they were not allowed to take any food for a minimum of 12 h. As far as liquids were concerned, only plain water intake was allowed.

One type of reference measurements in the pilot was 2 h after a meal and without the occurrence of an emergency situation, and the second reference measurement was also 2 h after eating a meal, but already with the occurrence of an abnormal or emergency situation. As for the second type of reference measurements, these were performed with the pilot in a fasted state, where the pilot was not allowed to take any food for at least 12 h, the exception being the intake of fluids in the form of unsweetened (plain) water. In the first and second type of measurements, no abnormal in-flight situation had yet occurred, but in the remaining measurements an abnormal or emergency situation had already occurred, but the pilots were not informed in advance of the exact time of the occurrence of this situation, nor on which flight such a situation would occur.

Before measurements started, the participants were asked to fill in a questionnaire that contained different types of questions that allowed us to find out basic information about the participant (gender, age, weight), about his/her family history, and about his/her current condition, where we assessed the length of the pilot's sleep per night, the last time he/she consumed it, and other parameters. Once the pilot completed the pre-flight questionnaire, his blood pressure and glycemia were measured using a glucometer. After the ground training was done, the HRV meter was put on the participant's index finger. We started recording HRV in the Elite HRV mobile app when the pilot was ready for flight. During the flight, we were careful to conduct ATC communications. HRV recording was initiated from pre-flight operations and continued until the aircraft stopped on the runway after landing at LZZI. After the HRV recording was completed, the pilot was given another questionnaire to complete, in which we focused on his/her psychological and medical condition after the flight and to assess whether the fasting glycaemia and the abnormal or emergency situation had a possible influence on the pilot's medical or psychological condition and the possible occurrence of errors during the flight. As well as before and after the flight, we performed blood pressure and blood glucose measurements on the pilot, which were later used to assess the possible influence of emergency situations on glycaemia.

4.2. Pilots

A total of ten pilots underwent the measurements on a voluntary basis and were informed in advance about the course of the individual measurements and the subsequent procedures. All research participants were KLD students undergoing pilot training at LVVC (mainly students in the professional pilot program), with each participant having a different number of flight hours. The fundamentals of IFR flying theory were the criterion for selecting the research participants, which were required to perform flights in different conditions.

The participants were predominantly male, as one female pilot participated in the research. Expressing the gender representation of the participants as a percentage, 90% of the participants were male (pilots, n = 9 participants) and 10% of the participants were female (female pilot, n = 1 participant). The mean age of the participants is a figure of 23.30, the youngest research participant was only 20 years old and the oldest participant was 26 years old. The basic data of the participants such as age and BMI value were shown in Table based on their statistical processing using arithmetic mean, median, maximum (max) and minimum (min) values.

Table 1 - Basic statistics on research participants [Source: Author]

	Arithmetic mean	**Median**	**Max**	**Min**	
Age	23,30	23,00	26,00	20,00	
BMI	23,04	23,43	26,69	19,41	

Through the questionnaire, we also collected other data about the pilots, such as the prevalence of certain diseases in the pilot, including family history, which may relatively affect the HRV results. It is important to note that no pilot is being treated for diabetes mellitus or cardiovascular disease.

Table 2 - Basic data of pilots [Source: Author]

Pilot	**Flight hours**	**Weight**	**Height**
Pilot 1	100 - 150	76 kg	160 cm
Pilot 2	100 - 150	66 kg	178 cm
Pilot 3	100 - 150	82 kg	185 cm
Pilot 4	> 200	65 kg	183 cm
Pilot 5	150 - 200	65 kg	175 cm
Pilot 6	50 - 100	60 kg	158 cm
Pilot 7	> 200	74 kg	178 cm
Pilotka 8	50 - 100	55 kg	153 cm
Pilot 9	150 - 200	65 kg	178 cm
Pilot 10	150 - 200	74 kg	176 cm

4.3. L-410 UVP-E20 flight simulator

The choice of the flight simulator to conduct the research was conditioned by several criteria. In order to assess the impact of abnormal situations on the pilot's glycaemic value and workload, it was necessary to have a wide selection of different types of AS and NS and to model different adverse conditions that would affect the crew's performance. Another criterion was realistic cockpit dimensions in 1:1 scale and general use of the simulator in the wide sphere of the investigated areas. After evaluating the options, the above criteria were met by the L-410

UVP-E20 simulator, a twin turboprop simulator that, by its design and implemented functionality, meets the requirements of the "FTD Level 2" qualification and, in addition, the "FNPT II MCC." When performing flights, there is also the possibility of obtaining audio and video outputs from the course of the flight, from which a number of elements can be subsequently evaluated in the assessment of the pilot's performance [22].

Figure 3 - Flight simulator interior [Source: University Science Park, Flight Simulator]

4.4. Rearch measurement technique

The selection of the types of equipment used was made on the basis of the research questions posed in the introduction to the thesis. Taking into account the ease of use of the instrumentation and the wide choice of measurement equipment needed for the research available on the current market, we decided to use the following measurement devices: the Contour Plus One glucose meter (with kit) and the HRV CorSense with ELITE HRV app.

4.5. LZZI airport and flight trajectory

All participants - pilots who were included in the research are pilots - students at LVVC and for the reason of greater unburdening of pilots we chose LZZI as the aerodrome, although the original plan of the research was to use several aerodromes (LZTT, LZIB), which would have allowed us to induce a greater load on the pilots, including the occurrence of an abnormal or emergency situation just before landing, after take-off, etc. Prior to each flight, pilots were given instructions in relation to the flight. SID (Starndard Instrument Departure) and STAR tracks (Standard Instrument Arrival) were flown.

After takeoff, the pilots proceeded toward the BILNA point and then the ILS for Runway 06 (RWY 06) was flown. The flight, without the occurrence of an abnormal or emergency situation, lasted approximately 20 to 30 min on average. A flight during which an unexpected emergency (NS) or abnormal situation (AS) occurred lasted depending on the pilot's handling of the situation, his experience and the phase of the flight in which the AS or NS occurred. When an AS or NS occurred, pilots used all available navigational aids as a source of situational awareness, ranging from magnetic compass to DME, NDB, and GPS position to ILS. Abnormal or emergency situations occurred at different phases of the flight; we mostly focused on the occurrence of these situations just after takeoff, in the turn, and during the approach to landing. We could see the effect of the pilot's alert state and the occurrence of these situations on the HRVs, which was reflected in the results.

In selecting specific abnormal and emergency situations, we focused on several types of malfunctions, whether aircraft electrical systems, navigation, hydraulic, etc. In most cases, we simulated a left or right engine failure, engine fire in individual measurements. Each pilot flew 8 flights, of which in some flights, the so-called reference measurements, there were no AS or NS. Each pilot had a combination of simulated failures during measurements of the effect of AS or NS on glycaemia and HRV. In some cases of simulated combination of failures and under reduced meteorological conditions, CFIT (Controlled Flight Into Terrain) occurred. In addition to the various disturbances, we also simulated degraded meteorological conditions for the pilots (15 kts winds, occurrence of turbulence, thunderstorms, etc.).

5. RESULTS OF MEASUREMENTS AND ANALYSIS

5.1. Processing blood glucose concentration results from Contour Plus One glucose meter

The results of the blood glucose levels of the research participants were recorded after each measurement in pre-prepared tables, where, in addition to the values of the blood glucose concentrations of the pilots, we also wrote down other necessary data that were related to the specific measurement and could also have a significant influence on the results. In the tables, we also recorded the time of glucose measurement before and after the flight in the simulator, the participant's blood pressure also measured before and after the flight. Of particular importance was the time elapsed since the last meal, and for the fasting measurements we required that the pilot had not eaten for at least 12 h prior to the simulator measurements.

For each glucometer reading, we recorded whether the pilot had experienced an abnormal or emergency situation during the flight, and since pilots experience stress during emergency and abnormal situations, the effect of stress, which increases heart rate as well as glycemia, should be evident in the research results. The glycemia results from the tables were processed for each pilot separately in the form of a graph. We have plotted the glycemia results in the form of two graphs, one graph showing the glycemia results of a particular pilot during all the measurements taken and the other graph focusing on the glycemia value in relation to the occurrence of AS and NS during the flight. Based on the graphs, we can compare the pre-flight and post-flight glycaemia values for the pilots represented by the blue and orange bars in the graphs.

5.2. Processing HRV results with Kubios HRV

The high HRV values we measured in our research using the CorSense HRV sensor reflect the ability of the ANS to adapt to the stressors acting on the pilot at any given moment. These higher values are just a result of the pilot's good health style and are also related to the performance of executive functions. On the contrary, its low values, which can even fall into negative numbers, are a huge disadvantage associated with the poor adaptability of the ANS, while it is related to fatigue, the occurrence of stress and exhaustion. We transferred the HRV results obtained for the pilots during the simulator measurements from the Elite HRV mobile app to a computer and analyzed the results using an innovative and easy-to-use software presented by Kubios HRV. Since we can obtain data through the software that are commonly parameters in HRV, especially in the time and frequency domain, the values that are particularly important for our research are those related to the sympathetic and parasympathetic branches of the pilot, marked in the results sheet as PNS Index for the parasympathetic branch and SNS Index for the sympathetic branch.

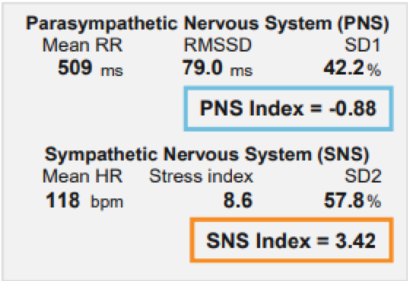


Figure 4 - Illustrative example of PNS and SNS Index results for pilot 10 [Source: Author]

From the above figure you can notice that in the graphs on the left part of the figure we can see the parameters or better said factors like mean RR, RMSSD, SD1 which are associated with parasympathetic and the part of the graph where sympathetic is shown we can see the factors mean HR, stress index and SD2. These are the factors that affect the aforementioned indices that are important for our research - PNS Index and SNS Index. The basic characteristics of the factors that influence parasympathetic and sympathetic are:

Influencing factors of PNS

- Mean RR - mean RR value, longer mean RR interval means lower heart rate and higher activation of cardiac parasympathetic;
- RMSSD - root mean squared difference of consecutive RR intervals, captures rapid changes in RR interval from beat to beat, strongly associated with the magnitude of the RSA component, high values indicate a strong RSA component and high parasympathetic activation of the heart;
- SD1 - Poincaré graphical index in normalized units, to estimate sympatho-vagal balance of ANS, calculate the ratio of low (LF) to high (HF) frequency power from HRV, reflects short-term variability.

Influencing factors of SNS

- Mean HR - mean HR (heart rate), higher heart rate is associated with higher cardiac sympathetic activation;
- Stress index (SI) - stress index, a geometric measure of HRV, reflects stress on the cardiovascular system, high values indicate reduced variability and high sympathetic activation of the heart;
- SD2 - describes long-term variability, use to project points onto a Poincaré plot.

The tables show us the PNS and ANS Index values for specific pilots. Specifically, the first table is a summation of these indices at the reference measurements that we took for each pilot in the research, for a total of 4 reference measurements, against which we then compared the index values when AS or NS occurred in flight. Due to the large number of measurements performed on the flight simulator, in this part of the paper we present the results of only those pilots for whom we found interesting values (pilot 3) and due to the influence of gender on HRV we also present the results of woman - pilot 8. We give a general assessment of the results of all pilots in the conclusion of the paper. For the reference measurements, pilot No. 10, who was fasted and had an occurrence of an abnormal or emergency situation during the flight, had low quality data. Also, one measurement for pilot #8 in the fasted condition with the occurrence of an emergency or abnormal situation had low data quality. Results with low data quality will not be evaluated. In the tables with PNS and SNS index values, these measurements with low data quality are marked in orange.

Table 3 - PNS and SNS Index values for reference measurements [Source: Author]

Reference measurements					
		After eating without AS/NS	Fasting state without AS/NS	Fasting state with AS/NS	After eating with AS/NS
Pilot 1	PNS Index	-0,13	-0,07	1,77	-0,92
	SNS Index	0,81	1,15	1,14	2,02
Pilot 2	PNS Index	-0,08	-0,62	1,85	-1,50
	SNS Index	1,10	1,64	0,62	2,80
Pilot 3	PNS Index	-1,05	-0,44	0,76	1,39
	SNS Index	1,46	1,20	0,83	1,94
Pilot 4	PNS Index	-2,01	-1,51	0,13	0,13
	SNS Index	3,05	1,65	0,96	0,53
Pilot 5	PNS Index	2,26	2,15	1,12	0,82
	SNS Index	1,87	0,79	1,49	1,69
Pilot 6	PNS Index	-0,13	1,24	1,68	1,80
	SNS Index	1,36	0,21	-0,43	0,33
Pilot 7	PNS Index	-0,62	-0,47	3,96	0,13
	SNS Index	2,38	1,73	-0,28	2,29
Pilot 8	PNS Index	4,86	2,87	2,09	3,13
	SNS Index	-0,15	-0,19	-0,35	-0,58
Pilot 9	PNS Index	1,66	1,89	1,49	3,78
	SNS Index	0,50	0,63	1,13	0,74
Pilot 10	PNS Index	-1,02	-1,78	-0,27	1,57
	SNS Index	3,06	2,68	1,79	2,27

Table 4 - PNS and SNS Index values for AS/NS occurrence during flight [Source: Author]

Measurements with AS/NS					
		Fasting state	Fasting state	Fasting state	Fasting state
Pilot 1	PNS Index	-0,62	1,39	-0,9	-0,27
	SNS Index	2,21	1,22	2,16	1,93
Pilot 2	PNS Index	0,42	-1,09	0,07	0,77
	SNS Index	1,4	3,54	0,82	1,02
Pilot 3	PNS Index	1,57	-0,05	-0,4	0,06
	SNS Index	0,91	0,99	0,92	0,84
Pilot 4	PNS Index	-0,62	-1,8	-0,68	-0,33
	SNS Index	2,21	3,51	2,04	1,28
Pilot 5	PNS Index	2,36	0,31	1,86	1,86

Measurements with AS/NS					
		Fasting state	Fasting state	Fasting state	Fasting state
	SNS Index	0,21	0,43	-0,01	0,28
Pilot 6	PNS Index	0,86	-1,02	0,13	1,65
	SNS Index	1,69	2,51	2,29	0,5
Pilot 7	PNS Index	3,96	1,96	0,87	0,85
	SNS Index	-0,28	0,11	0,02	0,38
Pilot 8	PNS Index	4,12	4,66	-1,02	3,43
	SNS Index	-0,43	-0,39	3,06	-0,15
Pilot 9	PNS Index	2,76	1,41	2,88	3,73
	SNS Index	0,53	1,43	0,92	0,65
Pilot 10	PNS Index	-0,79	-0,88	-1,3	-0,66
	SNS Index	4,25	3,42	4,25	3,81

5.3. Results of pilot 3

Because of the number of hours flown in training, Pilot 3 is a relatively experienced pilot and, based on experience, should not be expected to have a greater workload when abnormal or emergency situations occur than pilots with fewer hours flown. The first measurement was the reference measurement, which was taken 2 h after eating a meal. The measurement lasted for 20 min and 42 s, and no AS or NS occurred during the measurement; both the SNS Index and PNS Index values were within standard values. As the pilot was not under any stress load during the flight that could be felt due to hunger or the occurrence of AS or NS, the PNS and SNS values are relatively within normal limits, however, the PNS Index is already in negative values at the reference measurement, indicating an increase in the workload. Regarding the glycaemia values, the pilot took a meal 2 h before the first measurement and the glycaemia value was 5.3 mmol/l before the flight and dropped to 5.0 mmol/l during the flight. The pilot was not exposed to a stressful situation during the flight, therefore, the pilot was not expected to have an increase in glycaemia due to the applied stress, although the PNS Index value speaks of a moderate stress.

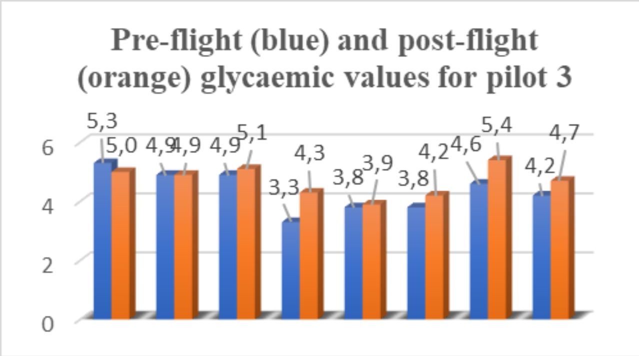
The second measurement (15 min and 19 s) was a fasting measurement, i.e., in a state where the pilot had last taken a meal at least 12 h prior to the measurement. No AS and NS occurred during the flight. PNS and SNS Index were within normal limits, even in this measurement both index values were better than in the 1st measurement. For this measurement, we expected a greater load to be exerted on the pilot due to the fasted state, however, compared to the reference measurement, the PNS Index value increased (Δ 0.61) and the SNS Index decreased slightly (Δ 26). The blood glucose values in this measurement remained at the same pre-flight and post-flight concentrations with a value of 4.9 mmol/l.

During the third measurement, the pilot experienced an abnormal situation, which consisted of a right engine stall, TCAS alert - TA (traffic advisory), and AHRS and HSI stall. The PSI Index was 1.39 and the SNS Index was 1.94. The pilot was 2 h after consuming food with a pre-flight glycaemic value of 4.9 mmol/l and a post-flight value of 5.1 mmol/l. We expected a slight increase in glycaemia after the occurrence of stressful situations, which is also visible in the graph, as the action of stress can increase glycaemia. Comparing this measurement with the first reference measurement, the PNS Index and SNS Index increased compared to the first measurement.

The next measurement, the fourth measurement, was the measurement when the pilot was fasted and the same abnormal situations occurred during the flight as in the third measurement, with one difference, that instead of a TCAS - TA alert, a GPS ejection occurred. The PNS Index and SNS Index values were in positive numbers, namely PNS Index = 0.76 and SNS Index = 0.83. The results of these values can be compared with the third measurement, which is our reference in this case (after eating a meal, with the occurrence of AS). We find that the PNS Index decreased compared to the third measurement, and the same was the case for the SNS Index. The pilot's glycaemia increased more significantly after the flight (Δ 1 mmol/l), which was expected as the pilot experienced AS. Before the flight, the pilot had a lower glycaemia than the first measurement as he was fasting, whereas before this flight the pilot had the lowest glycaemia value of all his measurements (3.3 mmol/l).

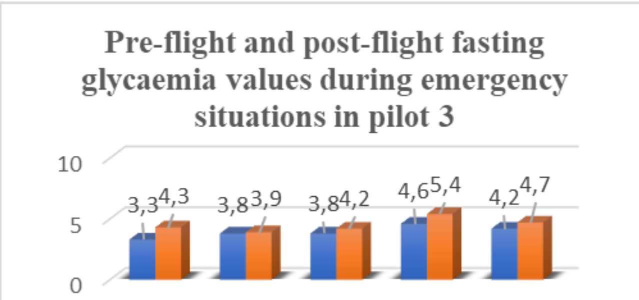
The PNS and SNS Index values at the fifth measurement were PNS Index = 1.57 and SNS Index = 0.91. The PNS Index increased compared to the second measurement and the opposite was true for the SNS Index, which decreased. During this flight, the pilot was fasting when a combination of several ASs occurred, the most serious of which were the following: left engine stall, GPS stall, altimeter stall, artificial horizon stall, AHRS stall, and the occurrence of turbulence with crosswinds and snow. Fasting glycaemia before the flight was 3.8 mmol/l and after the flight was 3.9 mmol/l, but we expected a larger increase in glycaemia due to exposure to more AS. The pilot felt an increased workload especially during the left engine stall that occurred after takeoff, which was later joined by the GPS stall along with the altimeter. The pilot had a higher HR when multiple ASs were combined.

From the tables with PNS and SNS Indices and from the graphs below with fasting glycaemia during AN we can assess that at the sixth and seventh measurements the value of both indices was similar. Compared to the reference second measurement (fasting, no AS), we can conclude that the PNS Indices slightly increased and the SNS Indices slightly decreased. In the sixth measurement, the pilot felt slight effects due to hunger, which manifested itself in a slight distraction and during the flight he started to have a slight headache and felt fatigue. At the seventh measurement, there was a steeper increase in post-flight glycaemia than was the case at the sixth measurement, as at the seventh measurement the pilot had a greater combination of ASs, the most severe of which he considered to be L engine, AHRS and artificial horizon deployment. He experienced an increase in glycaemia as a result of the increased workload imposed by the combination of multiple ASs.



Graph 1 - Glycaemia value for pilot 3 during all measurements [Source: Author]

In the last measurement, which was his eighth measurement, the PNS Index increased to positive values compared to the second measurement, which was fasted and without AS. There were a number of AS and adverse meteorological conditions encountered on this flight. On final, we simulated a left engine (L engine) failure for the pilot. We found the L engine failure to be a more burdensome AS for this pilot than the right engine (R engine) failure. For the adverse weather conditions, we simulated turbulence for the pilot during level flight and just prior to landing, in addition to rain. As for glycaemia, its value increased after the flight, which was the result of the action of several AS as a stressor on the pilot.



Graph 2 - Glycaemia value in pilot 3 during emergency situations (fasting) [Source: Author]

5.4. Results of woman-pilot 8

This pilot was the only woman who participated in our research focusing on glycemia and heart rate variability along with emergency situations.

For the first - reference measurement, the female pilot arrived 2 hours after the meal, and just before the measurement flight she performed a familiarization flight around the circuit to better master the measurements needed for the research. Before the flight, the pilot's glycaemia level was found to be 4.9 mmol/l, after the flight this value increased by 0.02 mmol/l to a value of 5.1 mmol/l. The PNS Index for the first reference measurement was -1.02 and the SNS Index was 2.51, the highest SNS Index measured so far during the reference measurement. It is important to note that no AS/NS occurred during this reference measurement.

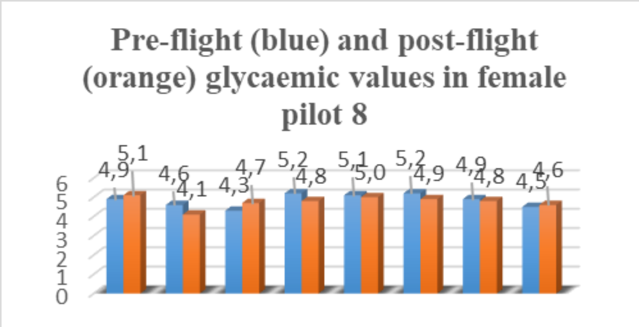
The second flight was characterized by the occurrence of abnormal and emergency situations for which the pilot was not very prepared. It had been 2 hours since the last meal was consumed. The pre-flight glycaemia was 4.6 mmol/l and after the AS/NS flight this dropped to 4.1 mmol/l, which was unforeseen as we expected the glycaemia to rise after the AS/NS. The PNS and INS Index values for this flight are shown in the table.

The next flight, the third flight in the series, was a fasting flight with AS/NS occurrence. During the flight, common abnormal and emergency situations occurred that were also experienced by other participants, so that we can also compare the greatest impact of given types of emergency situations on individual pilots. For the female pilot, in this reference measurement of a fasted AS/NS occurrence, we found that the greatest impact on the female pilot's HRV values was an engine fire that occurred during the approach to landing.

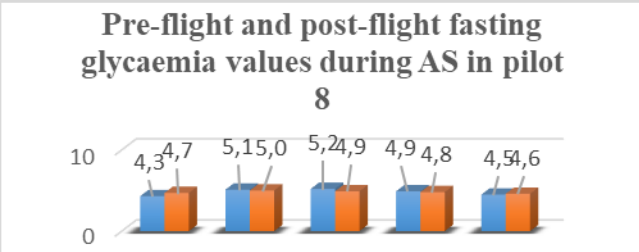
For flights four through seven, these were normal flights during which glycemic levels rose after the flight when the emergency occurred. No emergency or abnormal situation occurred during flight four, as the fourth measurement was a reference measurement for the pilot in the sense that it was a measurement when the pilot was in a fasted state with no AS/NS occurring. We later compared the other flights with this measurement in our overall general performance evaluations.

We consider it important to note about the influence of the fasted state on the female gender. Already during the measurements we took during the summer before the actual research on the flight simulator, which also belongs to the LVVC, we had another female pilot who also felt the effects of the fasted state on her in a big way. In the case of the measurements of female pilot #8, this was the sixth measurement in a row where the female pilot felt a large impact of the fasted state on her health and psychological state. However, the last time the pilot had consumed food was over 20 hours ago. The measurement on that day took place on the simulator in the afternoon. The pilot was experiencing a nervousness that resulted in a slight inattention during the flight when the pilot was distracted. Based on the evaluation of the questionnaire, we found that the pilot was experiencing fatigue, exhaustion, and irritability in addition to hunger. In addition, she also complained of headaches.

The last measurement for this female pilot was taken in the morning, with a total flight time of 5 minutes and 27 seconds. During the flight, abnormal situations such as right engine ejection together with left engine ejection occurred at different stages of the flight. The engine drop occurred in the first turn and just before landing the second engine was also dropped, while a crosswind was simulated before the descent to the runway, when the pilot failed to control the situation and the aircraft rolled over on the runway. The glycaemic value rose by a minimal amount after such a flight.



Graph 3 - Glycaemia value for pilot 8 during all measurements [Source: Author]



Graph 4 - Glycaemia value in pilot 8 during emergency situations (fasting) [Source: Author]

6. CONCLUSION

In the case of our research, carried out on a sample of 10 pilots who are students of the University of Žilina, we reached several results. The primary component of the research consisted of abnormal or emergency situations and fasting glycaemia values. During the emergency situations that we simulated for the pilots during the measurements at different phases of the flight, we found that glycaemia rose in the pilots in several cases after the flight. Gender also has a significant effect on fasting glycaemia, which also influences the pilots' response during abnormal and emergency situations.

However, each person is a unique creature and we believe it is only a matter of training and pilot skill to fly a flight with the occurrence of an emergency situation even in a better state of psychological well-being. Through research we wanted to find out which abnormal or emergency situations have a greater impact on the pilot. Much more stress was felt by the pilots during audio distress signals and during emergency situations that are not very likely to occur, such as one engine failure in a turn and the other engine failure in the approach phase of a landing. By comparing our results with those of other studies, we concluded that fasting glucose levels increase or decrease in healthy people (pilots) exposed to an abnormal situation.

REFERENCES

[1] VOZÁR, J. – KREZE, A. – KLIMEŠ, I. 1998. Diabetest Mellitus. 1. ed. Bratislava : SAP – Slovak Academic Press, 1998. p.286. ISBN 80-88908-20-5.

[2] JÚNIOR, W. P. DA C. – DA SILVA, T. A. 2020. Diabetes Mellitus: Main Characteristics And Perspectives For Civil Aviation. [online].

[3] NEWMAN, D. G. 2005. Diabetes mellitus and its effects on pilot performance and flight safety: A review. [online].

[4] HERCEG, P. a kol. 2019. Dia šlabikár+. 1. ed. Košice : Graphics Studio s.r.o., 2019. p. 383. ISBN 978-80-973473-0-7.

[5] BRITANNICA. 2022. Disorders of carbohydrate metabolism. [online].

[6] LEFÈBVRE, P. 2011. Diabetes as a Paracrinopathy of the Islets of Langerhans. [online].

[7] BARTOŠ, V. – PELIKÁNOVÁ, T. et al. 2003. Praktická diabetologie. 3. ed. Praha : MAXDORF s.r.o., 2003. p. 479. ISBN 80-85912-69-4.

[8] MOKÁŇ, M. 2008. Hypoglykémia. In Vnitřní lékařství. ISSN 1801–7592, 2008, y. 54, n. 4, p. 387-394.

[9] GANONG, W. F. 2005. Přehled lékařské fyziologie. 20. vyd. Praha : Galén, 2005. p. 890. ISBN 80-7262-311-7.

[10] REHNI, A. K. – DAVE, K. R. 2018. Impact of Hypoglycemia on Brain Metabolism During Diabetes. [online].

[11] BADA, V. 2002. Základy klinickej elektrokardiografie. 3. ed. Bratislava : Univerzita Komenského Bratislava, 2002. p. 124. ISBN 80-223-1718-7.

[12] YOUNG, K. A. – WISE, J. A. – DESAIX, P. et al. 2013. Anatomy & Physiology. [online].

[13] HAYLEY, Y. – BENTON, D. 2018. Heart-rate variability: a biomarker to study the influence of nutrition on physiological and psychological health? [online].

[14] FEDOTOV, A. A. – AKULOV, S. A. – TIMCHENKO, E. V. 2020. Methods of Mathematical Analysis of Heart Rate Variability.

[15] JAVORKA, K. et al. 2008. Variabilita frekvencie srdca. Mechanizmy, hodnotenie, klinické využitie. 1. ed. Martin : Osveta, 2008. p. 204. ISBN 978-80-8063-269-4.

[16] MACIEJEWSKA, M. – GALANT-GOŁĘBIEWSKA, M. 2021. Case study of pilot's Heart Rate Variability (HRV) during flight operation. [online].

[17] JAMES, D. V. B. – MUNSON, S. C. – MALDONADO-MARTIN, S. et al. 2013. Heart Rate Variability: Effect of Exercise Intensity on Postexercise Response. [online].

[18] FEDOTOV, A. A. – AKULOV, S. A. – TIMCHENKO, E. V. 2020. Methods of Mathematical Analysis of Heart Rate Variability. [online].

[19] CAO, X. – MACNAUGHTON, P. – CADET, L. R. et al. 2019. Heart Rate Variability and Performance of Commercial Airline Pilots during Flight Simulations. [online].

[20] WISE, J. A. – HOPKIN, V. D. – GARLAND, D. J. 2009. Handbook of Aviation Human Factors. [online].

[21] MOVISENS. 2022. EcgMove 3 – ECG and Activity Sensor. [online].

[22] NOVÁK, A., TOPOĽČÁNY, R., BRACINÍK, T. 2009. Výcvik leteckých posádok s využitím nových technológií. Žilinská univerzita, Fakulta prevádzky a ekonomiky dopravy a spojov, 2009. - 94 s. ISBN 978-80-554-0108-9.

[23] NOVÁK SEDLÁČKOVÁ, A., PITOR, J., MRÁZOVÁ, M. 2015. Crisis management in aviation. 1. vyd. - Bratislava : DOLIS, 2015. - 152 s., ilustr. - ISBN 978-80-8181-000-8.

https://doi.org/10.26552/ pas.Z.2022.2.16

SPECIFICATION OF ULTRALIGHT AIRCRAFT MAINTENANCE STANDARDISATION

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Abstract

The exact definition of an Ultralight Aircraft is still defined very differently from country to country. Internationally, there are different Ultralight Aircraft (UL) classes with nationally varying certification regulations. Accordingly, the term Ultralight Aircraft is used colloquially more or less comprehensively for Very Light Aircraft or Light Sport Aircraft. However, the latter are subject to much stricter certification and maintenance regulations. This work aims to compare the current legal situation in the European Union countries, extract the best practices, and create a proposal of how a new "state zero" should define the laws and regulations to create the best possible environment for UL maintenance. This thesis is written based on information and directions published on the websites of the responsible authorities of the respective countries, as well as communication with these authorities and first-hand knowledge obtained by conducting numerous interviews with people in the field of UL maintenance. The results indicate how different each country regulates the maintenance and continuing airworthiness of ULs and how important a harmonized regulation would be. It is especially important in order to have clarity as with larger aircraft and thus also to prevent numerous accidents and hazardous situations in the future.

Keywords

Law, Ultralight Aircraft, Europe, Standardisation, Introduction

1. INTRODUCTION

Although there have been uniform international rules for the registration and safety of aircraft and flights since the Chicago Convention in 1944, there are still categories of aircraft that are not subject to international standards. One of these is the so-called Ultralight (UL) or Microlight (ML) category. Usually, people from the aviation environment understand something under it and certainly know some, but it can be difficult to imagine an ultralight for people who are not familiar with it. Of course, it is a very light and small aircraft, but in the period of the last 40 years, a lot has changed in this category. It began with self-built constructions with which people tried to climb into the air to fly a few hundred meters. It was not uncommon for people to lose their lives in the process. Nowadays, however, it is safe and mostly engine-powered aircraft, which are produced by professional manufacturers. Above all, the opportunity to create or invent something that would allow people to travel faster in the future and at the same time independently, was often the motivation for many "do-it-yourselfers".

At that time, people who bought or built an ultralight to be able to fly whenever and wherever they want, would not be satisfied, if conditions and regulations for flying existed. Thus, the people around the ultralight aviation have always fought hard against the legislators of the countries and represented their rights to continue to claim the freedoms for themselves. Therefore, we now have our own ultralight category in almost in every country, which is independent of the international rules. However, with independence, we are facing new problems in the present time. Today, when we can move freely within the European Union (EU) or the Schengen area, each country has its regulations and laws for flying with ULs. Although there are a few countries with agreements and groups of countries that have established uniform rules, you mostly cannot simply fly into another country with an UL. Usually, it is necessary to obtain a permit from the relevant authority in the other country and plan an ultralight flight down to the smallest detail. Otherwise, you can get into trouble very quickly or must turn back. This means that the former understanding of freedom applies, but the lack of uniform rules also restricts us. The former understanding even seems outdated, considering the freedoms you have e.g., in traveling by car in the EU. To bring things up to date, uniform regulations of maintenance and servicing as well as registration and flight regulations in the states of the EU, would be necessary. Although there have been several attempts to achieve this, no one has yet managed to implement a uniform solution. Today, we are even further away from such a solution than we were 10 years ago. If it does not already exist, each country is working on publishing its regulation. These regulations deal with more and more details and with every detail a uniform solution is further and further away. Nevertheless, we think that this is the only way to achieve even greater freedom for UL flying and therefore this work deals with the maintenance and airworthiness of ultralight aircraft and tries to find the best solution for a uniform standard.

2. CURRENT STATE OF ULTRALIGHTS

2.1. Definition of Ultralight Aircraft

There are different terms for one and the same thing in other countries. Otherwise often different things are understood under one term. This is understandable, because not every country must an ultralight comply with the same characteristics and approval restrictions, and it can therefore be a completely different thing. In Europe, the term microlight or ultralight is mostly used. In the United States (U.S.), these aircraft tend to be known as Light Sport Aircraft (LSA) and the ultralight aircraft are a completely different category of aircraft up to 120 kg. Until now there have been several definitions of ULs. The first one, which was similar to todays, was the microlight definition from the JAA (Joint Aviation Authorities). There, UL were defined as aircraft with no more than two seats and a MTOM (Maximum Take-Off Mass) of up to 300/450 kg. The same definition was again published in the first BR (Basic Regulation) No. 1592/2002. The new BR (EU) No. 2018/1139, changed the name from microlights to aeroplanes, but again with the same weight limits. The only difference was the possibility to include a BRS (Ballistic Recovery System), that could put 15/25 kg on top. Another definition of these aircraft came from EASA with the new LSA category. The LSA could go up to 600/650 kg and could fly within the EASA member states without restrictions. The negative aspect of it was that all aircraft were under the scope of EASA and maintenance as well as airworthiness standards were a lot stricter than under the national law. However, in 2018 with the new BR also an exemption was included, which allowed every state that used the Option-Out (opt-out) to include ULs up to 600 kg to their national law. Now every aircraft owner whose aircraft has a MTOM up to 600 kg, can decide if he wants to register his aircraft under the national law with more maintenance freedom in his country but more travel difficulties; or if he wants to register it under the CS-LSA EASA rules, with more travel options but less maintenance freedom and higher costs. [1] [2]

2.2. European harmonization

Even though the European Aviation Safety Agency has been working since 2005 on the harmonization of the various national laws and definitions, the Basic Regulation (EC) No 216/2008 states in Annex II, that each country under the organisation can make its own national laws for UL and that these do not fall under the regulations of EASA. In other words, it would be against the national sovereignty of each country, when such a harmonization would be introduced. Of course, there are different opinions about a unification. As published on the website of the European Microlight Federation (EMF), the president of the organisation said the following in 2020:

"All EU countries agreed that microlight will not be regulated by EASA rules but by national rules. We keep our freedom, although sometimes it is difficult when there are differences between the national regulations. But harmonization means more constraints and risks for freedom." [3]

On the other hand, there are also many people who would welcome a unification because for them it would be exactly the opposite of the statement mentioned. Many expect more freedom and more possibilities through simplified travel to other countries and maintenance. Today, someone with a German UL (A) license cannot even rent an UL aircraft registered in another country, simply because the national laws do not allow it. The fear of losing freedom in UL aviation is understandable. Nevertheless, in some countries the trend of weakening laws and regulations, or no regulations at all, can get dangerous.

The CS-LSA is for most private aircraft holders not affordable. And if you are honest, it is also the exact opposite of what UL flying is all about. The strict controls and requirements of EASA for LSA aircraft are not what most people think of as freedom of flight. However, the two biggest problems for UL owners remain the sometimes-problematic travel behind the border and the various maintenance and airworthiness (initial and continuing) requirements of the respective countries, which make it almost impossible to maintain an aircraft in another country or to fly it there.

2.3. Advantages and Disadvantages of UL flying

Not the naming but the specifications and advantages of these aircraft are the main reasons why a lot of people want to fly and own them. One of the most influential advantages is lower prices. The buying prices start with the cheapest UL somewhere near 20.000 – 30.000 € for a new one and can get even cheaper when buying a second-hand aircraft, according to the numbers of the year 2022. Compared to light aircraft, fuel consumption may be less than half the gallons per hour.

Advantages:

- Overall rescue system on board (in some countries duty)
- Speed up to 350 km/h
- Range up to 2,000 km
- Lightweight materials with high strength (carbon, titanium etc.)
- Training costs around 50% lower than for conventional motorized aircraft
- Low financial outlay to obtain a license
- Low charter prices
- Low landing fees (calculated according to aircraft weight)
- Very quiet compared to conventional motorized aircraft
- "Un-bureaucratic flying" (almost no paperwork)
- Also suitable as an entry into professional flying
- More airfields that may be approached with ULs (no paved runway required, short breaking distance)

Disadvantages:

- Less flying freedom (daytime only, no IFR, etc.) / (subject to local regulations)
- Slower flight speeds
- Only one engine – less safety in case of engine failure
- More affected by crosswind, turbulences, and windshear
- Short flight training – huge amount of non-experienced pilots

2.4. UL (A) License

In each country the requirements for obtaining an UL license are different. While in some countries only a few hours of flying are needed and no minimum number of theory lessons is required, there are countries where you must complete over 40 hours of flying and in extreme cases even up to over 50 hours of lessons to be admitted to an examination.

To give some examples for illustration of how to obtain a UL license in different European countries we can first look at Italy. The theoretical part there consists of a minimum of 35 hours of classroom lessons held by professional instructors in a flight school. At the end of these lessons the students' knowledge is getting tested trough a written exam and will be evaluated by an Aero Club d'Italia (AeCI) examiner. Furthermore, if you want to obtain a license for the Advanced VDS (UL), which exists only in Italy, you must complete five more hours of flying with an instructor and eight hours of classroom lessons. More details to Advanced and Basic ULs can be found in the Italian Table later in this thesis. [2]

An opposite to these strict rules for obtaining a license can be e.g., France. Although France does not necessarily have poorly trained pilots or poor accident statistics, there is no minimum limit on flying hours or theoretical lessons. So, it could be much easier to take advantage of this and give someone a license after a few hours of flying. This not only allows pilots to enter the cockpit of an aircraft who cannot fly properly, but also makes the flight schools a danger to themselves. For example, a flight school can offer a lower price because of fewer flight hours for the training course. Also, other flight schools may choose this strategy to remain on the market. A dangerous competition arises, which makes use of badly trained pilots. [4] [5]

2.5. Amateur-built aircraft

The term amateur-built aircraft can have, just as UL, a different meaning in every country. In general, it is an aircraft built by individuals and licensed by the responsible authority. In the U.S. it is the FAA (Federal Aviation Administration), in European countries it is mostly the authority that is also responsible for UL. These aircraft get commonly licensed as "Experimental" and are only used for non-commercial, recreational purposes such as personal use or education. The builder must build at least 51% of the aircraft, so that it can get registered in the amateur-built category. In most countries the initial and continuing airworthiness is determined with varying degrees of industry-based oversight. [6]

2.5.1. Self-construction

A self-construction is a completely new development based on the company's (or builders) own designs. It requires extensive knowledge of the existing building regulations, aerodynamics, strength of materials, etc. To put the project into practice, the corresponding craftsmanship and skills are of course also required. This type of amateur construction is naturally reserved for only a few experts. [7]

2.5.2. Replica of a sample according to plans

This is done more often, but still requires exceptional craftsmanship in handling all materials such as metal, wood, synthetic resins, stringing materials, and the corresponding manufacturing processes. These usually must be acquired as construction progresses. [7]

2.5.3. Assembling a kit (kit airplane)

This is the most common way to build an amateur aircraft. Aircraft construction kits are offered in various degrees of prefabrication and price ranges but must still have a self-build share of at least 51% to still be considered a self-built aircraft with the corresponding advantages. [7]

2.5.4. Reconstruction or restoration of an old aircraft:

This is the variant of reconstruction or restoration of an old aircraft, but such projects must be discussed in detail with construction inspectors of the respective country before the project begins. [7]

3. LITERATURE

The only comparable literature that was found, was a report made by the Hawk Information Services Limited. The topic was Regulatory Options for the European Light Aircraft (ELA1), and it was published in November 2010. The aim of their work was to identify successful regulatory scenarios and practices that have been applied to the regulation of microlight aeroplanes under Annex II control in the Member States. They also wanted to rationalise the regulatory practices into the suggested frameworks of the proposed ELA1 process, which was current at that time. The work was commissioned by EASA and published as a pdf document on their official website. The goal of this report, to identify successful regulatory scenarios and practices in the UL sector was achieved. A suggestion was made on what this category would have to contain, and on which points one would have to focus during the creation. However, no proposal or example of such a regulation was created as it also was not the aim of the report. What worked out very well was the accident data and the legal basis for the initial and continuing airworthiness in a kind of database as a table. For this work, therefore, this table was taken as a template and brought up to date. Even during the preparation of this study, the authors encountered the well-known problem that most people do not want a uniform solution to ultralight regulations and reject them for the fear of losing their freedom. The advantages of the national regulations of the countries usually outweigh the advantages of a uniform solution by the ELA1 category and therefore this report remained only an information database for future ideas.

4. METHODOLOGY

There have been a few studies in the recent years that have looked at the regulatory and maintenance issues of light, very light and ultralight aircraft. One of these was the "Regulatory Options for the European Light Aircraft (ELA1)" study by the Hawk Information Services Limited company in the UK. This company did a very similar work of this subject in the year 2010 and used similar methods for information gathering and processing. The following methods were used for data collection:

- Surveys (email);
- Personal interviews (phone and face-to-face);
- Documentation review (published literature and documents of CAAs);
- Focus on stakeholder group (owner of flight schools and aircraft). [8]

The mentioned study was commissioned by EASA, because at that time there was already a talk of a uniform European maintenance solution for UL aircraft and their certification and maintenance regulations. As EASA made no significant changes since 2010, follow-up studies were not conducted, and the study/information remained at the status of 2010. Only eight countries within Europe were compared, which were also very similar and from the more advanced area of Europe as far as ultralight flying is concerned. Countries where UL flying is not so popular and not as much information are at their disposal were not represented and therefore a lot of information was not included. Nonetheless, this study showed a very good, elaborated table with the various regulations and laws of the countries and served as a template for our work. Since 2010, we found no mentionable attempts anymore for a proposal of unified regulations.

Language barrier and lack of interest: It was not always possible to get the necessary information of every country. Language barriers were encountered again and again, especially in developing countries in Europe. As a result, some countries had only limited, and sometimes no information in English and even in the year 2022 some countries do not have national laws for ultralight flying or are still working on those. This means that the search for information is very limited and does cost a lot of effort and money. As this is a student's diploma thesis for a university degree, it was mainly relied on published data and omitted data that was not available in every country. Of course, on the one hand, this is mostly rather unimportant information that does not strongly influence the work and the results. On the other hand, we sometimes had to leave out information of entire countries because they showed no interest in providing information for this study or did not publish anything that we could work with.

5. COLLECTED DATA

The scope of this thesis is targeted on EU member states. Information of 27 all countries of the EU was collected, and the most important information has been summarised in the form of a table. The countries have been listened in alphabetical order and for each country a short summary has been added, which retains the author's opinion, a brief assessment of the situation or possibly, for some countries, further information. The tables have been divided into 3 sections. The first and most important section is for initial airworthiness and defines the individual conditions for certification as well as the requirements to be met when manufacturing or purchasing a UL. These include points such as special equipment that the aircraft must have which distinguishes it from other countries, as well as who makes design standards, whether they are necessary and, if so, who is responsible for them. The second section deals with continuing airworthiness, whether and by what means an aircraft can remain airworthy. Other important points are, for example, the obligation to keep a logbook or whether there is a fixed maintenance schedule and who determines it. The third and final section deals with flight training and licensing. Here you can ask yourself questions such as whether there is a UL licence or what privileges you have in the country with this licence. These questions are answered here.

6. MAINTENANCE PROPOSAL

After comparing the information obtained and listed above, we have decided to elaborate a proposed table that could be used as a guide for other countries. Also included are the various regulations and laws of the countries, which of course are not listed here. It is not possible to go into too much detail here, as there are different aircraft that all require special maintenance, and every country has different kinds of these aircraft. A seaplane MTOM is probably useless in Slovakia and as well as the right of hiring an UL in Greece, where no one provides UL for rent. For this purpose, every piece of information from all the tables was evaluated, analysed and finally the best solution was selected for the final table. For each of these pieces of information, a summary and explanation of the choice was finally added below the table.

With this master's thesis, the author has attempted to create a proposal for a uniform European maintenance standard for ultralight aircraft. It can be stated that through this work a basic framework of this standard was created with the individual specifications on which value was placed. According to the author, this work can be used not only as an ideal proposal for a future maintenance standard but should also serve as an aid to interested parties in any field of UL aviation. Through the email survey conducted four months prior to this work, the author realized that many problems and contradictions exist in the current national regulations of the individual countries. Numerous people who are responsible for these regulations in the countries or who are very closely involved with the topic have already made clear, that they would be very interested in such a work and would like to see it.

ACKNOWLEDGMENT

This paper is an output of the project of the Ministry of Education, Science, Research and Sport of the Slovak Republic KEGA No. 048ŽU-4/2020 "Increasing key competences in aircraft maintenance technology by transferring progressive methods to the learning process".

REFERENCES

[1] Wildnordics.com. 2022. Differences in EASA and the FAA approach to Recreational Flying – Wild Nordics. [online] Available at: <https://wildnordics.com/differences-in-easa-and-the-faa-approach-to-recreational-flying/> [Accessed 16 March 2022].

[2] EASA. 2022. How does EASA deal with Light Sport Airplanes? | EASA. [online] Available at: <https://www.easa.europa.eu/faq/19386> [Accessed 10 March 2022].

[3] [Presidents page – European Microlight Federation. Emf.aero [online]. 2022. [Accessed 3 April 2022]. Available from: https://emf.aero/01-a-letter-from-dominique-mereuze-the-emf-president/

[4] INNOCENTI, EMILIANO. Aero Club L'Aquila - VDS - Ultralights or Microlights. Aeroclublaquila.it [online]. 2022. [Accessed 9 April 2022]. Available from: https://www.aeroclublaquila.it/en/flight-school/vds-ultralights-or-microlights.html

[5] Le brevet de pilote. Ffplum.fr [online]. 2022. [Accessed 10 April 2022]. Available from: https://ffplum.fr/debuter/le-brevet-de-pilote

[6] Experimental Aircraft Information | EAA. Eaa.org [online]. 2022. [Accessed 3 April 2022]. Available from: https://www.eaa.org/eaa/about-eaa/eaa-media-room/experimental-aircraft-information

[7] Aeroclub - Allgemein. Aeroclub.at [online]. 2022. [Accessed 4 April 2022]. Available from: https://aeroclub.at/de/sportverband/sektionen/motorflug/allgemein

[8] 6 Methods of Data Collection. Medium [online]. 2022. [Accessed 18 April 2022]. Available from: https://callygood.medium.com/6-methods-of-data-collection-e946e993b930

[9] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

[10] NOVÁK, A., SEDLÁCKOVÁ, A.N., BUGAJ, M., KANDERA, B., LUSIAK, T. 2020. Use of unmanned aerial vehicles in aircraft maintenance. Transportation Research Procedia, 2020, 51, pp. 160–170. ISSN 23521457.

[11] BUGAJ, M., URMINSKÝ, T., ROSTÁŠ, J., PECHO, P. 2019. Aircraft maintenance reserves - New approach to optimization. Transportation Research Procedia, 2019, 43, pp. 31–40. ISSN 23521457

[12] PECHO, P., HRÚZ, M., NOVÁK, A., TRŠKO, L. 2021. Internal damage detection of composite structures using passive RFID tag antenna deformation method: Basic research. Sensors, 2021, 21(24), 8236. ISSN 14248220.

https://doi.org/10.26552/ pas.Z.2022.2.17

NOISE LOAD AT THE AIRPORT M. R. ŠTEFÁNIK IN BRATISLAVA

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Abstract

The aim of the article is to describe the current state of noise pollution at the airport M.R. Štefánik and analyze the change in noise pollution when changing the occupancy level of the airport M.R. Štefánik in Bratislava. Another goal of the article is to design an optimal runway system that would be suitable for the future needs of the airport and to compare the current noise load of the current runway system with an alternative noise load when changing the configuration of the runway system. The article also briefly describes the noise, the factors influencing its spread in various environments, the reasons for the generation of noise in air transport and its negative effects on people or the environment.

Keywords

Noise. Bratislava Airport. Annex 16. Air operations. Runway system.

1. INTRODUCTION

Air transport is currently one of the fastest growing modes of transport, a statement that is particularly true of technological advances in propulsion units. The first aircraft used reciprocating engines, also referred to as propellers. These engines were characterized by a certain noise level, but only after the arrival of jet engines and their mass implementation in civil aviation, work began on certain regulations. In 1971, ICAO adopted the first noise standard under Annex 16. In the following years, this annex was expanded to include other standards and recommendations in new editions, and in 1983 ICAO created CAN and CAEP to help develop new or update existing standards and recommendations. According to ICAO, engine noise decreased by 75% between the 1960s and 2000.

2. CURRENT NOISE STATE AT M.R. ŠTEFÁNIK AIRPORT AND METHODOLOGY OF PREDICTION

2.1. Legislation

The current state of noise pollution at Bratislava Airport is subject to certain regulations by the state under Act no. 355/2007 and Act. no. 649/2007. Act no. 355/2007 Act on the Protection, Support and Development of Public Health and on Amendments to Certain Acts determines the conditions and requirements according to which noise load measurements are to be performed at airports and their surroundings in the territory of the Slovak Republic. [1] Decree of the Ministry of Health no. 549/2007 Coll. details of the permissible values of noise, infrasound and vibration and of the requirements for the objectification of noise, infrasound and vibration in the environment are laid down. [217]

2.2. Description of physical and technical conditions of M. R. Štefánik Airport

M. R. Štefánik Airport is located about 9 km from the center of the capital of the Slovak Republic, near the village of Ivanka pri Dunaji, in the cadastral area of Bratislava-Ružinov. Construction of the airport began in 1947-1948 and regular operation began in 1951. Currently, Bratislava Airport is located in a relatively densely urbanized area, which extends to the west, north, south and east of the airport, which complicates the physical development of the airport due to noise pollution affecting the population and the possible complaints of the population about noise. There is also a small Danube on the southern side of the airport, where due to the existing flora and fauna, there is an increased risk of aircraft colliding with birds that may nest here. [3].

2.3. Correlation and regression analysis

Air transport is generally influenced by many factors, the most important of which we would classify in basic categories such as. socio-economic factors, demand and supply factors, environmental factors and factors of other transport options. Therefore, it is important to say that the quality of each prediction depends not only on the chosen prediction method but also on the variables with which the prediction would work. Also, the quality of the prediction depends on the size of the budget intended to create the prediction or the experience of the people who created the prediction. [4]

From the point of view of airport planning and operation, it is very important to predict the future development of traffic, both in terms of future airport capacity requirements, which the airport should be able to adapt to in time, and in terms of profitability of the arrangements. or, conversely, that the arrangements in question are not unnecessarily exaggerated to such an extent that they are no longer justified and therefore not cost-effective. The methods that are commonly used in aviation to predict the development of traffic at airports can be divided into three main groups: qualitative methods, quantitative methods and decision analysis. In this way, they are divided according to ICAO in document no. 8991 of 2006. [5]

When examining the values of two or more different numerical characters, we can assume that there may be a statistical interdependence between certain variables examined. A possible feature of a certain statistical dependence may be a certain correlation between the given features, for example in the form of a direct ratio, and thus with a linear increase in the numerical value of variable A the numerical value of variable B increases or the value of the variable B. In this case, it is a direct linear statistical dependence. If the higher numerical values of the variable A correspond to the lower numerical values of the variable B and at the same time the higher numerical values of the variable B would correspond to the lower numerical values of the variable A, we speak of an indirect linear statistical dependence. To determine the statistical linear dependence, the correlation coefficient rxy between the values of the variables X and Y is calculated using two alternative relations:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_1-\bar{x})*(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_1-\bar{x})^2*\sum_{i=1}^{n}(y_i-\bar{y})^2}})$$

$$r_{xy} = \frac{n*\sum_{i=1}^{n}x_i\,y_i - \sum_{i=1}^{n}x_i*\sum_{i=1}^{n}y_i}{\sqrt{[n*\sum_{i=1}^{n}x_i^2-(\sum_{i=1}^{n}x_i)^2]*[n*\sum_{i=1}^{n}y_i^2-(\sum_{i=1}^{n}y_i)^2]}}$$

The value of the coefficient describes the correlation intensity of the investigated variables. The correlation coefficient has a value in the range -1 to 1. If the correlation coefficient has a value of 0, it means that it is an independence between the examined values. In the case of other numerical values, it is possible to use the following approximate scheme of the breakdown of the statistical dependence intensity given in Table 1. [6]

Table 1: Breakdown of the intensity of statistical dependence according to the respective value with respect to the interval on which the given value is located. [6]

The value of the correlation coefficient	**Level of linear dependence**
from - 0.1 to 0.1	Linear independence
from -0.4 to -0.1 or 0.1 to 0.4	Weaker addiction
from -0.7 to -0.4 or from 0.4 to 0.7	Moderate addiction
from -1 to -0.7 or from 0.7 to 1	Strong addiction

Regression analysis has many variants. In principle, regression analysis examines at least two numeric characters X and Y. The task of regression analysis in this case is to model the dependence of variable Y on variable X, where variable X is the cause and variable Y is the consequence, this simple two-variable variant is called single-criteria regression analysis. The relationship between the variables X and Y is expressed by the following formula:

$$y_i = f(x_i) + e_i$$

Where [xi, yi], i = 1, 2, ..., n is n points whose coordinates are expressed by the values of the variable X and the variable Y and ei is a random error also called a residual component or residual. [6] Residue is the error between the predicted value and the observed true value, it is a measure of how far the point is vertically from the regression line. The regression line is sometimes called the line of the best fit because it is the line that fits best when dragged through points, minimizing the distance of actual values from the predicted values, using the least squares method. In connection with the regression analysis, it is important to explain the confidence interval, which represents the proportion of calculated values that contain the actual value of the parameter [7].

However, if we assume or know that the variable Y is influenced by more factors than just one predictor X, it is usually a multi-criteria regression analysis, which can be used to express the effect of several independent variables on the observed indicator at the same time. Multi-criteria regression analysis should include all predictors of X affecting the observed variable Y. The dependence of factors X on the observed variable Y can be determined by correlation analysis or by building a correlation matrix, at the same time factors X must be as independent of each other, otherwise distortion of results. We write the multi-criteria regression analysis in the form [6].

$$y = b_o + b_1x_{1i} + b_2x_{2i} + ... b_kx_{ki} + e_i$$

Stepwise regression is a specific form of regression analysis that allows you to search a list of possible predictors, while helping to select the ones that provide the best regression model. This procedure is used when it is not entirely clear at the outset which predictors are most suitable for creating a regression analysis model. [8].

In 2019, 26,941 movements (take-offs and landings) of aircraft were handled at the airport out of the total number of movements at Bratislava Airport. Of the total number, there were 14,294 landings and 13,467 takeoffs. In terms of arrivals, the runway was the busiest in the direction of 31, with 11,066 movements. In terms of take-offs, the busiest runway was in direction 04, together with runways in directions 13 and 31. In terms of runways and runways in both directions, runway 13-31 was used for landings in 83.3% of cases. This is mainly due to the fact that the level of equipment with radionavigation approach devices is higher on this runway than on runway 04-22. In terms of take-offs, runway 13-31 was used in 50% of cases. Runway 04-22 was used in take-offs in 50% and on landings in 17% of cases. The noise load was calculated on the basis of a mathematical model of the area based on data from photogrammetry. The control was performed using a georeferenced digital orthophotomap. The calculation of the noise load caused by air traffic was done using the methodology of ECAC Doc. 29. The propagation of noise from ground sources was modeled using the ISO 9613 standard. The verification of the model took place in two phases, in both cases an airplane was used for verification. The calculation is performed for operation for 180 days. The area noise load from air traffic is made by displaying isophone equivalent sound levels A for individual reference time periods of the day. The calculation was also made in individual places in the affected settlements. 6 emission points in built-up areas around Bratislava Airport were determined for the calculation of specific values. At these points, the noise load in dB was calculated. The results of the noise analysis showed that air traffic noise most affects the residential areas of Ivanka pri Dunaji and Most pri Bratislave. Data were provided with the consent of Bratislava Airport by Euroakustik, s.r.o. [9]

3. NOISE LOAD ANALYSIS WHEN CHANGING THE LEVEL OF BTS AIRPORT

3.1. The current state of air transport in Europe and at M. R. Štefánik Airport

The latest published data from Bratislava Airport come from 2020. This year and also in 2021 was strongly marked by the global pandemic Covid-19, which affected air traffic around the world, either by various restrictions aimed at travel to and from high-risk countries, or phasing out. flights for a variety of reasons, including a slowdown in economic activity around the world. Air transport around the world has seen a huge decline in its economic activities. It was no different in Europe. According to data published on the Eurostat website, the number of passengers carried in Europe fell by 73% in 2020 compared to 2019, which accounted for only 277 million passengers carried by air. [10] In 2021, 64.3% of passengers, ie just over 409 million passengers, were carried in Europe compared to the previous pandemic of 2019. [11,12]. In the case of flights to Europe, 5 million flights were made in 2020 and by 2021 there were already 6.2 million flights. Compared to 2021 to 2020, this may seem like a big increase of 20%, but compared to the 11.1 million flights in 2019 in Europe, it is still only 54% more than before the pandemic. period. In the first quarter of 2021, the number of flights compared to 2019 was at the level of 38% to 34%. In the following months, however, with the advent of digital EU-Covid passports, with increasing levels of vaccination in the Member States and the gradual lifting of anti-pandemic measures, the market situation began to change when traveling within the European area. On August 27, there was a peak in the number of flights in Europe, with 26,773 flights. Compared to the peak number of flights performed in 2019, when 37,288 flights were performed, this was 28% less. The market situation remained stable during the winter months, when the pandemic situation in Europe began to deteriorate again. Air traffic in Europe during the winter period was between 75% and 80% of the level of the same period in 2019.

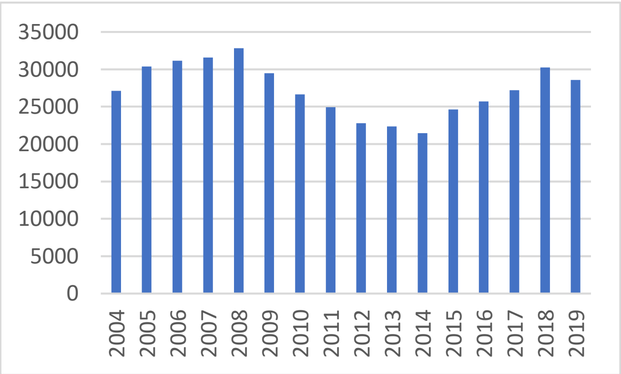
Slovakia and its neighboring countries recorded similar results in the number of flights performed. Slovakia recorded a 52% decrease in air traffic, Hungary recorded a 54% decrease, the Czech Republic recorded a 55% decrease, Poland a 46% decrease and Austria recorded a 52% decrease in air traffic. [13].

3.2. Development and current status of passenger numbers at BTS Airport since 2004

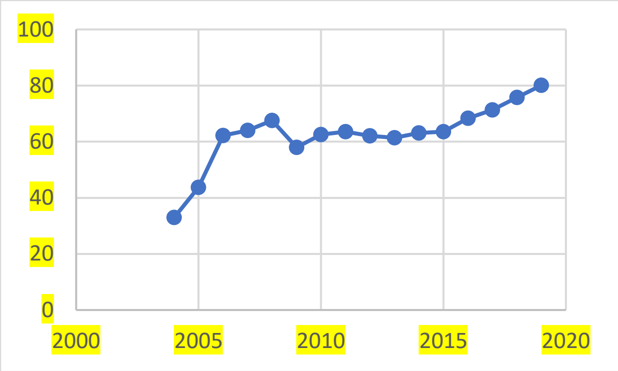
I divided the passengers at M. R. Štefánik Airport into 2 categories, according to the type of transport they used: scheduled air transport and non-scheduled passenger air transport. From 2004 to 2008, the airport saw a steady increase in the number of passengers handled. During this period, the number of passengers transported in scheduled air transport increased. In 2009, there was a decrease in the number of regular passengers, which was mainly due to the global economic crisis, which took place this year and due to which three airlines terminated operations at the airport: SkyEurope Airlines, Seagle Air and Air Slovakia. In the following years, the number of regular passengers handled continued to decline, while the share of passengers transported by non-scheduled air transport remained at roughly the same levels throughout the period, starting to increase slightly in 2010. The number of regular passengers decreased until 2014. Between 2010 and 2014, several airlines ended up at the airport, which resulted in a declining trend of passengers carried until 2014. 2014 was characterized by a stabilization of the total number of passengers compared to 2013, when less than 18,000 more passengers were carried. From 2015 to 2018, M. R. Štefánik Airport again saw a steady increase in the number of regular passengers, which also manifested itself in 2019, but where it was slowed down in recent months, and later in 2020 as a result of the impending pandemic Covid-19 and with it against pandemic measures, artificial flight disruptions, etc. there was a decrease in passengers and flights handled. The number of non-scheduled passengers during this period remained at approximately the same or similar level from 400,000 to 500,000, with the highest number of non-scheduled passengers being in 2017, when they reached 569,481. this number appeared to exceed 2 000 000 passengers, but there has been a sudden drop in passenger traffic in recent months. [14]

3.3. Development of aircraft movements from 2004 to 2019

The number of movements in the period under review between 2004 and 2019 developed similarly to the number of passengers handled in the same period. From 2004 to 2008, the number of movements gradually increased. The year 2009 was also as critical for the number of flights handled at M. R. Štefánik Airport as for the number of passengers handled. The number of flights handled in 2009 decreased by 11% due to the consequences of the global economic crisis and the collapse of several airlines operating at M. R. Štefánik Airport. The years 2010, 2011 and 2012 were characterized by a gradual decrease in flights handled from 10% to 7% compared to the previous year. The period between 2012 and 2014 was characterized by a gradual slowdown in the decrease in flights handled by 2% between 2012 and 2013 and by 5% between 2013 and 2014. In 2015, the number of flights handled increased by 14%. The following period from 2016 to 2018 was also characterized by a gradual increase in the number of flights handled, when in 2019 there was again a decrease in the number of flights handled due to the incipient pandemic at the end of the year. What is important to say, however, is that the load capacity utilization factor (load factor) either increased or remained at approximately the same level throughout the period under review between 2004 and 2019.



Picture 1: number of movements at the airport at M. R. Štefánik airport between 2004 and 2019. (number of take-offs and landings) [14]



Picture 2: Seat capacity utilization factor between 2004 and 2019 (average number of passengers per landing / take-off) [14, the autor]

3.4. Prediction of the development of air traffic at the airport M.R. Štefánik

I developed a forecast of air traffic at M. R. Štefánik Airport on the basis of historical data on airport occupancy in terms of checked-in passengers. Using regression stepwise analysis and correlation analysis, I identified the key indicators (predictors) that most affected the development of the number of passengers handled in the period from 2004 to 2019, when due to the global situation in connection with the outbreak of Covid-19 pandemic occurred in recent months. decline in the air transport market in Europe but also worldwide. Based on the determination of the given significant predictors, I subsequently created a model of prediction of the future development of passengers at M. R. Štefánik Airport for a long-term period using multi-criteria regression analysis. I set the long-term horizon until 2050. Both models have 3 possible development scenarios, namely the scenario with low, medium and high growth. In the following subchapters, I explained and described the results of individual analyzes and models, including individual predictors, the reasons for their selection, determination and their predictions, as well as the processed scenarios for the future development of air transport in terms of the number of passengers handled.

Using correlation analysis, I searched for cross-correlations and discarded data sets that were too high a cross-correlation - values of correlation coefficients at the level of 0.95 and more. Subsequently, the remaining values were retained and entered into the stepwise analysis.

Using the stepwise method (forward selection and backward elimination), the algorithm evaluated, based on the values of the examined numerical series of possible predictors, that the model of regression analysis predicts all movements at the airport (number of movements at BTS airport - take-offs and landings) includes three predictors of selected indicators: the number of passengers handled at Bratislava Airport, the Human Development Index and the number of IFR flights in Slovakia. These three predictors were characterized by very low p values and mean values. Standard Error in regression analysis indicates how accurate the model is - the higher the numerical value of the standard error, the more accurate the model, and vice versa, the smaller the numerical value of the standard error, the more accurate the model. This error expresses how accurate the estimated values are in relation to the real values and it is up to the analyst to assess whether the error is already too large or is tolerable for the model. I performed the stepwise regression method in the MATLAB program environment. The equation of the linear regression analysis based on the performed forward selection and back elimination has the following form:

$$y = x_1 * 0{,}0076 - x_2 * 164838 + x_3 * 16{,}7896 + 144231{,}2269$$

where x1 is the total number of passengers handled at M. R. Štefánik Airport, x2 is the value of the human development index and x3 is the number of IFR flights performed in Slovakia.

The residual errors of the model ranged from 1835 to -1395.79. These values express the direct difference between the predicted numerical values of the performed movements and the actual measured values of the performed movements. With the numbers in the estimates of the performed movements at the airport of M. R. Štefánik, the model ranged in the deviations from 0.01% to 17%. The model showed the highest values of deviations when predicting the total number of passengers handled in the first 3 years of the observed period, while predicting the total number of passengers handled during the remaining observed period, the model showed deviations from 6% to 0.01%.

Using forward selection and back elimination and correlation analysis, I selected and identified individual predictors based on which I subsequently made a regression prediction. Individual predictors were selected by comparing several models of regression analyzes using different combinations of predictors. The combination of the predictors "number of IFR flights", "Human Development Index" and "Number of passengers" was chosen on the basis of a certain assumption of the author and subsequently also the results of the regression analysis. The regression analysis, where these variables were chosen as predictors, had the lowest average value of the residual error (deviation) of the predicted values compared to the actual ones. The average error value was 0.04%. To calculate the estimate of future values of the monitored variable number of movements at the BTS airport, it was necessary to determine the future development of individual predictors. I determined the future development of predictors independently or took over from the forecasts of certain institutions in terms of medium and long term. I set the long-term horizon from 2019 to 2050.

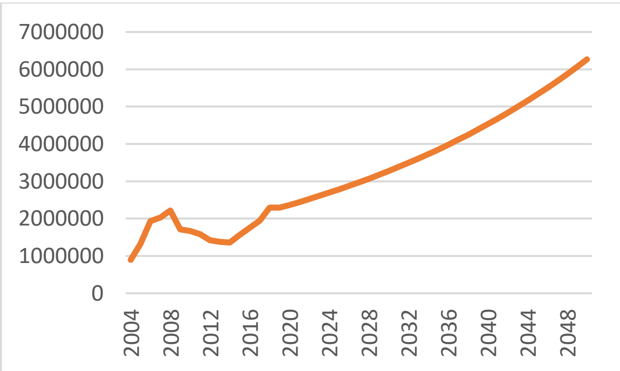
I took over the predictor "number of IFR flights in Slovakia" from Eurocontrol predictions issued for the period between 2021-2027 and 2021-2050. [15,16]

Eurocontrol predicts IFR flights in 3 scenarios - high growth, medium growth and low growth. Eurocontrol's forecasts take into account current and future challenges for air transport and its development. The forecast for the period from 2021 to 2027 takes into account the effects of the global Covid-19 pandemic in terms of epidemiological factors, factors affecting the aviation industry and macroeconomic impacts on gross domestic product. The prediction assumes three possible scenarios, where all three have specified factors influencing the epidemiological situation in the countries from which the specific impacts on air traffic will develop. The scenario with a high (fast) course assumes the end of the effects of the pandemic in the middle of 2023, and thus the return of air traffic to pre-pandemic values in 2019. The scenario with a medium level of development assumes the end of the pandemic by the end of 2023. In the course of this work, it is important to look at the possible development of future IFR flights in Slovakia, as well as the expected development of passengers at airports. Rapid and medium-sized scenarios assume that airports will be able to return to their pre-pandemic performance. The slow-moving scenario assumes that airports will have difficulty operating as in the pre-pandemic period. According to the IATA forecast, from 1 March 2022, a gradual return to pre-pandemic values of passengers carried within the European internal market is expected in 2022, when the number of passengers carried should reach 86% of the number of passengers carried in 2019 and 105% in 2024. [17]

Eurocontrol's long-term forecast for 2022 to 2050 does not take into account the Russian invasion of Ukraine, but assumes that this conflict will affect air transport developments in the medium rather than the long term. The prediction is based on pre-pandemic air traffic performance and focuses its prediction on the period after the end of the global Covid-19 pandemic. This prediction is also based on three different scenarios. The high-growth scenario assumes high economic growth in a world with a high level of globalization, with intensive support in investing in sustainable technologies and promoting green-sustainable aviation. The medium-growth scenario also appears to be the most likely and is characterized by medium-term economic growth, with regulations focusing on the environmental, social and economic aspects of air transport and its sustainability. This scenario is based on current trends in air transport and also on likely trends in air transport in the future. The low-growth scenario is characterized by slow economic growth in terms of flight conditions, higher prices for conventional aviation fuel and also sustainable aviation fuel, together with higher charges for air pollution. It also counts on limited investments in new technologies, or delays in starting these investments compared to previous scenarios. This scenario is based on the assumption that energy prices will be particularly high and at the same time there would be a strong economic downturn during the 30 years of forecast. [16] IFR flights within the airspace of the Slovak Republic are partly responsible for the generation of movements at M. R. Štefánik Airport, in cases where there are fewer such flights, due to the correlation coefficient between the observed variable "movements at BTS airport" and the predictor "number of We can expect that with the decrease in the number of IFR flights, there is a slight increase in movements at M. R. Štefánik Airport. In practice, we could explain this by the fact that under adverse external environmental conditions, some flights are forced to change from VFR to IFR or such flights are planned in advance as IFR, so some of these flights will not go to M. R. Stefanik Airport.

The correlation coefficient of the predictor "Human Development Index" with the observed variable "movements at the BTS airport" is - 0.4456, which means a weaker negative linear dependence. This means that the worse the HDI, the slightly higher the value of the number of movements made at the BTS airport. At first glance, this doesn't make much sense in general, if we look at it: "The healthier, more educated and richer the population, the more likely it is that such a population can afford to buy a ticket and fly, which should increase and the number of movements. Such an assumption, from my point of view, is correct only to a certain extent in the case of BTS airport. BTS Airport has been characterized by a steady increase in scheduled air traffic over the last 5 years. The providers of these services were, in most cases, low-cost companies that carried the majority of passengers to or from BTS. Such companies are characterized by a high load factor. An excellent example is Ryanair. In view of this, I think that the higher HDI is a sign that, on the one hand, the purchasing power of the population is increasing (better education usually has a positive effect on possible earnings) and the population's willingness to travel, as young people or people without more serious health complications healthier population). Thus, the higher HDI has a positive linear dependence with the predictor "PAX together", but looking at the types of companies that provide their services at BTS and the level of their provision, this may result in a slight reduction in the number of movements at BTS due to increasing HDI, as these low-cost airlines are trying to make the most of their services and therefore prefer to provide fewer flights instead of providing more flights with a slightly lower load factor, for example at 80%. , regularly and with a much higher load factor, bordering on 90%, as in the case of Ryanair. I predicted the HDI until 2050 on the basis of the trend continuation method, while the average year-on-year growth from 2020 to 2025 is 0.39%, and I kept this growth for the growth of this index until 2050. I estimate this increase partly on the basis of Eurocontrol forecasts, which in both scenarios predict either strong or stable average economic growth, while the scenario with low economic growth has so far proved to be the least likely. By 2050, according to my estimates, the HDI should reach 0.9215.

The predictor "Number of passengers handled" and the observed variable "movements at BTS airport" have a correlation coefficient of 0.5895. The correlation coefficient indicates the mean positive linear relationship between the observed variable and the predictor. In practice, this finding could be explained by the simple principle "the more potential passengers, the greater the offer - flights - airport movements". This assumption only applies to a certain extent, because most services at BTS are provided by low-cost carriers, which, due to their business models, try to make the most of their flights compared to traditional carriers. I based the prediction of the total number of passengers handled on the basis of predictions of annual percentage increases of air passengers in terms of long-term prediction (until 2050) from companies and organizations: Boeing, Airbus, The Air Transport Action Group, ICAO, International Clean Transport Council (The International Council on Clean Transportation (ICCT) averaging values for the same type of scenario (low, medium, high). This long-term growth at BTS is based on the assumption that trends in air transport will remain unchanged in the future and that BTS will maintain the same position on the regional market in the total number of passengers handled. The estimated year-on-year increase in passengers at Bratislava Airport by 2050 is 3.3%.



Picture 3: Priemerný medziročný alternatívny nárast cestujúcich na letisku Bratislava do roku 2050.

3.5. Scenario of the development of the number of movements at the M. R. Štefánik Airport for the long term

Based on the development of Eurocontrol scenarios, I created scenarios for the development of the number of movements at M. R. Štefánik Airport for a long time horizon. Horizon has 3 scenarios, and these scenarios are directly derived from the IFR predictions of Eurocontrol flights, my predictions of the human development index and the average defined annual growth of passengers at M. R. Štefánik Airport. The short-term scenarios have been developed for the recovery period from the global Covid-19 pandemic, and the long-term scenarios reflect alternative developments in the post-global pandemic period up to 2050. Scenario 2 is the most probable, given the development of air traffic so far compared to the IFR prediction of Eurocontrol flights.

In creating a scenario with medium growth of IFR flights in Slovakia for the long term, I use Eurocotrol's forecast for the period 2019 to 2050. This scenario is based on the assumption that the Covid-19 pandemic did not affect world markets as much as in Scenario 1, with the world economy and with it, air transport will recover from this crisis as early as 2024 and also from the assumption that the next economic growth will be stable and without major complications. The average year-on-year increase in IFR flights is set at 1.2% of the number of IFR flights in Slovakia in 2019, which were 821, which is 220 IFR flights more than in the previous scenario. According to estimates, the average growth of IFR flights in Europe and also in Slovakia should be accompanied by a certain degree of implementation of new technologies, which are friendly to refueling or emissions.

Table 2: Values for calculating the number of movements at BTS airport in 2050 with the average growth of IFR flights

Variable name	Value of average year-on-year growth in %	Initial value in 2019 and final value in 2050	
Number of IFR flights in Slovakia	1,2 %	562	821
Human development index	0,39 %	0,826	0,9158
Number of passengers handled	3,3 %	2 290 242	6 266 014

The resulting value of movements at M. R. Štefánik Airport in 2050 was predicted to be 54,406 movements with a medium growth of IFR flights.

3.6. Characteristics of San Diego airport and comparison with Bratislava airport

San Diego International Airport (San Diego International Airport) is an international airport in United States of America. It is located in the state of California, in the city of San Diego, about 3.2 km from the part of the city "Downtown San Diego", while the airport itself is located practically in the city center as well, which has similar or perhaps worse opportunities in terms of ability to physically expand in space as Bratislava Airport. I chose San Diego Airport because it has a similar regional geography to BTS Airport, has a partially similar runway system to BTS Airport, and has a higher number of flights and passengers than BTS Airport should have in the future. The airport is located in an area with a high level of urbanization. It has one runway, in which the axis of the trajectory is a densely built-up and populated area of the city of San Diego in both directions. The airport itself is surrounded on the north, east, west, and in part south by boroughs of San Diego. The second reason for the choice was the similarity of the technical parameters of the track system. San Diego Airport has one runway with a length of 2865 x 61 m, the runway surface is made of asphalt and the runway capacity is defined by the code PCN 75 / F / A / W / T. Compared to the runways at Bratislava Airport, this is a different type of surface (flexible), which is more demanding for regular maintenance. In this particular case, however, the runway at San Diego Airport has a payload advantage over runways at Bratislava Airport. In the case of track length, the difference is minimal and does not have a significant effect on operating performance. Both Bratislava Airport and San Diego Airport use VOR, ILS, DME and LOC radio navigation and landing systems. [18,19] The third reason for selection is the operating performance of both airports. At this point, I compare the current operating performance of San Diego Airport (from 2019) with the alternative operating performance of Bratislava Airport in the predicted period in 2050. According to the observed prediction from scenario 2, M. R. Štefánik Airport should handle approximately 54,406 movements with approximately passengers. , exceeding the limit of 6 mil. In 2019, San Diego Airport handled 231,354 movements, of which approximately 208,000 movements were operated by commercial companies and 12 thous. movements were operated by companies focused on the business model of air taxi. [20]

4. PROPOSAL FOR THE SOLUTION OF RUNWAYS AT BRATISLAVA AIRPORT FOR ALTERNATIVE OCCUPANCY OF THE AIRPORT IN THE FUTURE

From a comparison of the technical and physical parameters of the mentioned airports, I conclude that San Diego Airport and Bratislava Airport are very similar in certain respects. Both airports have a problem if they are to expand physically, as they are located in places with a high degree of urbanization, which complicates the expansion of both airports in terms of noise to the inhabitants living in the immediate vicinity of both airports. There is also a problem with the lack of space as such, San Diego Airport can probably try to expand only in the red marked area in Figure no. 7, while Bratislava Airport has slightly better conditions in terms of free space where it is located, but at the current rate of expansion of the surrounding municipalities, the already small space decreases more and more each year, which again increases the problem of noise in location and its negative impact on the population, thus increasing the negative relationship of the local population to the possible physical expansion of the airport. However, from the point of view of Bratislava Airport's operating capacities compared to San Diego Airport's operating capacities, it is very likely that Bratislava Airport will not have to significantly expand its runway system, as it should be able to handle an alternative number of movements compared to San Diego Airport's performance and runway configuration. from all three scenarios I've worked out. From the point of view of operating costs, however, I believe that M. R. Štefánik Airport does not need two runways for its operation. In this regard, I base both the comparison with San

Diego airport and the distribution of arrivals and departures on the individual runways, which are given in Chapter 2. The operating costs of maintaining two runways, I estimate, can be significantly higher than the operating costs of maintaining one runway. expensive. However, Bratislava Airport did not provide me with information including the airport's finances, so I was not able to verify this cost hypothesis.

5. COMPARISON OF ALTERNATIVE NOISE LOADS WHEN CHANGING THE LEVEL OF BTS AIRPORT AND WHEN CHANGING THE RWY CONFIGURATION

The work aimed to determine the change of alternative noise load at M. R. Štefánik Airport when changing the number of movements performed at the airport, and to determine the change of alternative noise load when changing the runway system depending on the alternative needs of future operations. In cooperation with Euroakustik s.r.o. I developed maps of alternative noise loads at Bratislava Airport with the predicted number of movements according to scenario 2. The number of movements was predicted to be 54,406 for 20506. The noise load of the airport is measured throughout the year and is divided into 2 half-year periods. As M. R. Štefánik Airport does not have the same level of occupancy during these two monitored periods, the calculation was performed for the six-month period, which has a higher occupancy level. In 2019, 16,501 flights were recorded during the busier period. The calculation for the predicted half-year period with a higher occupancy rate was determined on the basis of the percentage of flights from the busier half-year period 2019 to the total number of flights in 2019. Based on this percentage of flights in the summer half-year 2019, I calculated that while maintaining current trends movements at M. R. Štefánik Airport, 27,203 movements will be performed at Bratislava Airport in the summer of 2050. The ratio of the number of flights in the summer of 2019 and 2050 was determined by a numerical coefficient of 1.6948. Based on the assumption of maintaining the current trends of commercial air transport at the airport M. R. Štefánik using aircraft, I recalculated the number of movements in individual noise categories recorded on individual runways of Bratislava Airport from 2019 by a coefficient of 1.6948, and thus determined the approximate number of movements in specific noise categories at year 2050 on individual tracks. In the calculation, the emission noise parameters of the aircraft were considered as for the state in 2019. The values of alternative noise in 2050 using the current runway system range from 35 dB to 65db and more dB, depending on the monitored location and time for which it was given calculation done. The values of alternative noise in 2050 using the changed runway configuration range from 35 dB to 65 dB and more dB, depending on the monitored location and time for which the calculation was made.

6. CONCLUSION

From the produced noise maps it follows that the alternative noise load in 2050 will be similar in intensity to the current state of noise load at Bratislava Airport in the case of all monitored periods and both mentioned configurations of runway systems in this work. The assumption is that, based on the forecast, in the next 10 to 15 years there will be a reduction in noise emission parameters, especially for airplanes with jet propulsion units from about 4-7 dB, depending on the category and flight operation. This means that the future noise intensity could actually be a few decibels lower. The areas affected by noise in 2019 during the observed period "day" and "evening" do not differ much in size from the potentially affected areas in 2050, while maintaining the current configuration of the runway system. Municipalities that are not affected by noise pollution caused by air traffic at Bratislava Airport in 2019, but by 2050 should already be in one of the extended areas of noise, I will call "newly affected municipalities" for the rest of the work. In the case of the reference period "evening" in 2050, there should be a slight expansion of the area affected by airport noise to the north-east of the airport and the noise intensity in this extended area would be in the range of 45-55 dB. In the case of the monitored period "night", compared to the current noise load in the vicinity of Bratislava Airport, there will be a significant expansion of areas in all directions, noise pollution caused by aviation, not only within the territorial scope but also in some places there will increase . According to the forecast, the newly affected municipalities with noise intensity from 35-45 dB should include: Zlaté Klasy, Hviezdoslavov, partly Mierovo, Bernolákovo, western part of Pezinok, partly Viničné, Šenkvice, Kráľová pri Senci, Senec, Slovak Tomb, Veľký Biel, Čakany and Malinovo. The intensity of noise pollution would increase for the municipalities of Chorvátsky Grob, Most pri Bratislave and Ivanka pri Dunaji from the current 35-45 dB to 45-50 dB, and for the municipality of Miloslavov it would increase from the current 35-45 dB to 50-55 dB. Depending on the configuration change from the current system to the one-runway system in the 13/31 direction, the extent of the area affected by noise pollution as well as the intensity of noise pollution in some places would change. Some places originally affected by the noise load arising from the flight activity on runway 04/22 would no longer be affected at all during the monitored period "day" and "evening". Such municipalities include: Ivanka pri Dunaji, Zálesie, Chorvátsky Grob, Bernolákovo. The newly affected municipalities in the monitored time periods "day" and "evening" would include the following municipalities: Čierna Voda (western part of the municipality), Bratislava Rača, Bratislava Ružinov in the Trnávka part. These municipalities would be affected by the lowest noise intensity in the range of 35 - 45 dB. Regarding the estimated noise intensity and the extent of the affected area in the observed time "night", we see a big change in both cases. The extent of the area affected by noise pollution from Bratislava Airport has expanded in this time interval in practically all directions from Bratislava Airport to a certain extent. In comparison with the territorial range of noise during the time intervals "day" and "evening", the following municipalities added to the territorial range of noise in the time interval "night": Hviezdoslavov, Kvetoslavov, Mierovo, Thursday on the Island, Čakany, Zlaté Klasy, Tomášov, Malinovo, Zálesie, Ivanka at the Danube, northwestern Bernolákova, Chorvátsky Grob, southwestern Slovenský Grob, Čierna Voda and Marianka with noise intensity in the range from 35 - 45 dB. Bratislava Vajnory and Rača, where the noise intensity increased to 45-50 dB, and Miloslavov, where the noise intensity increased to 50-55 dB, are among the inhabited areas where the noise load intensity has increased. There was also an increase in the intensity of noise along the axis of the runway in the direction of 13 to 60 and more dB, in the area between Bratislava Airport and Miloslavov. Based on the results of the prediction of future movements at M. R. Štefánik Airport in 2050 and subsequent comparison with the current performance of San Diego Airport, which has only one runway at the current number of aircraft handled at the airport, I conclude that Bratislava Airport has a system of runways with sufficient capacity to handle the predicted number of future movements. However, in view of the operating costs of the current runway system, I would suggest canceling the runway in direction 04/22, as the airport would be able to handle the predicted number of movements without much difficulty, even according to the noise load using only one runway. the current assumption that the predicted noise values, during the day and at night, do not exceed the permitted noise limits. Given the estimated number of passengers in 2050, while the current trends in air transport continue, I also think that the airport is able to handle the predicted number of passengers in the number of 6 mil. per year, even if the airport terminal was originally designed to handle 5 mil. passengers per year. [21] The current airport terminal was completed in 2012, and there are currently various technologies for speeding up passenger check-in at the airport, such as automated baggage weighing and check-in systems, or passengers themselves, etc., which were just starting in 2012. they were not in the world or at all. Using various similar smart innovations, it is in my opinion very likely that the given estimated number of passengers in 2050 will be able to handle without major complications.

REFERENCES

[1] Slov-Lex: 355/2007 Z. z. [online]. Available on the Internet: https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2007/355/20211229 (citované 3.4.2022)

[2] Slov-Lex: 549/2007 Z. z. [online]. Available on the Internet: https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2007/549/20090701 (citované 3.4.2022)

[3] Google: Google maps. [online]. Available on the Internet: https://www.google.com/maps/@48.1678782,17.2058592,13.79z (citované 9.4.2022)

[4] A. Kazda - B. Caves: Airport Design and Operation. [online]. Available on the Internet: https://books.google.sk/books?id=rVtGCgAAQBAJ&pg=PA23&hl=sk&source=gbs_toc_r&cad=3#v=onepage&q&f=false (citované 10.4.2022)

[5] ICAO: Manual on Air Traffic Forecasting [online]. Available on the Internet: https://www.icao.int/MID/Documents/2014/Aviation%20Data%20Analyses%20Seminar/8991_Forecasting_en.pdf (citované 11.4.2022)

[6] doc. Ing. Vladimír KONEČNÝ, PhD. 2018. Ekonomická analýza v podniku cestnej dopravy a zasielateľstva: Návody na cvičenia. Žilina: Žilinská univerzita v Žiline. 2018. 193 s. ISBN 978-80-554-1470-6

[7] 7_22Internet archive: Introductory statistics by Illowsky, Barbara [online]. Available on the Internet: https://archive.org/details/IntroductoryStatistics_201904/page/n419/mode/2up (citované 13.4.2022)

[8] R. Sims, 2016. A Review and Application of Aviation Forecasting for Airport Planners: Master of Science. University of North Dakota, 2016. 41s [online]. Available on the Internet: https://commons.und.edu/theses/397/ (citované 11.4.2022)

[9] Ing. Milan Kamenický. 2020. Letisko M.R. Štefánika - Bratislava: Plošná hluková záťaž z leteckej prevádzky v roku 2019: posudok. Bratislava: Euroakustik s.r.o., 2020. 23 s.

[10] Eurostat: Air passenger transport decreased by 73% in 2020 [online]. Available on the Internet: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20211206-1 (citované 15.4.2022)

[11] Statista: Number of passengers carried by air in the European Union from 2008 to 2020 [online]. Available on the Internet: https://www.statista.com/statistics/1118397/air-passenger-transport-european-union/ (citované 15.4.2022)

[12] Statista: Year-on-year passenger traffic change of commercial airlines in Europe from 2013 to 2022* [online]. Available on the Internet: https://www.statista.com/statistics/658701/commercial-airlines-passenger-traffic-change-europe/ (citované 15.4.2022)

[13] Eurocontrol: Charting the European Aviation recovery: 2021 COVID-19 impacts and 2022 outlook [online]. Available on the Internet: https://www.eurocontrol.int/sites/default/files/2022-01/eurocontrol-think-paper-15-2021-review-2022-outlook_0.pdf (citované 15.4.2022)

[14] Letisko M. R. Štefánika: Ročné správy [online]. Available on the Internet: https://www.bts.aero/o-letisku/press/rocne-spravy/ (citované 16.4.2022)

[15] Eurocontrol: EUROCONTROL Forecast Update 2021-2027 [online]. Available on the Internet: https://www.eurocontrol.int/publication/eurocontrol-forecast-update-2021-2027 (citované 20.4.2022)

[16] Eurocontrol: EUROCONTROL Aviation Outlook 2050 [online]. Available on the Internet: https://www.eurocontrol.int/sites/default/files/2022-04/eurocontrol-aviation-outlook-2050-report.pdf (citované 21.4.2022)

[17] IATA: Air Passenger Numbers to Recover in 2024 [online]. Available on the Internet: https://www.iata.org/en/pressroom/2022-releases/2022-03-01-01/ (citované 21.4.2022)

[18] Letové prevádzkové služby: AIP Letecká informačná príručka [online]. Available on the Internet: https://aim.lps.sk/eAIP/eAIP_SR/AIP_SR_valid/html/LZ-AD-2.LZIB-sk-SK.html (citované 21.4.2022)

[19] San Diego International Airport [online]. Available on the Internet: http://www.airnav.com/airport/KSAN (citované 21.4.2022)

[20] San Diego International Airport: air traffic report summary. Calendar year 2019. [online]. Available on the Internet: https://www.san.org/Portals/0/Documents/Air%20Traffic%20Reports/2019_Year_in_Review.pdf?ver=2020-02-27-144247-470 (citované 22.4.2022)

https://doi.org/10.26552/ pas.Z.2022.2.18

DESIGN OF PARTICLE IMAGE VELOCIMETRY SYSTEM FOR THE WIND TUNNEL OF UNIVERSITY OF ŽILINA

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Abstract

Due to always ongoing innovation in research ability of our research facility it was decided to innovate already existing wind tunnel by implementing system of Particle Image Velocimetry. Main goal of this thesis is to create sufficient technical solution for implementation of Particle Image Velocimetry measuring systems. This system will allow creation of accurate measurements of aerodynamic forces and visualise airflow direction and its strength. Implementation of this system consists of designing sufficient structure to allow proper mount and movement of laser light source, which will be high power laser and mount for camera, which will be used to capture images of airflow of measured parts. In terms of laser stand, the main goal was to simplify the construction to decrease costs of structure and to create room for future upgrades and implementations of possible motorisation and electronic controls. For main construction were chosen steel profiles with square cut and size of 30x30 mm to match already existing construction used to stabilise measured part in test chamber. Implementation of this system of measurement will increase research abilities and it will create room for more projects, which depend on this method of measurement. Particle Image Velocimetry has wide range of usage from automotive industry through aviation to designing of spray nozzles. This will create large research opportunities for other facilities and professionals from different parts of industry, since this technology will be one of the first implemented into wind tunnel in Slovakia.

Keywords

PIV, Particle Image Velocimetry, PID, Aerodynamics

1. INTRODUCTION

Since mankind has longed to fly from ancient times, attempts have always been made to get man into the air so that he can soar freely like a bird. In order to find out the principle of flight of birds, engineers have tried to invent different ways of measuring the forces acting on them during flight. With these experiments came the first records of attempts to visualize the flow around bodies drawn by Leonardo Da Vinci. Further experiments led scientists to controllable spaces for experiments in aerodynamics. These spaces and objects are now known as wind tunnels. The first way of visualizing flow was and still is through the use of smoke. This method also persists mainly because of its effortlessness and simplicity. The invention of the light-emitting diode opened the way for new methods of measurement thanks to the possibility of concentrating this light into a single beam of high luminous intensity. The combination of these two methods gave rise to the measurement method now known as Integral Laser Anemometry. This relatively new technology finds its application in fields that deal with fluid flow around a body or flow directly through a body. The most widespread measurement set-ups are mainly used in water tunnel areas, or for research on the atomization efficiency of spray nozzles. This means that we will encounter problems and situations in the design process that occur exclusively in wind tunnel applications.

Since this measurement method relies on three main elements of the assembly, which are lighting, sensing and computation it is necessary to align these three elements to form a single unit in which these components are balanced. Good visibility of what is going on in the test chamber must be ensured by a suitable light source that is able to illuminate the space to such an extent as to allow seamless image capture. The image acquisition is the responsibility of the image acquisition equipment, which must ensure that the quality of the images is sufficient to allow calculations to be carried out on the basis of the images. The calculations are performed by software which allows a relatively fast and accurate evaluation of the captured image.

The aim of this research is to create a complete system that will be suitable for conducting research in the field of fluid flow, with the subsequent possibility of visualising the measured values, which can then be further processed according to the type of experiment.

2. MATERIALS AND METHODS

2.1. PIV technology

For our research we have chosen planar 2D method. This method will allow us to create basic computed measurements and visualisations with high precision of calculated results. 2D method was chosen also due to its lower cost in comparison with other methods and techniques. Since it is important for rig components like laser and camera to be fixed in place, so that they will not move during experiments and measurements it was necessary to design a rig, that will be capable of providing stability of components and their movability, which will allow us to set up the whole rig to or needs and into necessary position [1].

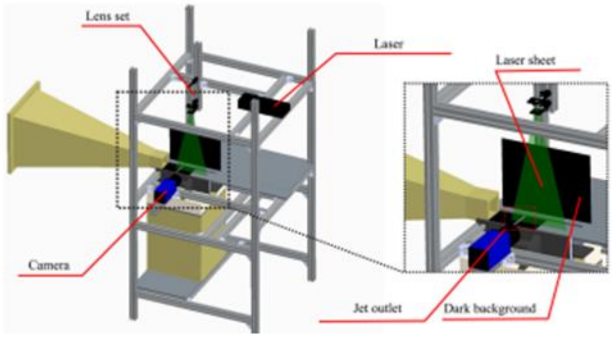

Figure 1: Description of 2D PIV rig [2]

2.2. Wind tunnel

The wind tunnel used for our research and implementation of PIV system is placed in the Research centre of University of Žilina. This tunnel is tunnel working with low speeds, and its maximum flow speed in test chamber is 100 km/h. Tunnel is in open air circulation configuration. Length of test chamber is 640 mm. This means, that reflective particles will travel through the test chamber in only 23 ms. Due to this speed and set number of frames of 90 for our experiment, it is necessary to use camera, that is capable of speeds as high as 4000 FPS. Due to this specification, it is necessary to pick the right research grade camera, since regular consumer cameras are not able of such speeds, and they are usually providing only around 60-120 FPS, which is too slow for the research needs [3]

2.3. Design of testing rig and component selection

Design has two parts. First part consists of laser mounting rig and second part is camera stative.

2.3.1. Design of laser mounting rig

Laser mounting rig has three separate parts. First fixed part is used for vertical element of the mounting mechanism. For this steel profiles with square cut and dimensions of 30 x 30 mm with wall thickness of 2 mm were used, to ensure size compatibility with already existing rig used for measuring aerodynamic forces, onto which this vertical element will be mounted.

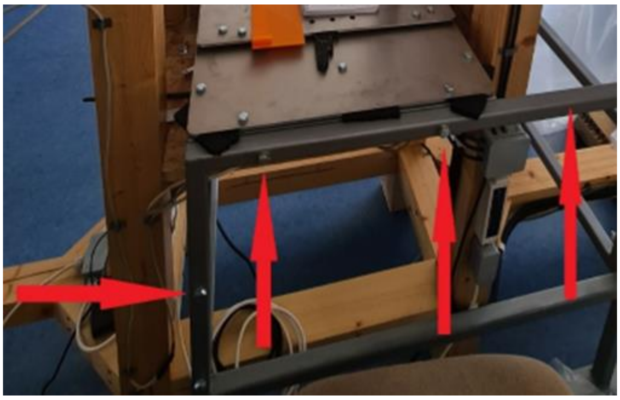

Figure 2: Testing rig with highlighted mounting areas of vertical element

For fixation of vertical element, three nut bolts with size of M10 x 110 mm and one M10 x 80 mm were d. To ensure ability to set testing height of mounted laser, use another steel profile with dimensions of 25 x 25 mm with length of 500 mm was used, to ensure possibility of vertical setting. This smaller profile is fitted into second part of vertical construction. Height of laser can be set in the span of 200 mm, and it can be fixed by usage of two M6 x 50 bolt screws in pre-drilled holes spaced by 20 mm. The same bolt screws are used to fix the smaller profile into the second part of vertical construction.

Horizontal movement is secured by T shaped rig. This rig has its fixed part, which us used for housing and securing of the T shaped rig. This rig consists of two steel profiles. One with dimensions of 20 x 20 mm and second one with 30 x 30 dimensions. Both profiles have square cut and 2 mm wall thickness. Movement of this rig is secured by 8 ball bearing balls with diameter of 5 mm. Due to use of these parts it was necessary to create groove in all four sides of the profile, thanks to which perfect alignment, fit and stability of both parts was ensured. The fixed part of horizontal construction is made using steel profiles of square cut and size 30 x 30 mm. For sideways move the smaller 20 x 20 mm is used. This ensured spacing big enough for usage of ball bearings of mentioned 5 mm diameter.

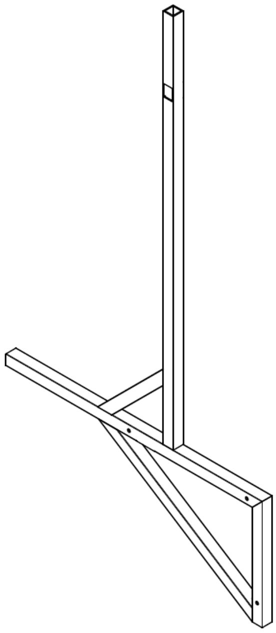

Figure 3: Design of vertical element of construction

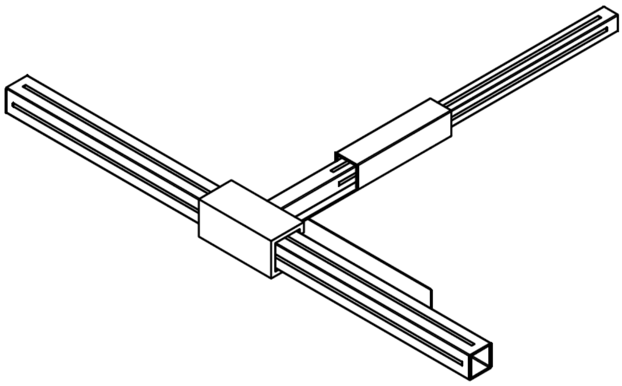

Figure 4: Design of horizontal construction

Horizontal construction can be fixed in set place by the usage of two M8 x 25 mm bolt screws. This size allows for area big enough to hold the rig in place and does not cut into groove for ball bearing balls. For lengthwise setting of the laser, 3D printed moving rig was designed, which has slide in mount for laser holder in its bottom part. Movement of this mount is also ensured by usage of six 5 mm steel ball bearing balls.

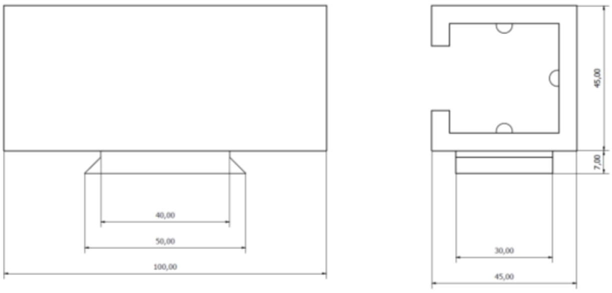

Figure 5: Design and sizing of laser holder rig

For mounting of laser, two-piece rig with ability to set angle of the laser was designed. First part has cut out for mounting onto laser mounter rig. These two parts are then fixed in place using M4 x 10 bolt screw.

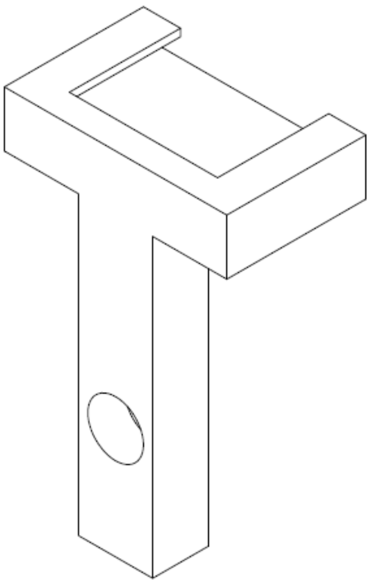

Figure 6: Design of fixed part of laser holder

To ensure setting of angle, this part has circular cut out with diameter 15 mm. This cut out has also hole for a fixing screw with diameter of 4 mm.

Second part of this laser holder consists of laser holder itself, which contains 10 mm extrusion with diameter of 15 mm. This ensures perfect fit and ability to set angle of the laser. Inner part of this holder has the same dimensions as laser, which are 33 x 33 mm. Bottom part of the holder has hole for M4 screw, which is used to tighten the fit for laser.

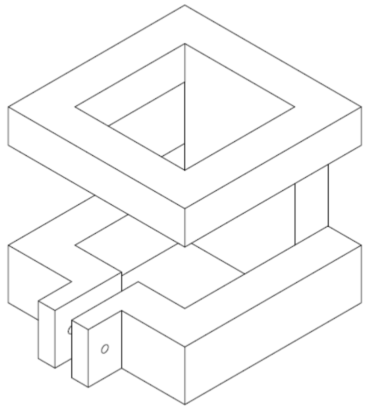

Figure 7: Design of rotational part of the laser holder

2.3.2. Choice of light source

Since we will use PIV in the wind tunnel with open air circulation, it was necessary, to choose laser, which will be bright and powerful enough to be visible in the daylight and in bright environment.

For our use we have chosen 400 mW laser with wavelength of 520 nm, which means, that the laser beam has bright green color. This laser is equipped with line optics, which means, that there is no need for optics, that would be normally used to change the collimated beam of light into line beam. This laser is capable of creating light line with angle of 110°. Thanks to this, smaller height over the test chamber is needed. This means, that the laser will not loose its power due to high height over the test chamber, which would be present in case of steeper beam angle.

Cooling of laser is passive, which ensures proper cooling of the unit. In case of high temperatures in the test facility, there is possibility of mounting cooling fan, which will help with cooling of the laser unit.

Laser is powered with 12 V DC power, which is converted using 220 V AC adapter.

2.3.3. Choice of camera

As it was mentioned earlier, camera, which will be used for high-speed capture has to be capable of capturing at rate of at least 4000 FPS. Due to this requirement, we have chosen the Mega Speed MS90K-SC camera, which has maximum framerate of 270 000 FPS. Camera is capable of resolution 1280 x 800 at 4000 FPS, which provides us with area big enough to conduct experiments. In case of upgrade of the tunnel high speed, there is still big enough reserve of possible usable framerate. For our use of flow rate in the test section of up to 100 km/h table of suggested minimum FPS for selected speed was created.

Table 1: Recommended minimum framerate based on flow speed

km/h	**FPS**	**km/h**	**FPS**	**km/h**	**FPS**
100	4000	67	3000	35	1500
99	4000	66	3000	33	1500
98	4000	65	3000	32	1500
97	4000	64	3000	31	1500

96	4000	63	3000	30	1500
95	4000	62	2000	29	1500
94	4000	61	2000	28	1500
93	4000	60	2000	27	1500
92	4000	59	2000	26	1500
91	4000	58	2000	25	1000
90	4000	57	2000	24	1000
89	4000	56	2000	23	1000
88	4000	55	2000	22	1000
87	4000	54	2000	21	1000
86	4000	53	2000	20	1000
85	4000	52	2000	19	1000
84	4000	51	2000	18	750
83	3000	34	1500	17	750
82	3000	50	2000	16	750
81	3000	49	2000	15	750
80	3000	48	2000	14	750
79	3000	47	2000	13	750
78	3000	46	2000	12	500
77	3000	45	2000	11	500
76	3000	44	2000	10	500
75	3000	43	2000	9	500
74	3000	42	2000	8	350
73	3000	41	2000	7	350
72	3000	40	1500	6	350
71	3000	39	1500	5	250
70	3000	38	1500	4	250
69	3000	37	1500	3	180
68	3000	36	1500	2	125
				1	45

2.3.4. <u>Choice of computer</u>

Since we are using for computation and visualization MatLab software with plugin PIVlab, the only requirement is minimum of 8 GB of RAM and SSD memory drive, which will ensure quick processing of captured images. We have chosen MatLab with PIVlab extension due to its user-friendly environment and simplicity. This software has also all the necessary features needed for conducting experiments in 2D PIV settings.

3. RESULTS

After considering all of the mentioned components of design and rig parts, we were able to create and calculate pricing list of all necessary components needed for completion of this testing rig. All components are listened in table below with their prices.

Table 2: List of components and material with their specific prices

Component	Amount	Prince in €
21,5" AOC E2270SWDN	1	123,90
Acer Aspire TC-1760	1	610,90
CAT6 UTP Patch Cord Cable	2 m	4,00
C-TECH KBM-102	1	7,30
Circular washer 10,5 x 20 mm	1	0,10
Circular washer 10,5 x 30 mm	3	0,50
Mega Speed MS90K-SC	1	2 400,00
MZTech Green laser module with cooling	1	295,00
Steel profile 20 x 20 mm	1 m	4,90
Steel profile 25 x 25 mm	0,5 m	2,34
Steel profile 30 x 30 mm	4,5 m	22,50
Protective glasses for green laser	3	45,00
Bolt screw M10 x 110 mm	3	1,30
Bolt screw M10 x 80 mm	1	0,40
Nut M10	4	0,25
Nozzle 1/4-M2	1	12,00
Total estimated price		3 530,39

Construction of the test rig had already begun, but came to a stop due to issues with sourcing of laser unit, due to which it was not possible to properly calibrate testing rig and demonstrate capabilities of flow computation and visualisation.

4. CONCLUSION

Due to always ongoing modernisation of wind tunnel in research facility it was only matter of time, when would this modern technology of flow measurement. Thanks to this research and design of testing rig it is possible to implement 2D PIV system, with possibility of further extension for stereoscopic or 3D methods. After obtaining selected laser in the near future, it will be possible to create measurements and visualisations of flow using selected software. While designing testing rig, the idea was to create simple but effective construction, in which task we have succeeded. Thanks to this design decision we have managed to keep the cost of materials low.

REFERENCES

[1] Markus Raffel, Christian E. Willert, Particle Image Velocimetry A Practical Guide, 2017, ISBN 978-3-319-68851-0

[2] http://opensourcepiv.weebly.com/a-brief-introduction-and-history-of-piv.html

[3] Jewel B. Barlow, William H. Rae, Alan Pope, Low-Speed Wind Tunnel Testing, 3rd Edition, February 1999, ISBN: 978-0-471-55774-6

[4] BUGAJ, M. 2020. Aeromechanics 1: fundamentals of aerodynamics. 1st ed. - Žilina : University of Žilina, 2020. 193 s. ISBN 978-80-554-1675-5.

[5] BUGAJ, M. 2015. Aeromechanika 1: základy aerodynamiky. Bratislava : DOLIS, 2015. - 208 s., ilustr. - ISBN 978-80-970419-3-9.

https://doi.org/10.26552/ pas.Z.2022.2.19

UNIVERSITY OF ŽILINA

DESIGN AND IMPLEMENTATION OF EQUIPMENT FOR PARTIAL USE OF COMBUSTION ENGINE EXHAUST ENERGY

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Abstract

The content of the diploma thesis was the design and implementation of equipment for the partial use of exhaust gas energy of the internal combustion engine and the possibilities of using this equipment in internal combustion engines. The aim of this work is to design a scheme and 3D model of the converter for energy recovery from exhaust gases based on magnetohydrodynamics, and also to provide scientific information and inform the reader as much as possible about the theory of magnetohydrodynamics and the use of these theories in energy recovery. The work provides scientific information in the field of hydrodynamics, magnetohydrodynamics of engines and emissions and in the practical part is designed and built magnetohydrodynamic converter which was one of the main objectives of this work together with key information from the researched area and their application to the converter.

Keywords

Magnetohydrodynamics, Hydrodynamics, Exhaust gases, Magnetohydrodynamic accelerator, Combustion engine, MHD

1. INTRODUCTION

Today, great emphasis is placed on themaximum use of energy resources due to the constant growth of the population and increasing demands on electricity, which is in contrast to the ever-decreasing supply of fossil fuels and non-renewable energy sources. For these reasons, the aim is to obtain new energy sources, increase the efficiency of existing sources or use the recovery of existing energy. This effort is reflected in all industries, including transport. Transport is also under great pressure from the environment and increasing environmental pollution due to the constant increase in air, car and shipping traffic. For small aircraft and cars, the internal combustion engine is the most widely used power unit. It is used in a wide range of vehicles. However, fuel combustion in these engines is quite imperfect. Only part of the energy supplied by the fuel during combustion is used for useful power and the rest of the energy goes unused. Much of the energy is released into the ambient air by cooling and exhaust. Additional losses are caused by the friction of the moving parts of the engine and only a small part of the energy is used, for example, to heat the cabin or drive the turbocharger. The generated waste heat can be used in many ways, for example for conversion into electricity or for other purposes. It all depends on the technology used. One such new technology is magnetohydrodynamics.

Magnetohydrodynamic (MHD) generators or converters are devices used to produce electricity in a relatively unconventional way. They use the passage of an electrically conductive substance through a magnetic field. Michael Faraday was already studying this phenomenon and in 1832 he tried to observe it. He performed an experiment in which he tried to measure the electric current generated by the saltwater flow of the River Thames in London in the Earth's magnetic field. [1] His experiment was not successful and many years after that it was not possible to build a functioning experimental facility. The turning point came in the 50s of the 20th century, thanks to the development of plasma physics and the development of materials for extreme temperatures. In many countries, intensive research has subsequently begun with great optimism. However, due to challenging technological problems, it was significantly subdued for several years, and only the United States and the Soviet Union continued to develop. In the 70's, there was a renewed interest in the operation of public transport generators in several countries, but nevertheless it was not possible to overcome all the problems and there was never a large commercial use.

To a lesser extent, research continues to this day, using new materials and technologies. The idea of the future is the use of public transport generators and converters as a source of electricity at the outlet of the fusion reactor. Another possible option is the construction of generators using the movement of seawater.

The subject of this work is the construction of a small functional model of public transport converter, which will work with the energy of hot gases in a magnetic field created by magnets. This is a very unconventional device.

The theoretical part of the work is devoted to a historical overview of existing technical solutions using the energy of hot gases or energy of exhaust gases and theoretical knowledge of magnetohydrodynamics. The experimental part of the work then describes the design of a 3D model of public transport converter and the design and construction of the model itself. The experimental part also describes the measurement and test of the functionality of the magnetohydrodynamic transducer model and the evaluation of the measured results.

2. INTERNAL COMBUSTION ENGINE AS A SOURCE OF PROPULSION

Most internal combustion engines used today are reciprocating internal combustion engines for liquid fuels. During the conversion of thermal energy into mechanical energy, thermodynamic processes take place, during which the state of the working substance changes, which in the case of internal combustion engines are exhaust gases generated by the combustion of fuel. The fuel is not fed to these engines continuously, as in combustion turbines, but periodically. This raises certain problems, such as the generation of nitrogen emissions from incomplete combustion. All reciprocating internal combustion engines operate with open duty cycles, ie at the beginning of each cycle we supply a new working fluid with the same initial thermodynamic parameters, which performs work in the engine and leaves with lower temperature and pressure.

The principle of operation of reciprocating internal combustion engines is the combustion of fuels directly in the cylinder of the internal combustion engine. A mixture of fuels with air, or only air, is sucked into the cylinder, depending on the type of engine. This is followed by a compression stroke, at the end of which the fuel mixture is ignited by a spark in the case of a petrol engine, or the fuel is ignited by the heat of compression in the case of diesel engines. The thermodynamic processes taking place inside the engine describe the theoretical cycles. These cycles are divided into explosive with constant heat combustion, equal pressure with constant pressure combustion and a mixed cycle in which combustion occurs partly at constant volume and partly at constant pressure

2.1. Petrol engines

Four-stroke petrol engines are engines for light liquid fuels, especially gasoline. They work on the principle of the Otto cycle, but the actual work cycle is different. In the first time of the operating cycle, the piston moves from the top dead center to the bottom and sucks a mixture of liquid fuel and air into the combustion chamber. This mixture does not form as easily as, for example, gaseous fuels. The efficiency of the heat conversion depends on the quality of the ignition mixture, because imperfect combustion occurs when the fuel is mixed poorly with air. This reduces the amount of energy gained that is contained in the fuel. In the second time of the cycle, the mixture is compressed (the temperature of the mixture reaches 350 ° C to 450 ° C), in the next third time the mixture is ignited by an electric shock and expands (temperature 2000 ° C to 2500 ° C). This time is also the only working time of the four-stroke engine. The fourth and final time of the cycle is the exhaust, in which the exhaust gases (temperature 800 ° C to 900 ° C), generated during combustion, leave the combustion chamber through the exhaust pipe without further use into the ambient air. One working cycle takes place during four piston strokes. This working cycle shows us the working diagram of the actual working cycle of the petrol engine.

2.2. Diesel engines

The diesel engine differs from the petrol engine mainly in the way of creating ignition mixtures. Only air is sucked into the diesel engine (first time - suction), which is then compressed (second time - compression), which causes heating (temperature 600 ° C to 900 ° C). The compressed mixture is injected with fuel, which ignites due to the temperature and expands (third time - expansion). Therefore, the compression ratio must be large enough for the compressed air to reach a compression temperature higher than the ignition temperature of the fuel. Subsequently, the exhaust valves are opened and the exhaust gases at a temperature of 600 ° to 700 ° are released into the air (fourth time - exhaust). The theoretical operating cycle of a diesel engine is shown in a mixed Sabbath cycle, but it also differs from the actual operating cycle.

The thermal balance of a diesel engine differs slightly from a petrol engine. The use of a mixed duty cycle increases the amount of energy converted to efficient engine operation. This can be seen in the diagram (Fig.4). With a diesel engine, the heat is used efficiently to drive the Qe axle (30% to 45%). Losses of combustion imperfections Qns (0% to 5%), radiation Qs (0% to 5%) and mechanical losses Qm (5% to 10%) are the same as for ignition. The values of losses in exhaust Qv (25% to 45%) and cooling (15% to 35%) differ [6]

3. THERMAL BALANCES OF ENGINES

Table 1 Thermal balances of engines

Thermal balances		**Petrol engine**	**Diesel engine**
Supplied heat		100%	
Energy efficiently used		25-35%	30-45%
Losses	Cooling	12-30%	15-35%
	Exhaust	30-50%	25-45%

The values given in the table show that the diesel engine uses the energy supplied by the fuel more efficiently than the petrol engine. Comparing the individual losses of both types of internal combustion engines, we can then determine the place that could be most effective for the application of some technology to use energy from exhaust gases. With a petrol engine, the biggest losses are exhaust gases, so it would be a good idea to place a heat recovery unit or other suitable device in the exhaust line. To place the unit in the exhaust pipe, it is important to know its effect on the behavior of the exhaust gases passing through it. Back pressure may build up in the unit or the temperature may drop so sharply that it would adversely affect the discharge of gases from the combustion chamber [12]. The installation location of the unit is selected according to the temperatures at which it operates. However, it is important to take into account that there is also a catalytic converter in the exhaust pipe, which requires higher operating temperatures for its function. Therefore, it is important to decide whether the unit will be located in front of or behind the catalytic converter. On the other hand, in the case of diesel engines, they make up a significant part of the cooling loss due to the higher operating temperatures of the engine, so it would be appropriate to use this waste heat as well.

3.1. Exhaust gas formation

Combustion of gasoline or diesel is an oxidation process in which the combustible components of the fuel (C, H or S) combine with oxygen. The energy contained in the fuel is converted into heat and the ambient air, which contains 21 volume percent oxygen, acts as an oxidant. [13]

An internal combustion engine needs a certain ratio of air and fuel to operate. Ideally, 14 kg of petrol and 1 kg of diesel require 14.5 kg of air to burn 1 kg of petrol. If we convert the weight ratio to volume, we will need about 10,000 liters of air to burn 1 liter of fuel. This ideal mixing ratio is sometimes referred to as a stoichiometric mixture. To facilitate the description of the individual regimes, a coefficient of excess air - lambda - has been introduced. A value of 1 indicates an ideal ratio, values greater than 1 belong to a lean mixture, values less than 1 represent a rich mixture. Although different engine operating modes use different mixes, from poor (lambda 1.05 - 1.3) offering low part load consumption to rich (lambda 0.85 - 0.95) for high full power deployment, the stationary (steady) mode of operation of the engine in today's engines is in a narrow interval around lambda 1 (mixture required for proper operation of the catalyst). This applies to naturally aspirated engines as well as supercharged engines. [13]

4. OVERVIEW OF TECHNICAL SOLUTIONS FOR THE USE OF EXHAUST GAS ENERGY

Many technologies are known in the industry which are suitable for use in the recovery of waste heat from a production process in the production of heat and electricity. Heat engines (Stirling engine, Rankin-Claus cycle, etc.) are often used for this purpose. Thanks to new modern materials, thermoelectric generators using the Seebeck effect are also beginning to appear for the use of waste heat in smaller applications [23];

Internal combustion engines already use devices that use the kinetic energy of the exhaust gases (turbochargers) to improve the efficiency of the engine. However, a relatively large amount of energy remains in these gases, which could be converted into another type of energy. As stated [25] according to the method of thermal energy conversion, the device is divided into

1) Thermo - dynamic:

- Stirling engine
- Rankine-Clausian cycle (steam or organic)

2) Thermo - electric:

- Seebeck phenomenon
- Thermophotovoltaics
- Thermal emission converters
- Thermal tunneling

3) Thermo - chemical

- Fuel cells
- Autothermal reforming (hydrogen production)
- Pyrolysis
- Gasification

4) Thermo – acoustic

Chapter 1 lists the common thermal efficiencies of internal combustion engines; the range of the petrol engine was 25-30%, the diesel engine 35-40%. As stated in the introduction, efficiency can increase efficiency with modern technologies, but not to a value higher than 45% [26]. This means that even in the most efficient modern engines, more than half of the energy supplied is not used and is dissipated in the form of waste heat.

Many exhaust energy technologies have been developed and are dominated by the following: mechanical turbo-compounding, electrical turbo-compounding, turbocharger, thermoelectric generator, six-stroke internal combustion engine and Rankine-Clausian cycle. [27], [28] To compare efficiency engines and technologies for the use of waste heat, a quantity called specific fuel consumption (msp) is often used. Msp indicates the ratio of the amount of fuel and the work obtained from this amount. The unit of msp is g.kW-1.h-1. The smaller the msp, the better the fuel utilized [29], [30].

5. THEORETICAL KNOWLEDGE OF THE PROBLEM OF PUBLIC TRANSPORT

At present, projects that operate on the principle of magnetohydrodynamics (MHD) are mostly only on a theoretical level because not all questions have yet been answered, such as efficiency or feasibility itself. Magnetohydrodynamic power generation provides a way to generate electricity directly from a fast-moving stream of ionized gases without the need for any moving mechanical parts - no turbines and no rotary generators. Several public transport projects started in the 1960s, but overcoming the technical challenges associated with creating a practical system proved to be very costly. Interest subsequently waned in favor of nuclear energy, which has since become more attractive.

Public transport power generation has also been studied as a method of obtaining electricity from nuclear reactors as well as from more conventional fuel combustion systems. [42]

5.1. Fundamentals of magnetohydraulics

Magnetohydrodynymics is the study of the behavior of a conductive fluid (liquid, gas or plasma) in a magnetic field. The relative motion of the conductive fluid and the magnetic field induces an electric field and currents. Electric currents build up a magnetic field in their surroundings and this mechanical effects affect the return movement of the conductive fluid. It is a complicated interaction of a conductive fluid with an electromagnetic field, strongly nonlinear phenomena and mutual transformations of magnetic, mechanical and thermal energy. The initial mechanism of transformation can be both a strong electric field (electric discharges) and strong currents and a strong magnetic field or a relatively intense mechanical movement of the plasma relative to the magnetic field. The first beginnings of magnetohydrodynamics were associated with experiments performed with mercury. In the 20s and 50s, it has inspired the further development of solutions to cosmic problems from the Earth's core, the Sun, stars and plasma in interstellar space. In the later period, laboratory research was developed, especially in the maintenance of plasma by magnetic field for controlled nuclear fusion. Galactic plasma, the interior of stars, laser and pincer plasma with high energy density in terrestrial laboratories combine a number of analogies through huge differences of tens of orders in spatial and temporal dimensions. In the cosmos, magnetic fields are the source of energy transformations, and in the laboratory environment, strong electric fields or intense electromagnetic radiation from powerful lasers.

Magnetohydrodynamics provides a deeper understanding of the context in space and the phenomena associated with high energy concentrations in laboratories for the study of X-ray sources and nuclear fusion. The magnetic field is a source of a form of noble energy with a strong self-organizational ability, manifested e.g. in magnetohydrodynamic turbulences, magnetic dynamics and stable annular and helical structures. [42]

6. DESIGN OF A SCHEME AND 3D MODEL OF A PUBLIC TRANSPORT CONVERTER FOR OBTAINING ENERGY FROM EXHAUST GASES

In order for the design of the magnetohydrodynamic transducer to work, it had to meet certain important conditions. The first and most important condition for operation was the fulfillment of the structure from the point of view of physical laws. We have verified this functionality by applying the physical laws that are responsible for the operation of our drive. Another important point that supported us in the fact that the device will work was the existence of some already functioning devices that use magnetohydrodynamic drive, and therefore for our public transport converter to work, it was necessary to follow the principles of operation such as the material used.

6.1. Principle of operation

The magnetohydrodynamic (MHD) converter we designed is used to directly convert thermal energy or heat into electrical energy. The basis is a fast flow of hot gases in the exhaust pipe containing free charged particles. If such a gas flows through a transverse magnetic field, the Lorentz force acts on the moving charged particles. [45]

This means that the positively and negatively charged particles divide inside the converter in the direction of the magnetic field in two directions to the stripped copper plates from which the copper conductor is led through which we dissipate the acquired electrical energy and thus obtain a closed electrical DC circuit.

We designed the device in the Creo 5.0 program, which enabled us to thoroughly develop a 3D model of the converter, which helped us in the later implementation.

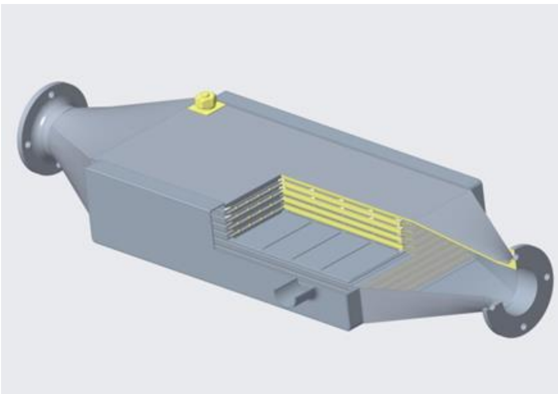

Figure 1 MHD generator

6.2. 3D model simulations

Another part of our work was simulations and analyzes of gas flow in the public transport inverter, so that we can imagine how hot gases will behave when passing through the inverter, whether vortices and the like will form. To create simulations and analyzes, we used the Ansys Discovery 2020 program, which allowed us to examine the gas flow in detail and also set the flow rate or gas temperature. We performed the first simulations on the first prototype model, which we improved even later according to the simulation results. The initial simulation was performed with hot gas which had an inlet temperature of 800 °C and a speed of 5 m / s.

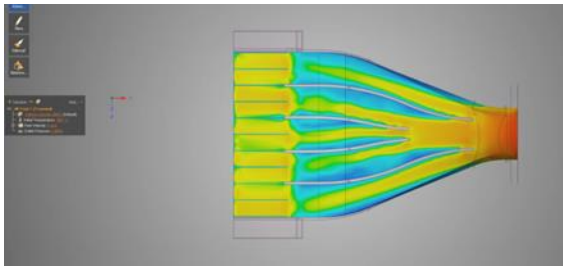

Figure 2 Model simulations

7. PRACTICAL IMPLEMENTATION OF A SIMPLIFIED PUBLIC TRANSPORT CONVERTER FOR OBTAINING ENERGY FROM EXHAUST GASES

After developing the design of the public transport converter, we embarked on the practical implementation of a domestic simplified converter. We used the proposal we described in the previous chapter and the theoretical knowledge we gained. During the implementation of the converter, we often encountered complications, but we managed to solve them all. We described the course of construction of the converter as we actually proceeded together with the complications that arose.

We decided to make the body of the public transport converter from tiles, which had to be prepared first and cut to suitable dimensions. in the initial stage of implementation of this device, it was necessary to obtain all the components to build a functional model of public transport converter. As mentioned above, from a logical point of view, ceramic tiles came to the skeleton of the device, which we cut to the desired shape and then glued with contact glue. After gluing the parts, we tried to heat the frame of the converter to a higher temperature and we found that the contact glue does not resist thermal radiation and the frame began to disintegrate, for this it was necessary to provide other more suitable fire resistant glue that we managed to buy, it is a high strength fast drying glue. a mammoth that passed the subsequent test and the converter skeleton remained solid even at high temperatures.

To successfully complete the test, it was necessary to provide state-of-the-art measuring equipment. For this test we used a professional digital multimeter brand FLUKE (see picture) which we connected to the plus and minus electrode of the public transport converter. To generate hot gases, we used a Berner gas burner that can generate a temperature of up to 800 °C. In the subsequent test, we injected hot gases through the skeleton diffuser through a magnetic field that distributed the positively and negatively charged particles of this gas to the measuring electrodes, which then transmitted the data to the measuring device. we repeated the test several times with a positive result. each time we managed to measure approximately the same values at the level of 50 mV. During the test, we managed to generate a direct current voltage and thus produce electricity from hot gases.

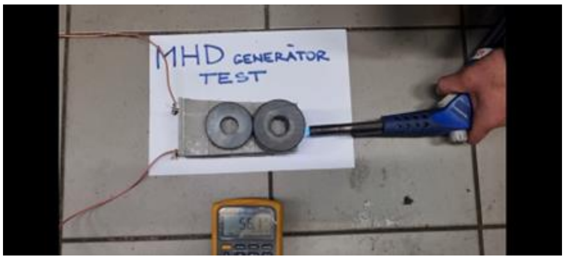

Figure 3 MHD generator test

8. CONCLUSION

This diploma thesis dealt with the design and construction of a magnetohydrodynamic transducer using permanent magnets and a conductive substance formed by hot gases. The theoretical part of the work lists the existing technical solutions that use the energy of exhaust gases and also explains the basic theoretical principles causing the operation of public transport converter.The experimental part describes the design of the public transport converter as well as the implementation of a simplified converter, which was constructed and which, together with its measured parameters, is the main output of this work. There is a problem of design and construction of individual elements of models. The measurement of parameters on the public transport converter model follows. The practical part also describes the measurement procedure. It goes without saying that all measured values and knowledge are presented and described, which are evaluated in the following paragraphs. When evaluating the measured parameters, it is first necessary to note that the primary goal of this work was to verify the theoretical function of the public transport converter. For this purpose, the model was designed and built from the ground up. The basic parameter that can be measured on the generator is the voltage on the unloaded electrodes. However, we also managed to measure direct current. When comparing the measured voltage with the theoretically assumed, we see that the values are very similar. The assumed theoretical value was 50 mV. The measured values on the individual electrodes of our inverter are 56.1 and 48.8 mV. The deviations are mostly due to the impossibility of precisely eliminating the effect of electrode polarization. In all measurements, the maximum generated voltage is close to the expected value, thanks to which we can confirm the function of the magnetohydrodynamic converter.Overall, the results achieved can be considered very convincing and it can be stated that the expectations and the assignment were met. A space is now opening up for further research, in which a number of optimizations could be made concerning the design itself as well as the measurement of parameters. Then it would be possible to achieve greater efficiency of the converter with the possibility of more accurate measurement of its parameters.

ACKNOWLEDGMENT

This paper is an output of the project of the Ministry of Education, Science, Research and Sport of the Slovak Republic KEGA No. 048ŽU-4/2020 "Increasing key competences in aircraft maintenance technology by transferring progressive methods to the learning process".

REFERENCES

[1] LIPSCOMBE, Giles, Jordan PENNEY, Roger LEYSER a Hayley Jane ALLISON. Water Under the Bridge. Physics Special Topics [online]. 2014 [cit. 2022-01-12]. Dostupné z: https://physics.le.ac.uk/journals/index.php/pst/article/view/743/517

[2] CELIŃSKI, Zdzisław. Nové zdroje elektrické energie. Praha: Státní nakladatelství technické literatury, 1985. ISBN 04-540-85.

[3] STROHL, G. Ralph a William D. JACKSON. Magnetohydrodynamic power generator. In: Encyclopedie Britannica [online]. 2007 [cit. 2022-01-14]. Dostupné z: https://www.britannica.com/technology/magnetohydrodynamicpower-generator

[4] JAN, Zdeněk a Bronislav ŽDÁNSKÝ. Automobily: Motory. 5. vydání. Brno: Avid, spol. s.r.o., 2008. ISBN 978-80-87143-06-3.

[5] KALČÍK, Josef a Karel SÝKORA. Technická termomechanika. Praha: Academia, 1973, 540 s.

[6] HROMÁDKO, Jan. Spalovací motory: komplexní přehled problematiky pro všechny typy technických automobilních škol. 1. vyd. Praha: Grada, 2011, 296 s. ISBN 978-80- 247-3475-0 (BROž.)

[7] ŠTOSS, Milan. Spalovací motory I. 1. vyd. Brno: VUT Brno, 1987, 261 s

[8] VLK, František. Paliva a maziva motorových vozidel. Brno, 2006. ISBN 8023964615.

[9] HROMÁDKO, Jan. Spalovací motory: Charakteristika automobilových paliv [online]. Praha: Česká zemědělská univerzita v Praze, Technická fakulta [cit. 2022-2-04]. Dostupné z: http://oppa-smad.tf.czu.cz/?q=system/files/2.Pr_.ppt

[10] ČSN EN 228+A1: Motorová paliva - Bezolovnaté automobilové benziny - Technické požadavky a metody zkoušení. CZ, 2018.

[11] ČSN EN 590: Motorová paliva - Motorové nafty - Technické požadavky a metody zkoušení. CZ, 2018.

[12] Ford study shows Rankine waste heat recovery system on a light-duty vehicle could almost meet full vehicle accessory load on highway cycle. [online]. 2011 [cit. 2022- 02-18]. Dostupné z: http://www.greencarcongress.com/2011/10/ford-study-showsrankine-waste-heat-recovery-system-on-a-light-duty-vehicle-could-almost-meet-fullv.html

[13] LANIK, Ondrej. Preplňování (1. dil). Teorie + mechanické preplňování [online]. 2004 [cit. 2022-02-20]. Dostupné z WWW: <http://news.auto.cz/technika/prep1novani-1-di1-teorie-mechanicke-prep1novani.htm1>.

[14] Směšovací poměr a emise. Střední škola automobilní Ústí nad Orlicí. [online]. [cit. 2022-02-25]. Dostupné z: https://www.skola-auto.cz/wp-content/uploads/2020/03/Smesovaci_pomer_a_emise.pdf

[15] TAKÁTS, Michal. Měření emisí spalovacích motorů. Praha: České vysoké učení technické, 1997. ISBN 80-01-01632-3.

[16] EGR ventil: Postrach moderních motorů. K čemu vlastně slouží? A proč je tak problémový?. Auto.cz. [online]. [cit. 2022-02-28]. Dostupné z: https://www.auto.cz/egrventil-postrach-modernich-motoru-k-cemu-vlastne-slouzi-a-proc-je-tak-problemovy-103380

[17] Oxid uhličitý. Integrovaný registr znečisťování. [online]. Ministerstvo životního prostředí. [cit. 2022-03-02]. Dostupné z: https://www.irz.cz/node/78

[18] Oxid uhelnatý. Integrovaný registr znečisťování. [online]. Ministerstvo životního prostředí. [cit. 2022-03-02]. Dostupné z: https://www.irz.cz/repository/latky/oxid_uhelnaty.pdf

[19] Intoxikaci oxidem uhelnatým je dobré nepodceňovat. Ministerstvo zdravotnictví České republiky. [online]. Státní zdravotnický ústav. [cit. 2022-03-04]. Dostupné z: https://www.mzcr.cz/Verejne/dokumenty/intoxikaci-oxidem-uhelnatym-nadalenelze-podcenovat_10202_1092_5.html

[20] Oxidy dusíku (NOx/NO2). Integrovaný registr znečisťování. [online]. Ministerstvo životního prostředí. [cit. 2022-03-05]. Dostupné z: https://www.irz.cz/repository/latky/oxidy_dusiku.pdf

[21] Polétavý prach. Integrovaný registr znečisťování. [online]. Ministerstvo životního prostředí. [cit. 2022-03-07]. Dostupné z: https://www.irz.cz/node/85

[22] Pevné částice. Emise z lidské činnosti ELC. [online]. [cit. 2022-03-08]. Dostupné z: http://emise.unas.cz/pevne--astice.html

[23] FIEDLER, Jan a Jiří POSPÍŠIL. Výhody a omezení malých kogeneračních jednotek. In: [online]. 26.9.2011 [cit. 2022-03-9]. ISSN ISSN 1801-4399. Dostupné z: http://vytapeni.tzb-info.cz/7866-vyhody-a-omezeni-malych-kogeneracnich-jednotek

[24] POSPÍŠIL, Jiří a Jan FIEDLER. Systémy společné výroby elektrické energie, tepla a chladu. In: [online]. 31.5.2010 [cit. 2022-03-10]. ISSN ISSN 1801-4399. Dostupné z: http://oze.tzb-info.cz/kogenerace/6519-systemy-spolecne-vyroby-elektricke-energietepla-a-chladu

[25] TOOM, Randolph. Waste Heat Regeneration systems for internal combustion engines. In: [online]. 2007 [cit. 2022-03-11]. Dostupné z: http://www.heat2power.net/downloads/GPC2007/20070618_heat2power_GPC_WHR _presentation.pdf

[26] HORST, Tilmann Abbe, Herman-Sebastian ROTTENGRUBER, Marco SEIFERT a Juergen RINGLER. Dynamic heat exchanger model for performance prediction and control system design of automotive waste heat recovery systems. Applied Energy. Elsevier, 2013, č. 105, s. 293-303. ISSN 0306-2619.

[27] HOSSAIN, Shekh Nisar a Saiful BARI. Waste heat recovery from the exhaust of a diesel generator using Rankine Cycle. Energy Conversion and Management. Elsevier, 2013, č. 75, s. 141-151. ISSN 0196-8904.

[28] SAIDUR, R., M. REZAI, W. K. MUZAMMIL, M. H. HASSAN, S. PARIA a M. HASANUZZAMAN. Technologies to recover exhaust heat from internal combustion engines. Renewable and Sustainable Energy Reviews. Elsevier, 2012, č. 16, s. 5649-5659. ISSN: 1364-0321.

[29] TRNKA, Jaroslav a Jaroslav URBAN. Spaľovacie motory. 1. vyd. Bratislava: Alfa, 1983.

[30] Brake Specific Fuel Consumption. Autospeed [online]. [cit. 2022-03-18]. Dostupné z: http://www.autospeed.com/cms/article.html?&A=112611

[31] Interesting Engines: The Napier Nomad. Spannerhead [online]. [cit. 2022-03-18]. Dostupné z: http://www.spannerhead.com/2012/10/29/interesting-engines-the-napiernomad/

[32] CONKLIN, James C. a James P. SZYBIST. A highly efficient six-stroke internal combustion engine cycle with water injection for in-cylinder exhaust heat recovery. Energy. Elsevier, 2010, č. 35, s. 1658-1664. ISSN: 0360-5442

[33] Stirlingův motor [online]. © 2010 - 2012 [cit. 2022-03-20]. Dostupné z: http://stirlingmotor.cz/index.html

[34] VOKÁČ, Luděk. Fyzika v praxi podle BMW. Parní turbíny a elektřina z tepla. [online]. 2011 [cit. 2022-03-21]. Dostupné z: http://auto.idnes.cz/fyzika-v-praxi-podlebmw-parni-turbiny-a-elektrina-z-tepla-p3a-/automoto.aspx?c=A110911_225827_automoto_vok

[35] ROSEBRO, Jack. Honda Researching Advanced Hybrid Drive with Rankine Cycle Co-Generation. [online]. 2008 [cit. 2022-03-21]. Dostupné z: http://www.greencarcongress.com/2008/02/honda-researchi.html

[36] PAVELEK, Milan. Termomechanika. 1. vyd. Brno: Akademické nakladatelství CERM, 2011, 192 s. ISBN 978-80-214-4300-6.

[37] FAIRBANKS, John W. Thermoelectrics Applications Review. In: [online]. 2007 [cit. 2022-03-022]. Dostupné z: http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2007/session6/deer07_fairba nks.pdf

[38] MIKYŠKA, Ladislav. Termoelektrické články. Praha: Státní nakladatelství technické literatury, 1964, 154 s.

[39] Current articles: Saving with steam. In: [online]. BMW Group, 02.02.2006 [cit. 2022- 03-22]. Dostupné z: http://www.bmwgroup.com/e/nav/index.html?http://www.bmwgroup.com/e/0_0_www _bmwgroup_com/forschung_entwicklung/science_club/veroeffentlichte_artikel/2006/ news20063.html

[40] KABEŠ, Karel. Význam termoelektrických generátorů rychle roste. [online]. 2011, č. 4 [cit. 2022-03-25]. Dostupné z: http://www.odbornecasopisy.cz/index.php?id_document=43318

[41] D. LALONDE, Aaron, Yanzhong PEI, Heng WANG a G. Jeffrey SNYDER. Lead telluride alloy thermoelectrics. In: [online].

2011 [cit. 2022-03-29]. DOI: http://dx.doi.org/10.1016/S1369-7021(11)70278-4. Dostupné z: http://www.sciencedirect.com/science/article/pii/S1369702111702784

[42] KUBEŠ, Pavel. Magnetohydrodynamika [online]. Praha Katedra fyziky FEL ČVUT [cit. 2022-04-03] Dostupné z: https://www.aldebaran.cz/studium/MHD.pdf

[43] Plazmový vesmír, Aldebaran [online].Praha Aldebaran Group of astrophysics [cit. 2022-04-08] Dostupné z: https://www.aldebaran.cz/astrofyzika/plazma/basics.php

[44] Teorie elektromagnetického pole, Aldebaran [online].Praha Aldebaran Group of astrophysics [cit. 2022-04-13] Dostupné z: https://www.aldebaran.cz/studium/elmg.pdf

[45] Magnetohydrodynamický generátor a jeho účinnost, V. Bednář*, J. Šleis** Fakulta jaderná a fyzikálně inženýrská, Břehová 7, 115 19 Praha 1 [online]. [cit. 2022-04-13] Dostupné z: http://fyzsem.fjfi.cvut.cz/2009-2010/Leto10/proc/mhd.pdf

[46] Magnetohydrodynamics (MHD),” Dictionary of Scientific Literacy, Richard P. Brennan (New York: John Wiley & Sons, Inc., 1992), p. 195 [online]. [cit. 2022-04-20] Dostupné z: https://www-skewsme-com.translate.goog/mhd.html?_x_tr_sl=en&_x_tr_tl=sk&_x_tr_hl=sk&_x_tr_pto=op,sc

[47] Yamato 1World’S First Superconducting Magnetohydrodynamic Propulsion Ship [online]. [cit. 2022-04-23] Dostupné z: https://www.spf.org/en/_opri_media/publication/docs/yamato-1.pdf

[48] ČERŇAN, J., HOCKO, M. 2020. Turbínový motor I. 1. vyd. Žilina : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 335 s.ISBN 978-80-554-1673-1.

[49] Černan, J., Škultéty, F. Design of the air velocity measuring inlet channel for the small jet engine. Transport Means - Proceedings of the International Conference, 2020, 2020-September, pp. 942–945. ISSN 1822296X.

https://doi.org/10.26552/ pas.Z.2022.2.20

REQUIREMENTS FOR CAT SET-IMC CERTIFICATION

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Abstract

The diploma thesis deals with requirements for certification of single-engine turbine aircraft involved in commercial air transport and operated in instrument meteorological conditions or at night. The work in the first part introduces the theoretical background of the whole problem and presents to the reader the reasons why the approval of this type of operation in Europe was necessary. Subsequently, the second part of the work states all necessary requirements for obtaining approval for this type of operation, including the legislative framework and the risk analysis. The following section in work demonstrates different values of risk periods along the same route, depending on different conditions affecting aircraft performance. It also introduces possible new means for increasing safety in case of engine failure and subsequent drift down. The aim of the work is to provide a comprehensive overview throughout the certification process and offer existing operators new solutions for their SET-IMC operations, which could also improve their level of safety.

Keywords

SET-IMC. Commercial air transport. Certification process. Risk analysis. Reliability program. Glide advisor.

1. INTRODUCTION

Not so long ago, the commercial operation with single-engine turbine aircraft in instrument meteorological conditions was approved by European Union Aviation Safety Agency. Since then, this type of operation has enjoyed popularity and has been on an upward trend among operators. This was also the main motivation for the development of this work as a comprehensive study of process for obtaining approval for this type of operation. At the same time, the aim of the work was to evaluate the current state of the issue and to provide current as well as future operators with a number of operational recommendations.

The thesis is divided into several logical parts. In the first part, the thesis describes the background of this issue at home and in the world. Explains the reasons for the differences in conditions in different countries of the world and why the harmonisation of this rules was necessary. The following section sets out the legislative requirements, market analysis and lists available programmes supporting this type of operation. The legislative requirements section deals with the current legislative requirements for aircraft equipment as well as for individual operators. The task of the market analysis was to highlight the growing trend of this sphere and introduce current aircraft on the market. The number of these aircraft in Europe has increased over the last period since the approval of this operation. This has created an opportunity for new operators to emerge. The preview of available software provides potential operators with an overview of the available technologies and how they can be implemented in their operation. The last part of the thesis provides information on the process of obtaining this permission and analyses a sample risk analysis calculation for two different flights. The thesis provides recommendations for operators in the conclusion.

The work concludes with the provision of guidance material for the process of obtaining certification approval for this type of operation, together with non-binding recommendations obtained through study and from author personal experience.

2. THEORETICAL BACKGROUND

Commercial operations with single-engine aircraft in Europe were approved for years. This was valid only for visual flight rules (VFR) and by day. Understandably, the pressure was later put on the authorities to extend this operation to instrument flight rules (IFR) and night. The term CAT SET-IMC has been and still is a quite unknown concept. It stands for commercial operations under special approval for single-engine turbine aircraft operated in instrument meteorological conditions or at night. Until now, only multi-engine aircraft have been allowed to engage in such commercial operations in European Union Aviation Safety Agency (EASA) countries. With the increasing number of single-engine turbine aircraft and the increasing reliability of their powerplants came the requirement from contracting states to certify this type of operation.

Several member states have previously expressed the need to develop specific operational and airworthiness requirements to allow commercial air transport with single-engine aircraft at night or in IMC. Increased engine reliability has led to the development of single-engine aeroplanes which are more economical, less environmentally harmful and have lower maintenance costs than multi-engine aeroplanes. [1]

Later the EASA developed NPA 2014-18 dealing with issue of CAT SET-IMC certification in EASA countries. This document proposed new provisions specifically drafted for CAT SET-IMC, which will amend Annex II, IV and Annex V to Regulation (EU) No 965/2012. The specific objective was to enable CAT SET-IMC operations in Europe through cost-effective rules that mitigate the risks associated with one engine failure to a level comparable to or similar to twin-engine aircraft operations. [2]

2.1. NPA 2014-18

This Notice of Proposed Amendment proposed changes to currently effective regulations and decisions. The text of NPA has been developed by the Agency based on the input of the Rulemaking Group RMT.0232/0233. In general, the document contains procedural information related to this task, technical content, proposed new requirements and regulatory impact assessment showing which conditions were considered. [2]

The main issues which were covered in this NPA are following: [2]

- some Member States currently allowed some of their operators to operate CAT SET-IMC flights under an EU-OPS exemption. These exemptions were based on different sets of conditions, which prevented a level playing field for operators who may operate CAT SET-IMC. In addition, European union (EU) operators face competition from Third Country Operators (TCO) who have been authorised by their authorities to operate CAT SET-IMC.
- issue of harmonisation as some foreign aviation authorities allowed for quite a long time this kind of operations
- ICAO alignment issue since ICAO allows these operations since 2005
- an environmental issue, as there were many single-engine aircraft available on the market at the time with better fuel efficiency, lower emissions and better environmental footprint.
- an economic issue since the current situation prevented the opening of new routes which could be operated safely and efficiently only by some single-engine turbine aeroplanes due to performance or operating costs.

2.1.1. <u>Affected parties</u>

Parties affected by this problem were mainly aircraft manufacturers, operators and national aviation authorities. Until then, only exempted operators could operate these flights, and then only in the territory of their own States or in the territory of Contracting States after first obtaining an exemption. However, Member States had to inform the European Commission of any exemptions they granted to individual operators. Operators and producers alike have been disadvantaged by the legislative situation in Europe. Manufacturers were producing aircraft designed and capable of operating under CAT SET-IMC conditions. Unfortunately, under these conditions they could only be operated abroad. In Europe, they could only fly non-commercially. [2]

At the time, there were three main types of aircraft on the market meeting all these requirements, namely the Cessna C208, Socata TBM700/850 and Pilatus PC-12. It should be noted that these three types accounted for 78% of the single-engine turboprops operating in Europe at the time and 74% in the USA. Regarding data on the current status of single-engine and multi-engine aircraft in service, the General Aviation Manufacturers Association carried out an analysis of the current numbers of aircraft in service in Europe and in the USA. The analysis identified 368 single-engine turboprop aircraft and 557 multi-engine turboprop aircraft in Europe. By comparison, the United States has a fleet of single-engine turboprop aircraft consisting of 2 647 aircraft and a fleet of multi-engine turboprop aircraft registered in the United States consisting of 4 695 aircraft. The ratio of aircraft in service in Europe and the USA was fairly equal, but in the USA at that time there were no restrictions even on single-engine piston aircraft. It could be therefore assumed that the approval of this type of operation in Europe would result in the development of this industry. [2]

Evidence that the current legislation has not favoured either operators or manufacturers can be seen in the following table, where it is obvious that there has been a significant reduction in the number of single-engine turbine aircraft in operation in the recent period.

Table 1: Number of SET aircraft operated in Europe in CAT [2]

	2005/2006		2013	
	No	Operator	No	Operator
France	2 1 3 1	Finistair Atlantic Airlift (AAL) Air Caraibes Aviation Sans Frontières	1 1 2 3 1	Finistair CAIRE Aviation Sans Frontières Saint-Barth Commuter VolDirect
Finland	0	X	1	Hendell Aviation
Germany	2	OLT	0	X
Greece	4	Aeroland	0	X
Norway	7 2	BenAir Kato Air	3	BenAir
Spain	7	AirPack Express	0	X
Sweden	3	Nordflyg	1	Nordflyg
TOTAL ESTIMATED FLEET	**32**		**13**	

In 2005/2006 there were 10 operators in Europe with a total of 32 single-engine turboprops in CAT. However, by 2013, this number had dropped to 8 operators with only 13 aircraft. In the USA, the opposite trend has been observed, namely an increase in both the number of these aircraft and operators.

The US fleet of single-engine turbine aircraft in commercial service has grown in recent years. In 2006, there were 542 aircraft in use by Part 135 regulated operators, but in 2013 this fleet increased by 24% to 673 aircraft. The main type was the Cessna C208. The following table shows how the US Part 135 single-engine turboprop fleet changed between 2006 and 2013 by type. [2]

Table 2: Number of SET aircraft operated in US under part 135 [3]

	2006	2013
CE-208	472	488
Kodiak-100-100	0	6
PA-46-500TP	2	8
PC-12-45	64	99
PC-12-47/E	0	68
TBM-700-	4	4
TOTAL SET Aeroplanes	**542**	**673**

2.1.2. <u>Safety risk assessment</u>

With the passage of time, the reliability of turboprop engines used on single-engine aircraft has reached a level of less than 10 failures per million flight hours. This value was the propulsion reliability target according to QINETIQ and JAA NPA OPS 29 Rev.

2. This rate was considered as the basis for this risk assessment regarding engine reliability.

When considering fatal accident rate of CAT SET-IMC operations, the study considered the latest National Transportation Safety Board (NTSB) statistics which were showing over the last 10 years an average fatal accident rate for Part 135 operations of 5.51/million flight hours. The data coming from the Breiling 2012 Annual Single Turboprop Powered Aircraft Accident Review was then considered to make the comparison between single-engine turboprop and twin turboprop aeroplanes operations. The content of this study was the operation of twin-engine turboprop aircraft and single-engine turboprop aircraft in the US and Canada through 2010. For the purposes of this study, only the years 2005-2010 have been considered. The fatal accident rate has been shown to be 3.96/million flight hours for twin-engine turboprops and 5.61/million flight hours for single-engine turboprops. At that time, within NPA OPS 29 Rev 2, only three aircraft were able to meet these requirements, a Cessna C208, a Pilatus PC-12 and a Socata TBM700/850. The resulting fatal accident rate for these aircraft was 4.44/million flight hours. Consequently, the safety rate of twin-engine and single-engine aircraft designed for this type of operation was almost the same, approaching 4/million flight hours. This target fatal accident rate of no more than

4 per million flight hours has been later chosen as the basis for this National Safety Report. [2]

As CAT SET-IMC in Europe has not been approved as such until then, apart from exemptions granted to some States and operators, it has not been possible to determine the current level of safety of this type of operation in Europe. Also, individual States and operators had approvals issued under different conditions, whether based directly on ICAO Annex 6 or on JAA NPA OPS 29 Rev. 2. Thus, the safety performance results of this operation were not considered relevant for comparison. Some States have applied an uncontrolled environment for this operation and some have approached the requirements set out in JAA NPA OPS 29 Rev 2. In order to assess the risk of such operations, the rulemaking group conducted a risk assessment of CAT SET-IMC operations. To this end, the group identified 8 main scenarios and for each of them evaluated the consequences in terms of probability and severity, first without any specific mitigations and then taking into account the mitigations under NPA OPS 29 Rev. 2. The main objective of this risk assessment was to determine whether the sum of the residual risk for each scenario is less than the selected target for fatality rates as described before. This risk assessment was also based on the selected powerplant reliability rate of 10 per million flight hours. The JAA NPA OPS 29 Rev 2 Regulatory Impact Assessment and the QINETIQ risk assessment were used for the resulting risk assessment. This risk assessment concluded that the mitigation contained in the NPA OPS 29 Rev 2 were found sufficient to at least allow reaching the required target fatal accident rate for CAT SET-IMC and that no further mitigation was specifically required reach this target. [2]

2.2. Comment-Response Document 2014-18

This document contains the summary of comments on NPA 2014-18 and the responses provided by the Agency as well as full set of individual comments. By the end of the consultation period, 157 comments had been received from affected parties including aircraft manufacturers, air operators, organisations and national aviation authorities. [4]

In general, these comments supported the implementation of the SET-IMC concept of operations as presented by NPA 2014-18. As a result, these comments led to the modification or addition of the required changes to the regulations.

As a result, 26 commenters provided 157 comments including 2 manufacturers, 8 competent EU aviation authorities, 7 air operators and several associations. Of the 26 commenters, 10 expressed a clear affirmative position on the proposed concept and only one was opposed to the proposed SET-IMC operation. [4]

The Agency accepted or partially accepted 77 comments which was approximately 49 ⍰ and 35 comments (22⍰) were noted or the commentator had no comment to the NPA. Only 45 comments (29⍰) were not accepted. [4]

2.3. Commission Regulation (EU) 2017/363

This regulation was adopted on 1. March 2017 and modified the current version of Regulation 965/2012 regarding the operation of single-engine turbine aircraft in IMC conditions or night. In addition, this regulation addressed the modification of hazardous cargo transportation training for special commercial operations, non-commercial complex aircraft operations, and special non-commercial complex aircraft operations.

The document lays down provisions relating to single-engine turbine operations in IMC or at night. Among other things, these provisions contain conditions for the approval of this kind of operation, namely that the State must ensure compliance with all conditions for approval of this operation. These conditions require the provision of a certain level of aircraft equipment, additional flight crew training, operating procedures, engine monitoring and reliability. It mandates the harmonisation of the same conditions between Member States and places responsibility on individual States and their competent authorities to issue approvals to operators for this type of operation. This Regulation provides for a transitional period during which operators who have previously obtained an exemption for this type of operation will be allowed to operate their aircraft under the specified conditions. By the end of this period at the latest, operators will have to apply for a new approval for their operation already under the new conditions laid down in Regulation 965/2012. [5]

The attachment to this Regulation sets out the individual conditions of approval for this operation and also contains the wording of the individual paragraphs and clauses as they are to be amended. With the introduction of this regulation ended the era when commercial operations with single-engine aircraft in IMC or night were prohibited in Europe.

3. STATE OF THE ART

This part described the current situation regarding the conditions of operation and obtaining approval for this type of operation. These requirements for certification are contained in Regulation No. 965/2012. For the execution of commercial air transport operations with single-engine turbine aircraft in instrument meteorological conditions or night, the operator shall obtain an approval for SET-IMC from a competent authority.

3.1. Requirements for operators

The regulation sets out a number of conditions that must be met and submitted to the competent authorities in order for a SET-IMC approval to be issued. The main requirement is to achieve an acceptable level of turbine engine reliability in world fleet operations for a given airframe and engine combination.

Specific maintenance instructions and procedures shall be developed to ensure the planned level of continuing airworthiness and reliability of the aeroplane and its propulsion system, which shall be included in the operator's aircraft maintenance programme. This should also include an engine trend monitoring programme except for aircraft with automatic trend monitoring system and also propulsion and associated systems reliability programme. [6]

The operator should establish the conditions for the crew composition and the training programme for those crews participating in these operations. This type of operation requires additional crew training, as there are certain specificities associated with it.

The operator must submit to the Authority elaborated operating procedures including the following sections: [6]

- aircraft equipment list, including its limitations and appropriate entries in the Minimum equipment list (MEL)
- flight planning
- normal procedures
- contingency procedures including non-normal and emergency procedures following a propulsion system failure, as well as forced landing procedures in all weather conditions
- monitoring and incident reporting

3.2. Risk assessment

The risk analysis is based on a calculation of the anticipated risk of an emergency landing with fatalities in case of engine failure for each planned route. Based on this, the operator determines the risk period to which the passengers and crew on a given flight are exposed. Based on this analysis, if there is no suitable landing site in the area, the competent Authority may extend this maximum risk period.

The concept of SET-IMC is based on engine reliability rate for all causes of 10 per million hours. In compliance with SET-IMC requirements this allow for overall fatal accident rate of 4 per million flight hours. According to experience with engine failures contributing to fatal accidents with 33%, for the purposes of this risk assessment the target fatal accident rate was reduced to 1.3x10-6. [7]

3.2.1. Methodology

The methodology of this analysis focuses on determining the probability of failure to reach a suitable landing site to execute a successful landing in the event of an engine failure. A successful landing is considered to be one where the aircraft lands on a surface where it is expected that no serious injury or fatality will occur, even though the aircraft may be substantially damaged. The objective of this methodology is to create a risk profile for each individual route, including departure, en-route, arrival and landing dividing this flight into appropriate segments and estimating the risk for each of these segments when engine failure can occur. [7]

When considering these individual segments in the resulting risk period, the following aspects must be taken into account. At first standard procedures of operator should be considered including contingency procedures in case of engine failure. Next the height of the airplane and lateral position at which the engine failure occurs. Meteorological conditions should also be taken into account including actual ambient temperature, humidity and pressure as well as cloud ceiling and visibility.

The duration of each phase of the flight determines the exposure time to expected level of risk. By summing up all the individual flight segments risk periods, the cumulative risk period can be obtained. The estimated risk is based on the following calculation. [7]

Segment risk factor=

$$\frac{segment\ exposure\ time\ (s)}{3600 \times probability\ of\ unsuccessful\ landing \times assumed\ engine\ failure\ rate\ per\ hour}$$

This type of matrix is often used during risk assessments to determine the level of risk by considering both severity against likelihood. This helps in decision making and identifying the level of risk connected with this. Below is the example of matrix used for considering level of risk for engine failure during each segment of flight.

		Likelihood							
		A 99-100%	B 90-99%	C 65-90%	D 35-65%	E 10-35%	F 1-10%	G 0-1%	H 0%
Severity	1								
	2								
	3								
	4								
	5								

Table 3: Risk assessment matrix

3.2.2. Risk tolerability and mitigating measures

The operator must assess all risks associated with operating on the routes in IMC or at night. In assessing the current risk, he should take into account the current weather on the route, the weather forecast, the availability of navigation and flight services, the applicable NOTAMs and the traffic density. In the event that the operator cannot maintain an acceptable level of risk, he must take all available corrective measures to ensure a sufficient level of safety. [7]

Measures mitigating level of risk: [7]

- Re-route a flight within a range of more suitable landing sites
- Re-route flight to an area where the suitable weather is present

- Use higher cruise level to extend glide range

Delay the flight to avoid weather or busy traffic

3.3. Aircraft equipment requirements

The one step in obtaining a CAT SET-IMC approval is to develop a project plan and assess the ability to meet all of the requirements for this certification. Before submitting any documents to the Authority for assessment, the operator should assess whether it will be able to comply with the published requirements.

The following items should be considered to ensure suitability of aircraft for CAT SET-IMC operation:

- Electrical generating system
- Attitude indicators
- Safety belts
- Weather radar
- Oxygen
- Navigation to landing sites
- Radio altimeter
- Landing lights
- Emergency electrical supply
- Ignition system
- Lubrication and debris detection
- Emergency engine power control

Aircraft intended for CAT SET-IMC operation must have the above mentioned equipment installed and fully operational. These requirements are stated in EU Regulation No. 965/2012 subpart L/SPA.SET-IMC.110.

3.4. The number of aircraft

General Aviation Manufacturers Association (GAMA) is an association whose objective is to promote and develop the safety and interests of commercial and general aviation. GAMA obtains aircraft delivery data from 39 manufacturers, including detailed aircraft registration data in 47 countries, representing the majority of the market share. Annual data containing statistics about shipped aircraft, hours flown per type and fleet type statistics are provided in this document on a regular basis. [8]

Table 4: Aircraft Shipments and Billings [8]

Year-end Aircraft Shipments and Billings

Aircraft Type	2020	2021	% Change
Piston Airplanes	1,321	1,393	5.5%
Turboprops	443	527	19.0%
Business Jets	644	710	10.2%
Total Airplanes	2,408	2,630	9.2%
Total Airplane Billing	$20.0 B	$21.6 B	7.6%
Piston Helicopters	142	181	27.5%
Turbine Helicopters	517	645	24.8%
Total Helicopters	659	826	25.3%
Total Helicopter Billing	$2.9 B	$3.7 B	28.0%

In 2021, GAMA released 2021 General Aviation Aircraft Shipments and Billings Report. It is the latest annual report showing the actual number of aircraft delivered to customers, based on their categories. An initial comparison shows that all segments have seen an increase compared to the previous year. These figures also demonstrate a gradual return to pre-pandemic values and a recovery of the aircraft market.

Aeroplane shipments in comparison with 2020 saw an overall increase 9.2 ▯ with 2 630 units. Of these segments, turboprops saw the largest increase of 19.0 ▯ with 527 units at the end of 2021. It clearly shows that this segment of aviation is currently the most developing among the others. [8]

3.5. SET-IMC certified aircraft types

As seen in the previous table, turboprops have seen a rise in popularity in recent years. In Europe, this is mainly due to the approval of SET-IMC operation. There are several manufacturers on the market who offer individual models that meet the conditions for this type of operation. The next table shows chronologically arrival of individual models on the market.

Table 5: SET-IMC certified aircraft [author]

Aircrft type	Purchace price	Number of seats	Cruising speed	Range	Number of ACFT
Cessna 208	2,15 mil €	10-14	186 KTS	1 070 NM	1373
PC12	4,45 mil €	8-11	290 KTS	1 850 NM	1293
TBM850	3,1 mil €	6	250 KTS	1 500 NM	338
Piper M500	2,1 mil €	6	260 KTS	1 000 NM	445
TBM900/960	4 mil €	6	330 KTS	1 730 NM	408
Piper M600	3,05 mil €	6	274 KTS	1 658 NM	194

The data in the table are summarised for the period 2006-2021 and are based on worldwide statistics provided by GAMA. From the table, it can be seen at a glance that the aircraft with the longest history on the market is also the most represented. In Europe the predominant type of aircraft is Pilatus PC12 but on the other hand in USA the dominating aircraft is Cessna C208 in many variants. [8]

As this type of operation has been approved and is approved almost worldwide, more new aircraft types are expected to come to the market in the near future.

3.6. Available software

In today's electronic age, there are many programs and software used in aviation on the market. These programs offer many possibilities, whether they are planning programs, navigation programs or programs that calculate the performance of the aircraft. The largest share of the aviation market today is still held by multi-engine aircraft. Unfortunately, the aviation software market is also adapted to this.

Since commercial operations with single-engine turbine aircraft in IMC conditions has not been approved in Europe for so long, there are still not a large number of applications on the market supporting this type of operation regardless of whether they are planning software or electronic flight bag (EFB) software. This problem, on the one hand makes the process of obtaining an approval under consideration by the Transport Authority more difficult and otherwise reduces the options available to flight crews in selecting the appropriate software for their use.

There are currently several programs available on the market providing an environment for this kind of operation. The following chapters describe some of the features of these programmes.

3.6.1. *ForeFlight*

ForeFlight belongs to the Boeing company, which has many years of experience in the aerospace industry. ForeFlight Mobile is the integrated flight app that gives users all the essentials for visual VFR and IFR route planning, flight plan filing, and flying worldwide. This application offers users two different environments. For the planning department, it offers an interface ForeFlight Dispatch and for the flight crews, it offers the ForeFlight Mobile application.

It incorporates these sub applications:

- ForeFlight Dispatch
- Fore Flight Mobile EFB
- ForeFlight SETOPS

3.6.2. *Garmin Autonomí*

Garmin is one of the leading avionics manufacturers in the market. Every year it comes up with new instruments and features that increase the level of safety and reduce the workload for the crew. The latest innovation introduced at the turn of the year is the range of autonomous functions offered by its new avionics equipment.

It incorporates these programmes:

- Autoland
- Electronic stability and protection
- Emergency descend mode
- Smart glide

4. CERTIFICATION SPECIFICATIONS CAT SET-IMC CERTIFICACION

Obtaining certification for this type of operation is a complex and lengthy process. The content of this chapter should help potential candidates for this certification to speed up the process and to understand the specifics of this operation in more detail.

The previous chapters explained the background to this problem and then presented the legislative framework relating to it. This chapter demonstrates the practical application of the before-mentioned regulations and laws. The following figures should be taken as recommendations and information only. The final responsibility lies with the relevant authorities under what conditions and to what extent they will approve the operator for this type of operation.

As is already known from the regulation, it is operations requiring Specific Approval. This means that previously the operator should have been granted an Air Operator Certificate (AOC).

4.1. Operational manuals

It is a controlled document required within each organisation that has been granted an AOC. It is important that these manuals are prepared in accordance with the prescribed structure of this document and contain only the necessary items reflecting the type of operation of the organisation concerned.

4.1.1. *OM-A*

OM-A focuses in general on the organisation. It is a document that does not focus specifically on one type of aircraft. It contains the basic policies of the company, its structure and the division of responsibilities. It has a standardised structure and contains some of the following sections:

- Organisation and responsibilities
- Management system
- Crew composition
- Qualification requirements
- Flight time limitations
- Operating procedures

If the operator operates more than one aircraft type and not only SET-IMC aircraft, then a separate manual shall be issued for that operation. This manual has several changes and additions related to the specifics of this operation.

4.1.2. *OM-B*

OM-B is most often used directly by pilots. It contains type-related procedures. In the case of SET-IMC operations, it contains additional restrictions on the aircraft approved for the operator's type of operation. It also contains detailed procedures and workload distribution in the event of engine failure and subsequent drift-down.

4.1.3. *OM-C*

This contains route and aerodrome information. It can also contain some recommendations for contingency situations in SET-IMC flying. For example after lift-off crew shall consider delaying the landing gear retraction until the briefed altitude for safe straight forced landing on the rest of the same runway is reached. Also, in case of engine failure, the actual speed can be traded for altitude, until reaching a best glide speed. On the approach, crew shall keep higher speed during standard 3 degrees approaches to have sufficient energy available to reach a runway in case of engine failure.

4.1.4. OM-D

The last one is the training manual. In the case of SET-IMC operations, it incorporates additional requirement for flight crews. As mentioned before, minimum flight time requirements for flight crews are here. It states minimum flight time requirement for commander as minimum of 700 hours total time and a minimum of 400 hours as pilot in command.

This part focuses especially on training of emergency procedures and failures of individual systems. The regulation directs that, where a suitable full flight simulator is available, training and testing should be conducted on it. Unfortunately, since the SET-IMC operation is not available for a long time, there are not enough suitable devices available. In normal practice, training and checking are carried out on the aircraft themselves. However, the use of these training devices would have a great contribution to the safety of this operation and to the training of the crews, as various situations can be simulated on the simulator.

4.2. Validation flight

The validation flight is the last step before issuing an operational specification on the SET-IMC. After submitting all the required documents to the Authority and preparation of all operations manual, the validation flight can be conducted. The validation flight should be conducted under VMC conditions with a person authorised by the competent Authority.

It is a normal flight, where the loss of thrust of the engine is simulated at a given moment. This is simulated by running the engine at idle speed. At the same time IMC conditions are simulated for the pilot. The purpose of this flight is to demonstrate to the competent Authority the ability to meet all conditions in reality and to make a safe landing at the chosen alternate aerodrome.

Following the completion of this flight, the Authority is expected to issue a new operational specification to an operator with SET-IMC approval.

4.3. Risk period comparison

Part of the planning for each SET-IMC flight is a detailed analysis of its route. The flight path should be selected by taking into account the current availability of emergency areas during the flight. These areas should be chosen on the basis of predetermined priorities. Priority should be given to airports with instrument approaches to at least one runway. In the event that such an aerodrome is not available at some stage during the flight, airports with runway lighting and a non-instrument runway should be considered. If such an airport is not even available, the criteria are progressively reduced. The availability of suitable airports is not the only aspect to consider when planning. The level of risk is also influenced by other factors such as winds aloft, weather, aircraft performance, etc. To show how these factors affect the flight, two flights were compared.

4.4. Recommendations

4.4.1. Risk analyses

From the analysis it was found that changing aircraft performance is not taken into account when using ForeFlight's automated risk analysis. Only the standard model is used. To increase the accuracy of the calculation of this analysis, it is recommended to use actual performance models.

4.4.2. Glide advisor

Currently available glide advisor systems do not take into account the current wind drift and speed. This can cause major inaccuracies in the calculations at high altitudes. Integrating actual winds into these systems would significantly improve their accuracy.

5. CONCLUSION

The diploma thesis deals with the commercial operation of single-engine turbine aircraft in IMC in European countries. For a long time this type of operation was not approved in Europe, but recently there has been a change in the legislation and therefore the approval for this operation was granted. As this type of operation is characterised by lower operating costs, greater accessibility and low environmental footprint, it has great potential for growth in the future.

The first section of the thesis presents the history of this problematic, mainly in Europe and the USA. In the US, these operations have been approved for more than 20 years, but in Europe, on the other hand, they were prohibited until 2017. Due to safety concerns, this operation was approved with several restrictions and conditions. This is followed by another part of the paper which describes the current state of the art. This section is divided into several sub-sections, which further describe the legislative framework of this problem, the current situation on the SET-IMC aircraft market with brief description of these aircraft and finally a list of available software related to this type of operation.

The final section provides information directly related to the procedure for obtaining this special operation approval, including the process of obtaining AOC. For a better insight and understanding of the risk analysis, the last section provides a sample risk assessment and the principle of calculating the whole risk period for a given flight. The work provides several recommendations on flight planning but also some recommendation on flight software being used. From the above it can be concluded, that the objective of the work to analyse this operation and provide a guidance manual throughout the certification has been met.

This work can be used for the needs of various organizations or operators intending to establish this type of operation. As aviation and its technologies are rapidly evolving, the work also provides an opportunity for further risk analysis and the development of corrective actions along with further recommendations for use of new software and electronic devices. It also offers the possibility of extending the study on operations and risks to non-EU countries, as this work dealt with operations under EASA conditions only.

REFERENCES

[1] Terms of reference RMT.0232 and RMT.0233 [Online]. https://ulc.gov.pl/_download/wiadomosci/08_2012/draft_tor_rmt_0232_-_0233_-_cat_single_engine_imc.pdf (cited 2022-04-03)

[2] Notice of Proposed Amendment 2014-18, RMT.0232 &RMT.0233[Online]. https://hub.easa.europa.eu/crt/docs/viewnpa/id_270 (cited 2022-04-04)

[3] FAA, U.S. FAA Part 135 Air Carrier Database [Online].https://www.faa.gov/licenses_certificates/airline_certification/135_certification/ (cited 2022-04-04)

[4] EASA, Comment-Response Document 2014-18 [Online]. https://www.easa.europa.eu/downloads/20048/en (cited 2022-04-07)

[5] Commission Regulation (EU) 2017/363 [Online]. https://eur-lex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX%3A32017R0363&from=EN (cited 2022-04-07)

[6] Regulation (EU) No 965/2012 [Online]. https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELE%3A32012R0965&qid=1649401475582(cited 2022-04-07)

[7] FOCA GM/INFO [Online]. https://www.bazl.admin.ch/dam/bazl/de/dokumente/Fachleute/flugoperationen/gm-info/GM_INFO_CAT_SET_IMC.pdf.download.pdf/FOCA_GM_INFO_CAT_SET_IMC_Final_Version_Iss1_Rev2.pdf (cited 2022-04-10)

[8] GAMA, Aircraft Shipment release 2021 [Online]. https://gama.aero/news-and-events/press-releases/gama-releases-2021-aircraft-shipment-and-billings-report/ (cited 2022-04-10)

[9] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

[10] BUGAJ, M., URMINSKÝ, T., ROSTÁŠ, J., PECHO, P. 2019. Aircraft maintenance reserves - New approach to optimization. Transportation Research Procedia, 2019, 43, pp. 31–40. ISSN 23521457.

https://doi.org/10.26552/ pas.Z.2022.2.21

TECHNICAL AND PROCEDURAL RESOURCES OF OVERHEAD BIN SECURITY

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Abstract

The article deals with the design of safety systems to prevent the opening of overhead wires in situations that are not in accordance with safe operation. The paper discusses possible variants of the functioning of the locks, as well as a theoretical part focused on the reasons for such behaviour of passengers. Subsequently, the article describes two options for locking overhead bins and a description of their operation and manufacture. The article concludes with an assessment of the usability of the locks and their potential.

Keywords

Safety, Evacuation, Security, Overhead bin

1. INTRODUCTION

Nowadays it is very easy to get access to records, photos or videos of evacuations. It can be clearly seen that up to 50% of the passengers are taking their luggage out, thus delaying the evacuation and potentially endangering the lives of other passengers. The article therefore discusses the possibility of preventing the removal of luggage from overhead bins. The article discusses in detail two types of locks, one manual, which could be incorporated into existing aircraft, and the other, fully automatic, which could be used in new aircraft.

2. ANALYSIS OF THE JUSTIFICATION OF THE PROBLEM ADDRESSED

2.1. Passenger behaviour in stressful situations

The irrational behaviour of passengers in airplane accidents and subsequent evacuations is probably, according to studies, conditioned by the fact that the common public perception of airplane accidents is that they are extremely rare and, when they do occur, they are mostly unsurvivable.

One of the most significant aviation accidents that contributed to significant changes in aviation safety was the Boeing 737 accident in Manchester. During take-off, the left engine failed unexpectedly and subsequently leaked fuel. The escaping fuel ignited and part of the left engine caught fire. The crew aborted the take-off and the aircraft left the runway with the wind directing the fire towards the rear of the fuselage. The fire service did not arrive at the scene until 5 minutes after the accident, evacuation was made difficult by smoke at the rear door and the failure of the right front door. In the accident, 55 of the 137 people died from toxic smoke inhalation. [2][4]

Extensive studies of crowd behavior and behavioral aspects during evacuation have been conducted as a result of this accident. Thus, it was found that the most critical aspect in evacuation is time. On average, one minute elapses between the detection of a problem, the completion of the cockpit checklist and the signal to evacuate before the evacuation begins. But a minute, if it is obvious that an emergency has occurred, is a very long time for passengers, during which panic is the main word in the passenger cabin. During this minute, passengers take evacuation into their own hands, disregarding the instructions of the cabin crew to remain seated, and begin to take their luggage from the overhead bins and begin to evacuate. One such case can be demonstrated by the 2018 Smartwings incident where passengers began to evacuate themselves after smoke from a vehicle on the tarmac entered the aircraft. Despite the crew's request to calm down, the passengers fired the evacuation slide, which was blown away by the still running engine, and a passenger who was standing by the door fell on her head from the door, fracturing her skull as a result of the fall, and was taken to hospital in a critical condition. She eventually succumbed to her injuries. It is therefore very important that cabin crew are assertive enough to prevent illogical and dangerous behaviour by passengers. [3]

Other major delays in evacuation, apart from taking their hand luggage from the overhead bins during evacuation, include separating family members from the group during evacuation, thus blocking of evacuation areas may occur. In 2004, The Flight Safety Foundation published a memo indicating that passengers do not perceive a life-threatening situation if they do not see smoke or fire. [2]

2.2. Statement of the Problem

Adequate attention should be paid to emergency evacuation during the investigation in order to gain a better understanding of the actual behaviour of the occupants so that evacuation procedure designs can be improved. According to what has already been elaborated about the emergency passenger behaviour, it is found that as a result of the behaviour, almost 50% of the passengers delay the evacuation by removing their belongings from the overhead bins. The lock on the hand luggage compartments, the design of which is elaborated in this thesis, aims at preventing the possibility of opening the compartment. If passengers are made aware in the safety instructions that it is not possible to remove their luggage, the probability that they will not attempt to do so during an evacuation increases, thereby increasing the likelihood of survival for themselves and other passengers.

Aircraft evacuation systems and their safety features, which include, for example, chutes and doors, must be certified for real-life operations and environmental factors such as wind, rain, snow, non-standard aircraft position, etc. The need to ensure that people do not carry their luggage when evacuating from the aircraft may also be a reason why

the use of evacuation slides is necessary. These slides were not designed to be used to evacuate luggage, which can damage them, as can, for example, heels. When a slide is damaged, it is usually impossible to continue using the slide as the air escapes out of the slide and does not maintain its integrity.

Last but not least, the lock would fulfill as a secondary benefit of directing passengers in situations where it is needed. It would therefore prevent, for example, a passenger walking across the cabin already during taxiing after landing. By preventing passengers from getting up immediately after landing and "queuing" before the aircraft is fully stopped on the stand, it may make the job of cabin crew easier.

3. SURVEY OF TECHNICAL SOLUTIONS

At present, it is not possible to find central locking of luggage compartments on airlines or aircraft. However, the proposal for central locking has already been addressed by ICAO, as the statistics on evacuation speak clearly and it is clear that there is a need to combat delays in evacuation times. According to some debates and suggestions, compartment locking can also have a negative effect on evacuation. [5]

The current designs that are currently available on the market are mostly addressed by companies specialised in the production of overhead bins. Among the most basic is the classic keyed lock, which is also the focus of this thesis. However, these classic key locks are not used as central locking of all compartments to prevent tampering during evacuation, but as overhead bins that are used by the crew. Overhead bins used by the crew are, depending on the type of aircraft, the first or/and last compartment in a row in which the crew store their personal luggage and contain equipment such as first aid kit, passenger blankets, safety cards, nausea bags, etc.[6][7]

3.1. Requirements for locks

Several types of locks were proposed during the development of this thesis. The most ideal design, which has the prospect of working, is further elaborated in the continuation of the thesis, but it was necessary to compare several variants. From the lock as the main criteria of the work requires:

- Seamless functionality,
- simplicity,
- the smallest possible weight,
- the possibility of easy repair,
- the least possible burden on the crew,
- autonomous operation that does not interfere with the integrity of the aircraft,
- heat resistance

4. IV. DESIGN AND MANUFACTURE OF THE OVERHEAD BIN LOCK

4.1. Magnetic manual lock

The entire magnetic lock is designed and constructed for printing on a 3D printer. The lock is composed of a mechanism cover. A movable lever, one side of which extends to block the opening of the movable part of the overhead bin, and at the other end of the lever is a magnet that is magnetically attracted to the outer magnet to open it. A latch which by its movement locks the movable lever with the magnet in the permanently unlocked position. A fuse is created for 3D printing from components not directly on the main locking mechanism, against which the sliding lever and larger magnet are blocked, this magnet is used by the deck crew to unlock the overhead bin from the outside.

The components were designed in Autodesk Fusion 360. Unlike the first theoretical lock design, the lock latch, its location and its shape had to be modified. The movable locking paw and the stop had to be modified so that the lock could be positioned between the movable and non-movable parts of the luggage compartment and still be unlocked despite the thicker material used on the overhead bins.

Figure n.1 – Components for 3D printing of magnetic lock [1]

Figure n.2 – Modified magnetic lock release stop [1]

After printing all the necessary parts on the 3D printer, they were cleaned of excess material that is produced during 3D printing, the details were adjusted and the magnetic lock was assembled into a single unit. Once assembled, its functionality was tested and it was placed on a model of an overhead bin where its functionality and reliability was also tested.

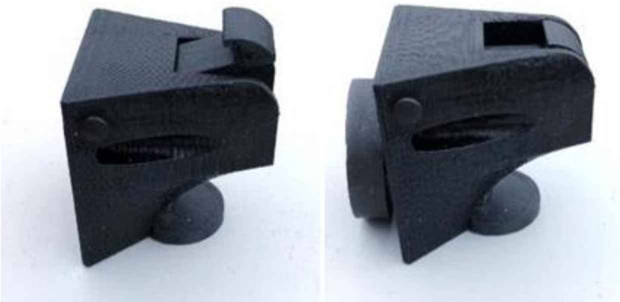

Figure n. 3 – Final magnetic lock prototype [1]

4.2. Automatic RFID lock

The RFID lock was more complicated to manufacture, although its technical design did not need to be changed from the original theoretical design. The lock contains more components and also wiring, along with an electrical source,

in the case of this work the source was solved by a battery. In the design, the locking was solved by servo or magnetic lock, for the construction, the final solution was chosen to be electromagnetic locking, because this solution better suits the requirements for the location on the overhead bin.

In this article an open Arduino platform with connected peripherals is used, which is suitable for the purpose of prototyping so-called embedded systems. The next section first describes the components used to build a demonstration system capable of controlling the overhead bin locks according to the commands of the on-board personnel and then the software operation when programmed.

When an authorized access card is inserted, the system goes into an "open" state. At the same time, the user is informed of the progress of the action on the attached LCD display. In the "open" state after opening the locks, a protection interval is set when the system does not read data from the RFID transceiver. Due to the fact that the same RFID authorization card or tag is used to re-lock the overhead bins, this protection interval is necessary to avoid constant switching between open and closed state in case the RFID card is attached to the transceiver for too long an interval. The duration of the protection interval was chosen to be 4 seconds. Changing the duration of this interval is possible by a minor modification of the code.

If the system is in the "open" state and the RFID card with authorized access is reattached, the system enters the "closed" state. Both locks are locked at the same time and the LCD display informs the user about the progress of the action. Again, a protection interval of 4 seconds is present to prevent accidental unlocking if the RFID card is moved too hesitantly near the reader.

If in any state, either "open" or "closed", a card with unauthorized access is attached, the system will not perform any action, inform via the LCD display, and remain in the current state.

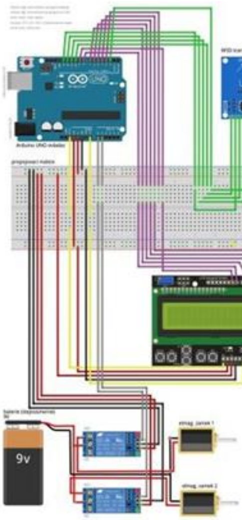

Figure n. 4 – Component wiring diagram [1]

5. EVALUATION OF THE BENEFITS FOR OPERATIONAL SAFETY AND COSTS FOR THE OPERATOR

There are a few basic categories that can be identified as the main benefits of safety locks, which are the problem areas in emergency evacuation as well as in the normal operation and disembarkation of passengers:

- Increased safety on board, reducing the possibility of removing luggage from the compartments and thus considerably speeding up the overall evacuation.
- Organization and restriction of passenger movement in critical situations such as take-off, landing or turbulent conditions. Due to the inability to handle and access their luggage during these and other parts of the flight where it is needed, the movement of passengers around the aircraft is reduced.
- Discharging passengers by group from the aircraft in such a way as to avoid disturbance of its stability on the ground due to movement of the centre of gravity. At the same time, there is new potential for low-cost airlines in the possibility of paying extra for early departure. The locks allow only part of the overhead bins to be opened, there is no need to open them all at once.

The approximate weight of both prototypes was about 150 grams per lock. The overhead bins in an aircraft average, depending on the specific type, are about 20 luggage bins per side, so 40 overhead bins in total and 40 required locks. Thus, there is an approximate weight increase of 6 kilograms per aircraft when locks are installed. This increase will increase the Basic Operating Mass. The locks are evenly spaced, so they do not affect the centre of gravity of the aircraft. At the same time, the Boeing 737, on which the locks have been implemented, has its centre of gravity almost at the centre of the aircraft, it is located near the wings and therefore the effect of the locks is negligible. The total weight of 6 kilograms is also negligible compared to the take-off weight of the aircraft, which is around 79 tonnes.

6. CONCLUSION

The conclusion of this work is the evaluation and development of two selected means to lock the luggage compartments in the passenger cabin. In the first, theoretical part, the thesis deals with topics closely related to the main focus of the thesis. A magnetic, manual, lock and an automatic lock using radio frequency identification for locking and unlocking were selected for further investigation and production.

The selected locks were first designed theoretically. Subsequently, two prototype locks were also manufactured. Several modifications were made during the manufacturing process to make them usable in operation and to meet the requirements imposed on them. Subsequently, their functionality was tested and their characteristics were analysed. At the same time, the benefits of this component when used in operation, their theoretical cost and the cost in operation were evaluated.

It was found that neither the center of gravity nor the cost of manufacturing and implementing them would be so substantial as to affect aircraft operations or economically disrupt airline budgets. The work was based on the fact that a passenger will only experience evacuation from an aircraft once in his/her lifetime, therefore his/her behaviour is often irrelevant. At the same time, the 90 seconds for evacuation assumes a seamless evacuation, where no passenger intentionally, or due to stress, delays the evacuation. Locks preventing the removal of luggage from overhead bins could speed up evacuation if passengers were informed of the locks. At the same time, the locks are not strong enough to withstand the onslaught of intense efforts to get into the bins. Finally, locks on the baggage bins could help with scheduling passengers to exit the aircraft so that they are no longer trying to lift and climb into the aisles during taxi, as well as coordinating the exit of passengers down the aisles by separately unlocking the overhead bins.

The purpose of this article was to evaluate and design locks to prevent luggage from being removed from the overhead bins at times when this activity is not consistent with security procedures. The two proposed locks meet the purpose of the article and are applicable to real operation. This minor change, the addition of cabin security, could effectively expedite evacuation, thereby potentially saving the lives of other passengers. It would also make the job of cabin crew easier when directing passengers during critical parts of the flight, or in situations where passengers need to be seated. Airline safety departments today are looking for the intersection between financial costs and safety improvements, so the proposed solution could open the door for companies to win new ACMI contracts.

REFERENCES

[1] Author

[2] PANIC AND HUMAN BEHAVIOR FIRE & EMERGENCY SITUATIONS [online]. www.ctif.org, [cit. 2022-03-01]. Dostupné na internetu: https://www.ctif.org/news/panic-and-human-behavior-fire- emergency-situations#:~:text=Five%20human%20Behavioral%20Patterns%3A% 20According%20to%20Quarantelli%E2%80%99s%20%28 1980%29, They%20include%3A%20warning%2C%20withdrawal%20 movemen t%2C%20shelter%2C%20and%20return

[3] IDNES.CZ/ZPRAVODAJSTVÍ – ŽENA VYPADLA PŘI EVAKUACI Z LETADLA SMARTWINGS ZE SKLUZAVKY [online]. www.idnes.cz, [cit. 2022-01-05]. Dostupné na internetu: https://www.idnes.cz/zpravy/zahranicni/smart-wings-travel-service- zena-evakuace-rozbila-si-lebku.A180323_161449_zahranicni_hm1

[4] PASSENGER BEHAVIOR DURING AIRCRAFT EVACUATIONS [online]. www.skybrary.aero, 5 s. [cit. 2022-02-11]. Dostupné na internetu: https://skybrary.aero/sites/default/files/bookshelf/4362.pdf

[5] ASSEMBLY — 40TH SESSION TECHNICAL COMMISSION – AGENDA ITEM 30: OTHER ISSUES TO BE CONSIDERED BY THE TECHNICAL COMMISSION INTRODUCTION OF THE CENTRALIZED-OPERATIONAL LOCKS FOR THE AIRCRAFT OVERHEAD BINS [online]. www.icao.int, 4 s. [cit. 2021-11-26]. Dostupné na internetu: https://www.icao.int/Meetings/a40/Documents/WP/wp_110_en.pdf?f bclid=IwAR1HKbUtRKiun_U2tPdjDRk4C3ptSa7lUUkKkM9BRJ72 X9UGUMEwB81CUHs

[6] LUGGAGE BINS [online]. www.general-aero.com, [cit. 2022-03- 04]. Dostupné na internetu: https://www.general-aero.com/en/applications/luggage-bins?fbclid=IwAR2A1jw7ntyyn5RP76Oz701mjviHddaFoGqqTurZIi X_T9DumgOPWxDTlUM

[7] BIN LATCHING SYSTEMS [online]. www.harperengineering.com, [cit. 2022-03-03]. Dostupné na internetu: https://www.harperengineering.com/bin-latching-systems?fbclid=IwAR1rP7Lfjzhsmol07PzPxn8Da7_ukD--VA0rJ0sbegZigsRS3jAAc8idh_c

[8] BUGAJ, M., NOVÁK, A. 2010. Všeobecné znalosti o lietadle : drak a systémy, elektrický systém. - 1. vyd. - Žilina : Žilinská univerzita, 2004. - 247 s. - ISBN 80-8070-210-1.

[9] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

https://doi.org/10.26552/ pas.Z.2022.2.22

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THE COVID-19 CRISIS AND ITS IMPACT ON CHANGES IN AIR TRANSPORT

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Abstract

The aim of this paper is to identify the effects of the corona crisis on air transport and the changes that this crisis has brought. It deals with the analysis of selected airlines, navigation service providers and airports from the EU (Slovakia, the Czech Republic, France), the United Kingdom, the USA and the United Arab Emirates, whose economic indicators as well as economic and operational results show how the measures in place affect their operation. The aim of this paper is to provide a comprehensive view of how air transport has changed as a result of the pandemc COVID-19, as well as to make proposals for revitalization measures to help the aviation sector.

Keywords

COVID-19, aviation, measures, airports, air navigation service providers, airlines

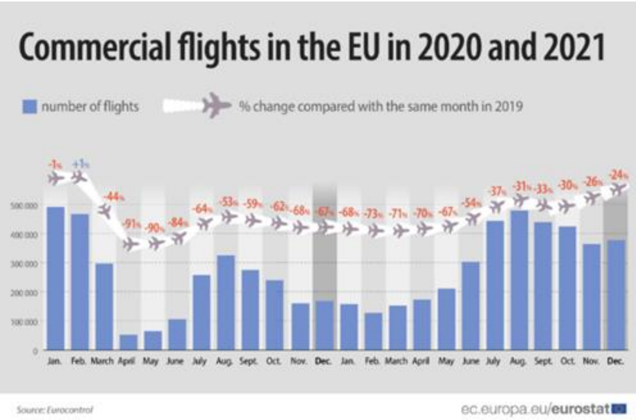
1. INTRODUCTION

Air traffic has been affected in the past by various events that have significantly affected usual traffic. However, none of them had as much impact as the COVID-19 pandemic. During the crisis, civil air transport reached a complete bottom. The mobility of people was limited and the only flights that could be operated were flights due to the repatriation of citizens. Following the ban on civil flights in the Slovak Republic on the 13 March 2020, the first repatriation flight from the United Kingdom took place on the 24 March 2020. [1].

2. GLOBAL IMPACT ON AIR TRANSPORT

2.1. Airlines

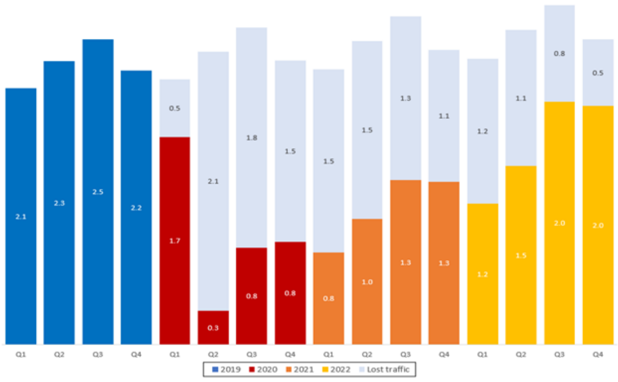
In the pre-pandemic years, airlines were experiencing strong economic growth, but in 2020 revenues fell by as much as 55%. Although the situation is estimated to have improved significantly in 2021, it will still lag the values of 2019. [2]



Picture 1 Commercial flights in the EU. Source: [3]

2.2. Airports

The pandemic dramatically reduced airport activity and reduced their aeronautical and non-aeronautical revenues. During the pandemic, the airports were closed or operated only to a limited extent. In most cases, airports remained open only for repatriation flights or freight [4].



Picture 2 Quarterly global passenger traffic projection compared to pre-COVID-19 forecast (2019–2022, in billions of passengers). Source: [5]

2.3. Air navigation service providers

Although the work intensity of air navigation service providers has declined, it remains necessary to maintain a high quality and secure highly qualified workforce, which required high and fixed costs. With the decline in air traffic during the pandemic, the revenues of air navigation service providers also fell. However, the crisis has caused some airlines using air navigation services to postpone or stop paying at all [6].

Measures to protect the aviation sector, which forms are significant part of the national economy, have not been implemented uniformly and differed in scope or different timings. The most significant aid was State aid, which was provided under three different schemes:

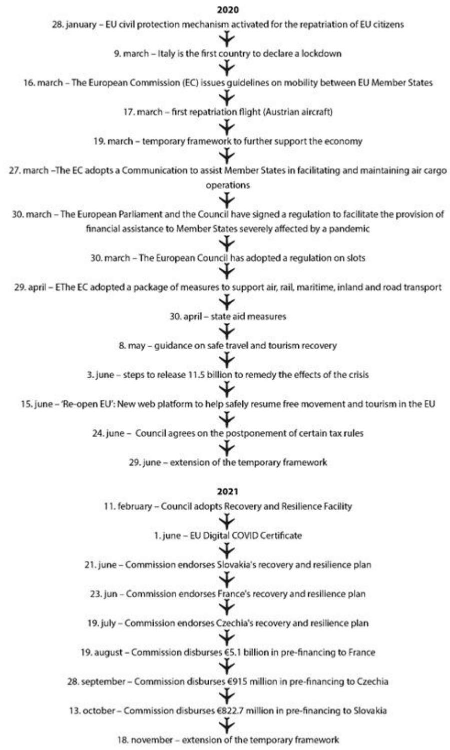
- ad hoc - targeted at one airline perceived as a "national interest",
- support for individual airlines in the wider context of overall corporate schemes,
- industrial programs available to all companies in the air transport sector.

Some countries, such as the United Kingdom or the United States, have applied sectoral air transport schemes. The United States has provided financial support to airlines through a law called Coronavirus Aid, Relief. And Economic Security Act (CARES Act). As a result of this law, as early as December 2020, seven major airlines secured loans of approximately $ 20 billion [7].

Another measure was a temporary exemption from the airport's slots, when airlines did not have to use at least 80% of their slots to ensure that the right to these slots was maintained in the next flight season. This prevented "ghost flights" that were unecological and uneconomical. The European Commission has reduced this limit to 50%. The measure was later extended until the 29 October 2022 and was also increased to 64% as the pandemic situation improved [8].

On the 26 March 2020, the European Commission issued guidelines to facilitate air freight operations. These operations were to be exempted from the night curfew and airport time limits. In order to speed up and simplify air freight transport, this guideline allows the use of civil aircraft for the transport of cargo and relieves the crews of these aircraft from travel restrictions, provided that they show no signs of coronavirus infection [9].

The pandemic has forced airlines to reduce their costs through their aircraft. As far as possible, airlines began deploying smaller aircraft on each route, which had a chance to fill up. The average aircraft capacity dropped from 146 seats to 141 in 2021. Long-range aircraft such as the Airbus A330 or Boeing B777 suffered the most [10].



Picture 3 Global capacity share by aircraft type, February 2020. Source: [10]

Types of state aid:

• direct grants and tax benefits,

• subsidized state guarantees for bank loans,

• public and private loans with preferential interest rates,

• existing credit capacities and their use,

• additional flexibility to allow the state to provide short-term export credit insurance if needed,

• recapitalization [12].

3. ANALYSIS OF THE ECONOMIC AND POLICY MEASURES TAKEN ON THE AIR TRANSPORT AND THEIR EFFICIENCY

The paper evaluates a selected airline, airport and air navigation service provider from European Union countries (Slovak Republic - Air Explore, M. R. Štefánik Airport, LPS SR, Czech Republic - Smartwings, Václav Havel Airport in Prague, ANS CR, France - Air France , Charles de Gaulle Airport (DSNA), United Kingdom - British Airways, Heathrow Airport, NATS, United States - American Airline, Los Angeles Airport, FAA ATO and the United Arab Emirates - Emirates, Dubai Airport and GANS. The analysis is based on several indicators (total revenue, (loss) / profit before tax, number of passengers carried / number of flights handled, total costs, EBIDA and total cost ratio). The most important selected indicator is the total cost ratio, which shows the overall efficiency of the company [13]. Financial data in other currencies used in the analysis were converted into euros using the average annual exchange rate in the given year. The valueswere drawn from the annual reports of the companies, which were available at the time of writing.

3.1. *Slovak republic*

As part of the pandemic, Air Explore was forced to lay off its employees, reduce costs and recorded a dramatic drop in flights. Its total revenue in 2019 was almost the same as its costs, but these rose sharply after the outbreak of the pandemic [14].

At the time of writing, the annual report of 2021 was not yet available. However, the figures show that M. R. Štefánik Airport was already at a loss before the start of the pandemic, and in 2020 its loss deepened despite a 10% cost reduction. Airport costs increased by almost 62% in 2020 [15].

LPS SR handled almost 800,000 fewer flights in 2020 than in 2019. The loss in 2020 reached 18.3 million euros and the total cost ratio increased by almost 65% compared to 2019 [16].

3.2. *Czech republic*

At the time of writing, the Smartwings annual report 2021 has not been issued and the 2020 annual report did not contain enough data. In 2019, Smartwings' total revenues were almost the same as costs. In 2020, total revenues fell sharply. Total cost ratio in 2019 remained just below 100%, which puts the company in a more advantageous position [17].

Almost 4.4 million passengers passed through Václav Havel Airport in Prague in 2021, which is an increase of 19.7% compared to 2020, but a decrease of 75.4% compared to 2019 [18].

ANS CR reports from 2020 and 2021 were not issued. In 2019, however, they handled 95,000 flights and their total cost ratio was 95.43% [19].

3.3. *France*

In 2019, Air France KLM had an annual operating profit of around € 750 million and carried more than 104 million passengers [20]. As a result of measures to prevent the spread of coronavirus and restrict mobility, the company had to reduce its activities, which led to significant losses. In 2020, sales fell by 60.3%, which means that the annual operating loss amounted to -3.7 billion euros [21]. Only 34,065,000 passengers were carried in this year. According to the total cost ratio indicator, Air France's costs rose disproportionately in terms of profits in 2020. Although they fell in 2021, they still failed to return to pre-pandemic levels.

The decrease in passengers at Charles de Gaulle Airport was very significant, reaching 60.4% between 2019 and 2020. The EBITDA indicator shows an increase of 583 million euros compared to 2020 compared to 2021 [22]. Although Charles de Gaulle Airport's costs increased, it managed to maintain good total cost ratio values and made a profit during the pandemic.

At the time of writing, the DSNA air navigation service provider did not have the necessary data from the 2020 and 2021 annual reports published.

3.4. *United Kingdom*

British Airways' total revenues in 2020 deteriorated by 69.9% compared to 2019 [23]. During the first six months of the year, passenger capacity remained low. Compared to the equivalent period in 2019, it was only 14%. Although profits are kept low, it appears that losses at the end of 2021 may no longer be as high as in 2020 [24]. Although British Airways had relatively good total cost ratio results before the pandemic, total cost ratio rose sharply in the first half of 2021, to 229.22%.

In 2021, the number of passengers at Heathrow Airport fell by 2.7 million, because of stricter measures than in the European Union. Operating costs decreased by 17% in 2020 compared to 2019, while EBITDA decreased by 86.1% over the same period [25]. The airport's total cost ratio rose by almost half in 2020, but the company still managed to keep its profit in positive territory. Subsequently, in 2021, the total cost ratio fell to 68.37%.

In the case of NATS, an important figure in this case is the fact that in the annual report the fiscal year ends on 31 March. Because of this, at first sight, data may be skewed over the years. Due to restrictions on international air traffic and restrictions on mobility, there was a decrease in flights by 73%. While in 2020 it was 2.48 million flights, in 2021 it was only 661,000, although the difference between 2020 and 2019 does not seem so different [26].

3.5. *United States of America*

American Airlines' total capacity decreased by 24.7% in 2021 compared to 2019. EBITDA in 2021 increased by 61.07% compared to 2020 [27]. Total cost ratio rose by 66.81% in 2020, but in 2021 approached the percentage of 2019 again.

At Los Angeles Airport, at the end of fiscal year 2021, which runs from 1 July, total passenger carried was 29,05 million, 53.7% below fiscal 2020 and 67% below pre-pandemic levels in 2019 [28]. Although the total cost ratio increased slightly after the pandemic, its values were below 70% throughout the pandemic.

As the US air navigation service provider ATO is part of the FAA, which is made up of many other similar organizational units, insufficient information was found to carry out further analysis following the example of other companies.

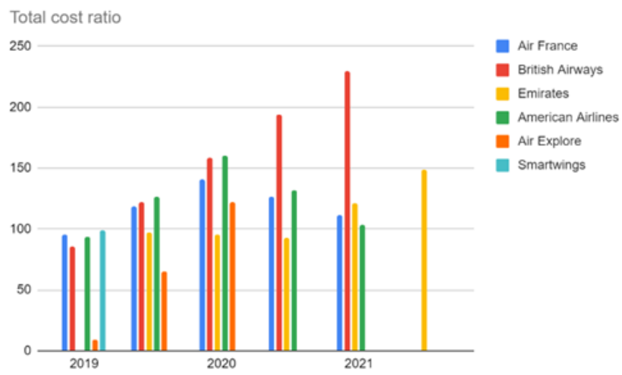
F. United Arab Emirates

Emirates carried 6.6 million passengers in 2020/2021, down 88% and seating capacity down 83%. The airline's total cost ratio increased sharply only in the fiscal year 2020/2021, by as much as 51.08% to 148.41% compared to the fiscal year 2018/2019 [29].

Neither Dubai Airport nor the air navigation service provider GANS had any annual reports published and therefore it was not possible to analyze and compare these companies with the others.

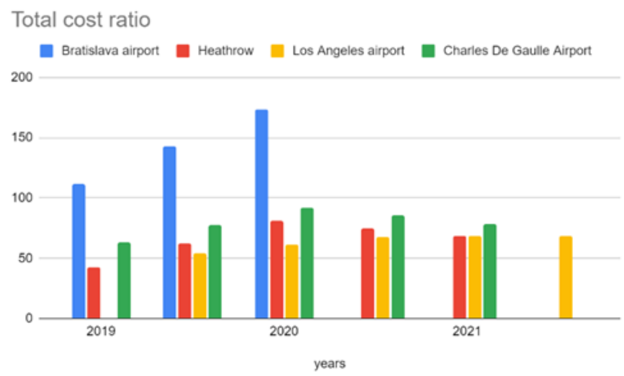
4. ANALYSIS OF SELECTED COMPANIES

Every company tried to deal with the COVID-19 crisis as best as they could, and it is clear from the above data that most would have managed it very hard or not at all without providing a helping hand from the government. The European Union's most significant response to mitigating the impact of the pandemic has been to apply the Temporary Framework. However, it was difficult to balance the state aid so as not to distort competition. This was shown by the example of Air France, which had to give up its 18 slots at Orly airport in favour of a competing company precisely because of the imbalance. The European Commission also distinguished between different types of State aid, which included subsidized interest rates on loans, recapitalization measures and state loan guarantees that could be linked to additional conditions, which the French Government took advantage of and conditional on the environmental conditions that Air France had to accept. The United States, like the European Union, has responded by helping the aviation sector by temporarily abolishing fees and providing financial assistance under the CARES law. Thanks to this assistance, anti-pandemic measures began to climb back to pre-pandemic levels around mid-2021 as demand for domestic flights. From the countries compared, it seems that the United Arab Emirates has best managed the pandemic situation precisely because of its efforts to raise people's awareness, which has meant rapid vaccination of people and the possibility of cancelling measures more quickly. The Emirates Group based its tactics on gaining people's trust, and the measures put in place were conditional on protecting the health of passengers and employees at a high level. The individual indicators taken from the annual reports are reflected in the graphs below. However, some figures may appear skewed due to different start and end dates for the fiscal year. The figures are shown in millions except for total cost ratio values and the financial figures are given in euros. However, the ability to manage a pandemic is best illustrated by the total cost ratio indicator, which unifies the data into comparable quantities.



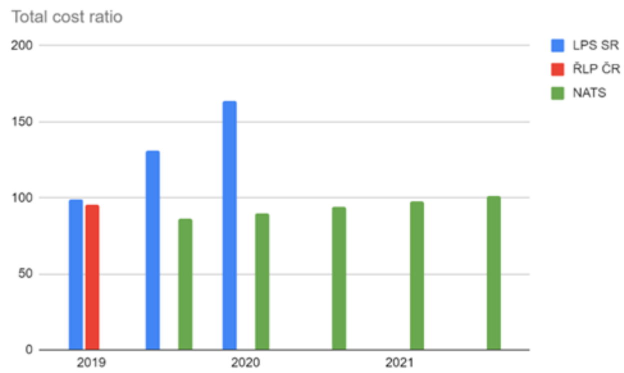
Picture 5 Airlines – Total Cost Ratio Source: Author's

According to the total cost ratio indicator, we can see how most airlines have increased revenues. The highest value is shown by British Airways, but this figure is skewed by the fact that the available results of the year were only available for the first half of the year, during which restrictions still prevailed, so it is assumed that this value will be adjusted after a comprehensive annual report. The imaginary curves of American Airlines and Air France are again very similar, copying the shape of the inverted letter V. Emirates is again distorted by the different beginning of the fiscal year.



Picture 6 Airports – Total Cost Ratio Source: Author's

The imaginary curves of Paris and London airports are very similar. It is very likely that Bratislava Airport will have a similar curve, but it will appear only after the publication of the annual report for 2021. However, this airport has the highest cost - airport costs exceeded profits and according to the imaginary curve, airport management was not efficient enough even before the pandemic, while during the situation worsened.



Picture 7 Air navigation service providers – total cost ratio Source: Author's

The imaginary curve shows how total cost ratio rose sharply within the management of the Air Traffic Services of the Slovak Republic, while NATS values rose only slowly and remained below 100%, which means that their management is profitable.

According to the results of the analysis and comparison, American Airlines is the one that is the fastest to recover from pandemic restrictions. Emirates could be a comparable company, but due to a lack of information due to a different fiscal year schedule, we can only estimate this situation.

From the point of view of airports, the imaginary curves of Charles de Gaulle Airport and London Heathrow Airport were the best. Both data sets for these airports showed similar behaviour, which could have been expected at the time from a pandemic situation.

It is not possible to obtain relevant and authoritative results within air navigation service providers due to the lack of information from the annual reports which best describe the economic performance of the companies concerned.

The cost values revealed that, of the airlines being compared, American Airlines and Air France, which increased their costs in 2020 but were gradually declining again to profitable levels, managed the pandemic situation best. According to the total cost ratio indicator, Paris and London airports handled the pandemic very similarly and, despite the increase, are returning to the values of 2019. Within the available data on navigation service providers, we can only evaluate the English provider, NATS, tendency.

5. OBJECTIVES AND METODHOLOGY

The aim of this paper was to examine the impact of the pandemic on the air transport and to evaluate the effectiveness of the measures taken. Subsequently, thanks to the information gathered, propose several revitalization measures that could help the aviation industry to better achieve pre-pandemic conditions and build greater resilience to similar crises that could occur in the future.

The method of analysis with comparison was used in achieving the set goals.

6. PROPOSAL FOR REVITALIZATION MEASURES FOR THE AIR TRANSPORT SECTOR

6.1. Financial reserves

This measure could apply to all three aviation sectors that we have addressed in this paper. As can be seen from the first part, several events have had a negative impact on the air transport in its relatively short history. Some events are very difficult to predict and therefore airlines should strengthen their resilience to such situations. They could increase their cash reserves, either voluntarily or through regulation, thus reducing the need for rescue packages each time a crisis strikes. They should also work to make their operations more agile - that is, they could improve their ability to reduce supply quickly and cost-effectively when demand suddenly falls, by increasing the variability of their cost base.

6.2. Extension of focus

The US aviation market is specific in that a significant proportion of passengers are business travellers who travel exclusively for work at various conferences or other business trips. However, the pandemic and travel restrictions have forced companies to adapt to restrictions and restrict travel for work. Almost everything was done online. People have become accustomed to this regime and there has been a decline in this category of passengers even after restrictions have been lifted. In this case, to compensate for such a decrease, US airlines could consider expanding capacity to other passenger categories. Increasing their focus on holiday travel would mean reconfiguring the aircraft cabin to accommodate more economy class tourists and less capacity for business and premium class seats.

6.3. Hygiene and customer service

During the pandemic, Emirates sought to restore customer confidence by providing free COVID-19 medical coverage to all passengers and by raising the possibility of changing the flight date at no additional charge. Despite the fact that travel arrangements are being relaxed and many countries no longer impose any entry conditions on COVID-19, airlines should focus on ensuring in-flight hygiene and thorough disinfection so that passengers can feel safe. They should also be flexible about the changes that can be brought about by seemingly ending crises or other events that could affect the air transport. It is precisely such companies that will be focused on customer service and will elegantly and clearly solve the operational problems that will be sought.

6.4. Cost effectiveness and safety

The duration and scale of the pandemic have forced companies to reduce their costs, not just in air transport, and to find ways to deal with the situation as best they can. Airlines, airports, and air navigation service providers should consider their cost structures and adapt their strategies after the end of the pandemic to be more cost effective. However, regardless of efficiency, safety should remain a priority.

6.5. Events

Václav Havel Airport in Prague held weekend programs on its premises for families with children to attract them to the airport. The events were educationally entertaining. These events could be a great way to promote airports, which could also serve to regain demand for air services. Through such programs, people could learn more about the hygiene or other measures, benefits, or services that the airport and airlines provide, and thus build trust and create demand. In this way, concerns about aircraft infections as well as current flying concerns could be alleviated in potential future passengers. Ultimately, the key will be the interaction with people, whether in the form of various events or advertisements.

6.6. Digitalization

The idea of increased digitization began to develop long ago, but the high costs discouraged many companies and airports from the implementation of modern technology as long as the current regime was sufficient. However, the coronary crisis has forced airports to take steps that have led to greater hygiene, maintaining sufficient spacing and minimizing the gathering of people in one place, for example while waiting in the baggage advice. More advanced technologies have speeded up the passenger handling process and have also brought benefits in terms of contactlessness and the ability to have all the necessary documents with you in digital form without the need for unnecessary paper waste.

6.7. Multi-source financing

Successful companies that want to establish themselves and stay in the market must be flexible and ready to respond to various obstacles. The crisis caused by COVID-19 has caused a significant outage in the main activities of airlines, airports, and air navigation service providers. All these sectors should focus on attracting other financial resources thanks to the products offered as the main one. A good example is the already mentioned Prague Airport, which was able to increase its non-air revenues in a non-standard way by holding events for families with children. There could be various trainings and other activities within air navigation service providers to help them increase their profits.

6.8. Fleet modifications

The original idea of designing the huge aircraft was a congested network, which meant an increased risk of possible collisions. The routes on which several smaller aircraft flew daily have been replaced by a smaller number of large transport aircraft, and this has led, among other things, to a reduction in the workload of navigation service providers. The pandemic has forced air carriers to consider, among other things, reducing costs by disposing of old or overpriced aircraft. British Airways also removed the last Boeing 747 from its fleet, and 14 aircraft "retired" in the Emirates. Despite the fact that Emirates immediately added three new A380s to its fleet, we can see from the results of their total cost ratio in 2020/2021 that they were largely unable to cover their costs effectively.

7. CONCLUSION

The results show that although the aviation sector was one of the hardest hits by the pandemic. It began to recover relatively quickly and regain growth. It is slowly returning to pre-pandemic times and gaining a foothold in the market. Returning customer confidence and better efficiency in responding to operational challenges are key elements of a complete return to the limelight.

ACKNOWLEDGMENT

This paper was supported by national grant scheme VEGA 1/0695/21 Air transport and COVID-19: Research of the crises impacts with a focus on the possibilities to revitalize the industry.

REFERENCES

[1] Letisko BTS vybavuje repatriačné lety Slovákov a nákladné lety. Bts.aero [online]. 2020, 24.3.2020. [cit. 10.3.2022]. Dostupné z: https://www.bts.aero/o-letisku/press/tlacove-spravy/letisko-bts-vybavuje-repatriacne-lety-slovakov-a-nakladne-lety/

[2] BOUVER, Jaap a kol. Taking stock of the pandemic's impact on global aviation. McKinsey [online]. 2022, 31.3.2022. [cit. 15.3.2022]. Dostupné z: https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/taking-stock-of-the-pandemics-impact-on-global-aviation

[3] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220112-1

[4] The impact of COVID-19 on the airport business – and the path to recovery. Airport Council International [online]. 2022, 24.2.2022. [cit. 21.3.2022]. Dostupné z: https://aci.aero/2022/02/24/the-impact-of-COVID-19-on-the-airport-business-and-the-path-to-recovery-4/

[5] https://aci.aero/2021/11/01/the-impact-of-COVID-19-on-the-airport-business-and-the-path-to-recovery-3/

[6] Weathering the storm: Air navigation service providers versus COVID-19. Hungaocontrol [online]. 2020, 23.4.2020. [cit. 10.3.2022]. Dostupné z: https://en.blog.hungarocontrol.hu/post/weathering-the-storm-ansps-versus-COVID-19/

[7] Financial Assistance: Lessons learned from CARES Act loan program for Aviation and Other Eligible Businesses. U.S. Government Accountability Office [online]. 2020, 10.12.2020. [cit. 17.3.2022]. Dostupné z: https://www.gao.gov/products/gao-21-198

[8] Members' Research Service. 'Ghost flights': EU rules for airport slots. European Parliamentary Research Service [online]. 2022, 21.1.2022. [cit. 5.4.2022]. Dostupné z: https://epthinktank.eu/2022/01/21/ghost-flights-eu-rules-on-airport-slots/

[9] Green lanes – Ensuring the free flow of goods and services. Európska komisia [online]. [cit. 16.3.2022]. Dostupné z: https://ec.europa.eu/info/live-work-travel-eu/coronavirus-response/transportation-during-pandemic_sk

[10] ROWLAND, Becca. Fleet Changes with COVID-19: Time for the New. OAG [online]. 2021, 24.2.2021. [cit. 17.3.2022]. Dostupné z: https://www.oag.com/blog/fleet-changes-COVID-19

[11] Časový prehľad opatrení EÚ. Európska komisia [online]. [cit. 29-3-2022]. Dostupné z: https://ec.europa.eu/info/live-work-travel-eu/coronavirus-response/timeline-eu-action_sk

[12] State aid: Commission approves €29.8 million Slovak aid scheme to compensate airport operators for damage suffered due to coronavirus outbreak and to support them in this context | EU Commission Press. Pubaffairsbruxelles.eu [online]. 2020, 23.12.2020. [cit. 20.3.2022]. Dostupné z: https://www.pubaffairsbruxelles.eu/state-aid-commission-approves-e29-8-million-slovak-aid-scheme-to-compensate-airport-operators-for-damage-suffered-due-to-coronavirus-outbreak-and-to-support-them-in-this-context-eu-commission-press/

[13] Nákladovosť (Total Cost Ratio). Managementmania.com [online]. [cit. 7.4.2022]. Dostupné z: https://managementmania.com/sk/nakladovost-total-cost-ratio

[14] AirExplore, s. r. o. Register účtovných uzávierok [online]. [cit. 6.4.2022]. Dostupné z: https://www.registeruz.sk/cruz-public/domain/accountingentity/show/705401

[15] Výročná správa 2020. bts.aero [online]. [cit. 5.4.2022]. Dostupné z: https://www.bts.aero/content/08/vyrocna-sprava-2020-opt.pdf

[16] LETOVÉ PREVÁDZKOVÉ SLUŽBY SLOVENSKEJ REPUBLIKY – Výročná správa 2020. LPS [online]. [cit. 5.4.2022]. Dostupné z: https://www.lps.sk/images/vs/vyrsprava2020sk.pdf

[17] Výročná správa Smartwings 2019. smartwings.com [online]. 2021, ferbruár 2021. [cit. 6.4.2022]. Dostupné z: https://www.smartwings.com/images/vztahy-s-

investory/audited-consolidated-financial-statements-ifrs-as-of-december-31-2019.pdf

[18] Prague Airport Handles Nearly 4.4 Million Passengers in 2021. prg.aero [online]. 2022, 13.1.2022. [cit. 7.4.2022]. Dostupné z: https://www.prg.aero/en/prague-airport-handles-nearly-44-million-passengers-2021

[19] Výročí zpráva ŘLP 2019. vyrocenky.cz [online]. 2020, 10.9.2020. [cit. 7.4.2022]. Dostupné z: http://www.vyrocenky.cz/letecka

[20] Number of passengers uplifted by Air France KLM from 2010 to 2021. statista [online]. [cit. 8.4.2022]. Dostupné z: https://www.statista.com/statistics/406687/air-france-klm-passenger-numbers/

[21] Air France KLM Full year 2019. airfranceklm.com [online]. 2020, 20.2.2020. [cit. 8.4.2022]. Dostupné z: https://www.airfranceklm.com/sites/default/files/q4_2019_press_release_en_8855736.pdf

[22] ADP 2021 full year results. Parisaeroport.fr [online]. 2022, 16.2.2022. [cit. 8.4.2022]. Dostupné z: https://www.parisaeroport.fr/docs/default-source/groupe-fichiers/finance/relations-investisseurs/information-financière/résultats-et-chiffre-d'affaires/2021/adp--2021-cp-full-year-results.pdf?sfvrsn=8235dfbd_2

[23] British Airways annual report 2020. iairgroup.com [online]. [cit. 23.3.2022]. Dostupné z: https://www.iairgroup.com/~/media/Files/I/IAG/annual-reports/ba/en/british-airways-plc-annual-report-and-accounts-2020.pdf

[24] British Airways annual report 2021. iairgroup.com [online]. [cit. 23.3.2022]. Dostupné z: https://www.iairgroup.com/~/media/Files/I/IAG/documents/british-airways-interim-reports/ba-2021-q2-imr-final.pdf

[25] Heathrow limited RESULTS FOR THE YEAR ENDED 31 DECEMBER 2021. Heathrow.com [online]. [cit. 23.3.2022]. Dostupné z: https://www.heathrow.com/content/dam/heathrow/web/common/documents/company/investor/reports-and-presentations/financial-results/2021/Heathrow_(SP)_Limited_Q4_2021_results%20release_final.pdf

[26] NATS holding, Annual Report and Accounts 2021. nats.aero [online]. [cit.27.3.2022]. Dostupné z: https://www.nats.aero/wp-content/uploads/2021/07/NATS-Holdings-Ltd-2021.pdf

[27] UNITED STATES SECURITIES AND EXCHANGE COMMISSION. American Airlines [online]. [cit. 24.3.2022]. Dostupné z: https://americanairlines.gcs-web.com/static-files/deb58cec-bf67-418f-a0f0-022fb75939fc

[28] Fiscal Year 2020-2021 Budget Performance Review. LAWA [online]. 2021, 2.9.2021. [cit. 25.3.2022]. Dostupné z: https://www.lawa.org/-/media/lawa-web/lawa-investor-relations/files/lawa-annual-budget/fy-2021-budget-performance-review-june-2021.ashx

[29] The Emirates Gropu Annual report 2020/2021. Emirates [online]. Dubai. [cit. 11.3.2022] Dostupné z: https://cdn.ek.aero/downloads/ek/pdfs/report/annual_report_2020.pdf

[30] TOMOVÁ, A. a kol. 2016. Ekonomika letísk. Žilina: Žilinská univerzita v Žiline EDIS-vydavateľské centrum ŽU. 2016. 219 strán. ISBN 978-80-554-1257-3.

[31] TOMOVÁ, A., NOVÁK SEDLÁČKOVÁ, A., ČERVINKA M., HAVEL K. 2017, Ekonomika leteckých spoločností, 1. vyd. Žilina: EDIS, 2017. 274 s. ISBN 978-80-554-1359-4.

[32] TOMOVÁ, A., HAVEL, K. 2015. Ekonomika poskytovateľov leteckých navigačných služieb. vyd. - V Žiline : Žilinská univerzita, 2015. - 154 s. ISBN 978-80-554-1153-8.

[33] TOMOVÁ, A., MATERNA, M. 2017. The Directions of On-going Air Carriers' Hybridization: Towards Peerless Business Models? Procedia Engineering, 2017, 192, pp. 569–573

[34] NOVAK, A., BADANIK, B., BREZONAKOVA, A., LUSIAK, T. 2020. Implications of Crew Rostering on Airline Operations. ISSN 23521457.

https://doi.org/10.26552/ pas.Z.2022.2.23

SPECIFIC RISKS OF HELICOPTER AERIAL WORKS AND THEIR ELIMINATION

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Abstract

Safety is the highest priority in all aspects of air transportation. This paper is focused on different hazards and risks that might be encountered by helicopters during different types of aerial works and offers ways to mitigate those risks. The introductory part lists companies who are currently licensed for helicopter aerial work in Slovakia and outlines different types of aerial works. The methodology process describes four steps, which are then executed in the central part of the paper. The main part was written as a result of combining two different approaches to hazard identification – reactive and proactive – which encompassed studying and analyzing reports from helicopter accidents and incidents, as well as brainstorming techniques with assistance from aviation professionals. The results provide different mitigating techniques to lower assessed risks to tolerable values, along with alternative proposals of risk mitigation to air operators

Keywords

safety, aerial works, helicopters, hazards, risks

1. INTRODUCTION

Helicopter aerial work is a process that possesses high risk due to its specific operating conditions. When combining complicated technology and a challenging task in a limited space, many situations arise that may have negative consequences. When performing aerial work, the specified minimum flight altitudes are often exceeded, as well as the safety distances from obstacles are reduced. The helicopter can often be in a dangerous situation and the ground staff is also exposed to various risks when handling the cargo, for example. The execution of such activities requires professional guidance and management of all persons involved in the process. This type of work can only be carried out safely through a thorough risk assessment, complete use of all risk mitigating options, careful selection of suitable work materials and staff, as well as extensive training of staff.

2. THEORETICAL INFORMATION

Currently, there are six companies that hold the license to operate helicopters for specialized activities (SPO) in Slovakia. The companies are:

- HELI COMPANY, s.r.o.
- Aerial East, s.r.o.
- AIR – TRANSPORT EUROPE
- AVE Fermo, s.r.o.
- TECH-MONT Helicopter company, s.r.o.
- UTair Europe, s.r.o. [1]

2.1. Aerial work

The Aviation Act of Slovak Republic (Act No. 143/1998 Coll.) defines aerial work as follows: “Aerial work are paid aviation activities performed in agriculture, forest industry and water management, construction, healthcare, advertising, photography, patrol, sightseeing flights and similar activities” [2]. The aircraft is usually specially equipped and the crew on board is familiar with the risks associated with the work.

2.1.1. Aerial advertising

Aerial advertising can be defined as operation of an aircraft for the purposes of displaying advertisements in the sky, pulling banners, displaying aeronautical signs, dropping leaflets, or making announcements from the aircraft.

2.1.2. Aerial construction activities

Helicopters are often used in the construction of masts, power lines or cableways in an inaccessible terrain, but also to increase the efficiency and safety of work performed at heights. They are also often used in densely populated areas, where it is often impossible to use cranes. Helicopters are used to transport parts of equipment, concrete, or other building materials. Other aeronautical construction activities include construction of power lines and telecommunication towers or masts. The advantage here is the process of cargo transportation, which is attached to the helicopter by an external load device, which practically does not limit the dimensions of the cargo. However, the limiting factor here is the weight of the cargo, which depends on the type of helicopter used.

2.1.3. Aerial firefighting

Airplanes and helicopters are an integral part of forest firefighting and often must be operated at low altitudes in a dangerous environment. They are often used to deliver emergency equipment and supplies to hard-to-reach and dangerous places where they can apply fire suppressants quickly and effectively. Management of the forest fire extinguishing process includes operation of aircraft for fire detection and control purposes, as well as the discharge of a specific substances intended for firefighting and fire prevention. The process also includes transporting firefighters to fire affected areas. Helicopters have a certain advantage in such activities because they can fly at low speeds, require a relatively small take-off / landing area, and can quickly turn.

2.1.4. Aerial frost protection

Helicopters are also used in orchards, whereby creating air turbulence, warm air is being moved to a cooler surface, therefore protecting the fruit from frost and consequent damage. The optimal flight altitude for this job is very low, often under 100 feet with a flight speed of 8 to 40 km/h. The flights only stop when the air temperature rises above the critical temperature for the possible crop damage [3]. Helicopters are also used to dry cherries after storms, often being the fastest and the most effective way to save crops. Helicopter flies just above the treetops and creates turbulence that blows most of the rainwater away.

2.1.5. Aerial photography and filming

Aerial photography is operation of aircraft for the purpose of photographing or recording information using a camera or other measuring and recording equipment. Currently, aerial photography or filming can be performed from any flying device, from hot air balloons to fighter jets. However, helicopters are the most practical platform used by aerial photographers. The advantage over airplanes is the ability to fly with removed doors, so that the windscreens or parts of the wing do not interfere with the view. Other advantages include the ability of a slow flight and good maneuverability.

2.1.6. Aerial survey

Aerial survey can be defined as the operation of aircraft for the purpose of conducting aerial observations of objects and phenomena, wildlife, or other observations, as well as for the purpose of examining objects and phenomena by means of a camera or other measuring and recording devices. In agriculture, helicopters are used to monitor crops and survey livestock over large areas.

2.1.7. Aerial transport of external cargo

Wood is among the most frequently transported cargo by helicopter, mostly collected from hard-to-reach areas. Helicopters are also used to transport various types of materials, such as construction or assembly material. Other operational helicopter uses include supplying areas otherwise inaccessible or transporting large equipment, such as air conditioning, to the roofs of tall buildings.

2.1.8. Adventure flights and flights at air shows

Adventure or experience flights can be defined as operation of an aircraft for the purpose of providing passenger recreation. Flights usually start and end at the same airport. Air show flight means any flight activity intentionally performed for demonstration purposes or as an entertainment program for an air show or other public aviation event. Training demonstration flights and flights to and from the air show can also be considered as air show flights.

2.1.9. Agricultural flights

The use of aircraft in agriculture is mainly for treating crops against pests by releasing insecticides and other chemicals. Aerial spraying can be defined as the operation of aircraft to disperse products in agriculture, horticulture, forestry or in protection of public health. Aerial spraying activities are carried out by aircraft equipped with tanks for liquids or solids, which are discharged at low altitudes to ensure their optimal application.

2.1.10. Forest liming

Helicopters are the preferred means to use when liming forests due to its maneuverability, low flight speed and the ability of placing the limestone used for the operation directly in the desired location, as opposed to the airport. Special containers with a device that regulates the amount of applied lime are often used.

2.1.11. Patrol flights

Police support from the air plays a key role in tackling crime and protecting the public in the search for suspects or missing persons, giving support to law enforcement, surveying dangerous situations, or assisting in a vehicle chase. The advantage of helicopter use for patrol flights is the speed of search in large areas and reduction of the risk to the ground forces. Helicopter intelligence flights also provide information to the public in dangerous situations through real-time aerial shots when remote and hard-to-reach places can be reached quickly.

2.1.12. Power line / pipeline inspection flights

Inspections performed by helicopters usually include inspections of transit pipeline, inspection of oil pipeline system, protection zones, detection of possible leaks, and monitoring the condition and safety of the system. In addition, inspections of high voltage power lines are often performed by helicopters as well.

2.1.13. Rescue flights

This type of operation is mainly intended for the evacuation of people or animals from areas that are difficult to reach by land. Other irreplaceable services provided by helicopters are assistance in traffic accidents or mass accidents, provision of first aid in remote areas, transport of critically ill patients to hospitals, or transport of medical supplies.

3. METHODOLOGY

To ensure safety in the performance of any aerial work, it is necessary to assess the risks through the process of hazard identification and risk evaluation. To examine this process in detail, the methodology has been divided into four steps:

3.1. Definition of analysis process focus

In the first step, we determine on which area the risk analysis should focus on. In case of companies that operate helicopters, this may involve a risk assessment in terms of:

- risks related to workplace,
- risks related to persons,
- risks related to the area of operation, or
- risks related to the activity performed.

In the administrative or maintenance part of the helicopter operating company, we can talk about assessment of risks related to the workplace, i.e., specifically with the place where these administrative or maintenance activities are performed. In the operations department we talk mostly about the risks directly related to the activity performed, whether it is the performance of commercial air transport or aerial work. The objective and scope of the risk assessment process should also consider internal and external factors that affect safety of the performed activity.

3.2. Identification of hazards and risks

Hazard is a condition that can potentially cause damage or injury. Risk is defined as the possible outcome of a hazard, expressed by its probability and severity of consequences. However, the probability of risk occurrence is irrelevant in the identification phase; if there is even a small chance that a risk may appear, we must include it. Risks that may arise can be taken from many sources including reports, inspections, audits, brainstorming sessions, or expert reviews [4]. The aim is to identify hazards before accidents, incidents or other safety-threatening events occur. Furthermore, risks can be identified by studying investigation reports from accidents or incidents that happened to operators in the area. This method will be the main risk identification method used in this paper, which will be complemented by a brainstorming session and an external information research, sourced mainly from internet and aviation professionals.

3.3. Risk assessment

It is necessary to evaluate the risk to be able to identify appropriate corrective measures to increase occupational safety. The two main factors in assessing risks are the probability of their occurrence and the estimated extent of damage caused. The factors defining the probability of damage are:

- duration and frequency of exposure,
- probability of event occurrence,
- options to prevent or limit damage.

Regarding the extent of the damage, we can distinguish between minor and severe injuries, permanent health consequences, and even the death of persons. Estimating, or evaluating existing risk is a very subjective process. A decision process should be used for a proper evaluation. Companies operating in Slovakia are obliged to use the tables provided by the Transport Authority, which are specially adapted to a specific operator. The values of financial losses are determined according to the type of aircraft operated by the company. When assessing risks by their severity, it should be assessed by taking the worst-case scenario of the event into account. The severity of risk is determined according to the following table:

TABLE I. RISK SEVERITY ASSESSMENT

Severity	**Persons**	**Environment**	**Material value and assets**	**Reputation**	**Value**
Catastrophic	More casualties	Massive negative effects, pollution	Huge financial losses, >50,000€	International impact	**5**
Hazardous	Casualties	Effects are difficult to remove	Large financial losses, <50,000€	National impact	**4**
Major	Major injuries	Significant local negative effects	Significant financial losses, <20,000€	Major impact	**3**
Minor	Minor injuries	Small negative effects	Large financial losses with small damage, >1,000€	Limited impact	**2**
Negligible	Superficial to no injuries	Negligible or no negative effects	Financial losses with negligible effects, <1,000€	Little to no impact	**1**

To determine the probability of a risk, we should ask: "what is the probability that a risk will occur?" In addition to the probability, we can also talk about the number of situations where which the event occurred in the past. The risk probability is determined according to the following table:

TABLE II. RISK PROBABILITY ASSESSMENT

Probability	**Definition**	**Value**
Frequent	This accident happens, such an event has already occurred in the company, it often occurs in the history of aviation.	5
Occasional	Sometimes this accident can occur. It already happened in society.	4
Remote	Unlikely, but possible. The event is rare in history.	3
Improbable	Very unlikely, but it has already occurred in the history of aviation.	2
Extremely improbable	Extremely unlikely, almost unthinkable. Such an event has never occurred before.	1

Existing protective measures are always considered when determining the probability and severity of a risk. After defining the severity and probability of risks, the company compiles a safety risk assessment matrix, which allows it to assess tolerability of the risks. Risks can be assigned into one of three categories:

- intolerable – if the risk is assessed as intolerable, the company's activities should be stopped immediately, and the operation should not continue until significant risk mitigation measures have been taken to minimize the risks as much as possible;
- tolerable – additional risk mitigation measures should be taken to lower the risk, while monitoring the severity and likelihood of their occurrence. However, if, even after these measures have been taken, the risk cannot be reduced to an acceptable level (e.g., due to high financial costs), the operation may be carried out after management approval;

- acceptable – in this case, the adverse consequences of the risk are not serious / unlikely to occur; there is no need to further reduce the risk. [4]

Based on the values in Tables 1 and 2 and their subsequent multiplication, the risk acceptance value is determined (see Table 3). An unacceptable level of risk is shown in red, an acceptable level in yellow and an acceptable level of risk is shown in green.

TABLE III. SAFETY RISK MATRIX

Risk probability	Risk severity				
	Catastrophic 5	Hazardous 4	Major 3	Minor 2	Negligible 1
Frequent 5	25	20	15	10	5
Occasional 4	20	16	12	8	4
Remote 3	15	12	9	6	3
mprobable 2	10	8	6	4	2
Extremely improbable 1	5	4	3	2	1

3.4. Specification of protective measures

The fourth step is a selection of measures to protect safety in aerial work operations after previous risk assessment. Economic aspects often play a key role in the selection of appropriate measures. Expensive investments can ultimately bring benefits, whether from an economic or safety point of view. In such cases it is necessary not only to look at the amount of the initial investment, but also at its effects spread over time. Another important aspect is the time aspect – how long it will take to implement the corrective action. The third aspect is the effectiveness or practicality of applied measures, how much the measures will reduce the risk and whether it is practical given the available technology, state legislation or the administrative and financial capabilities of the company. Another aspect of choosing the correct protective actions may be the enforceability of the measures and the ability of employees to accept and implement them. Lastly, possible additional security issues the measures may bring must also be considered. It is necessary that any measures taken and their effectiveness are subsequently verified.

4. RISK ANALYSIS

4.1. Hazard identification and risk specification

In aviation, hazard can be considered as a hidden possibility of damage / injury / loss of life that occurs in some form in the system or in the external environment. This possibility of damage can take various forms, such as natural or technical hazards. Hazards are part of all aviation activities, but their effects and possible consequences can be reduced through mitigation measures. In aviation, assessed potential for adverse consequences resulting from a hazard is called risk. The aim of mitigation measures is to reduce the likelihood that the hazard will result in a dangerous situation. Identifying these hazards is the first step in the safety risk management process. According to the ICAO Safety Management Manual, there are two main methods to identify hazards. These focus on the past – a reactive method that analyzes past accidents and serious incidents; and present – a proactive method that uses analysis of less dangerous situations and their frequency and determines whether hazard could lead to an accident. The manual also mentions a third method – predictive. [4]

The first step in obtaining safety information will be the use a reactive method of hazard identification. As an external source, we will use reports from accidents and serious incidents that occurred during helicopter operation in Slovakia and the Czech Republic. At the time of writing, final reports from 2009 to 2020 were available on the website of the Ministry of Transport and Construction of the Slovak Republic. According to the website of the Air Accidents Investigation Institute of Czech Republic, 38 accidents / serious incidents occurred from 2003 to 2021.

For the purposes of reactive hazard identification, general aviation flights were not included in the further investigation as these flights do not fall under companies subject to strict safety regulations. Another group excluded from the survey are training flights, thus giving us fourteen final reports to use for hazard and risk factor identification. To avoid the assumption of relationships between individual factors, we will not use the term "cause" of the accident.

Based on the conclusions of the accident / serious incident report analysis, hazards in Table 4 were identified, which can be divided into five groups. These groups are hazards associated with 1) pilots, such as insufficient experience or risky behavior, 2) technology, 3) work performed, 4) regulatory framework, which are external factors affecting the company, and 5) situational circumstances, such as weather or type of operation [5]. Some reports in the conclusions mentioned several factors contributing to the accident. The resulting factors were simplified and assigned to the appropriate subgroups after classification.

TABLE IV. RISK FACTORS FOUND IN ACCIDENT REPORTS

Hazard groups	Risk factors	Number
Human factors	Risky behaviors	2
	Violation of procedures	3
	Continuation of the task despite unfavorable conditions	1
	Lack of experience	4
Technology	Insufficient engine power under the circumstances	1
	Technical failure	4
	Specific helicopter behavior in certain flight modes	1
Performed work	Insufficient risk analysis	2
	Insufficient procedures	4
	Insufficient training	2
Regulatory framework	Insufficient rules	1
	Missing elements in helicopter pilot training	1
Situational factors	Low altitude	2
	Meteorological conditions	8
	Challenging terrain	5
	Errors of other persons involved	2
	Insufficient marking of obstacles	1

According to table 4, adverse meteorological conditions were the most frequently mentioned risk factor in the conclusions of the investigation reports, particularly reduced visibility due to fog, nighttime, turbulence or blinding by the setting sun. The second most common factor was operation in difficult mountain terrain. Furthermore, factors such as lack of pilot experience, technical failure of the helicopter or insufficient operational or emergency procedures for the performed activity were often mentioned.

Based on the analysis of the above-mentioned accidents and incidents, following risks occurred during the execution of aerial work, helicopter rescue services and commercial air transport, which are later used in determining the specific risks for each type of aerial work:

- Transport of external cargo – steel rope contact with tail rotor, dropping of a foreign object from the cargo, destruction of the load during transport due to rotation and inadequate securing of the load.
- Photo flights – inappropriate management interventions, risk-taking in order to achieve the required photograph, technical failure over a built-up area, inability to reach emergency landing area.
- Measuring flights with an extended probe – contact of the probe with trees in a mountainous terrain, prescribed obstacle clearance exceeded.
- Adventure flights – technical failure during operation in difficult mountain terrain, inability of the pilot to respond to helicopter behavior in a specific flight mode.
- Pipeline inspection – pilot overload, forgetting to turn on carburetor heat resulting in engine failure.
- Rescue flights – sudden deterioration of meteorological conditions, blinding by the setting sun, contact with overhead power lines, contact with trees in mountainous terrain at night, continuing the mission despite deteriorating visibility conditions.

We can then divide the above-mentioned risks into risks that may be present in all types of aerial work and risks that are specific to individual tasks. General risks include a sudden deterioration of meteorological conditions, engine failure, or insufficient ability of the pilot to respond to an abnormal situation resulting from insufficient training or experience. This paper will only focus on risks we consider specific to each task.

The second way to identify risks is a proactive method. It focuses on potentially dangerous situations, which are identified, and based on them risks are assumed. One of the common ways is a brainstorming session and use of information from external sources, such as similarly oriented organizations, professional media, or aviation authorities. General data obtained from Heli Company, s.r.o. were used, which were expanded over a period of several weeks with risks obtained from brainstorming and professional literature. As a result of these activities, risks were defined, which are assessed later in this paper.

4.2. Risk analysis

For the purposes of this paper, only selected aerial works are evaluated.

4.2.1. Pipeline inspection flights

Helicopters are used primarily for visual inspections of large pipeline systems, identifying leaks and any interventions that threaten reliability of the distribution system. In some countries, aircraft sensors are being developed to identify leaks that cannot be found by visual inspections. To perform these tasks safely and efficiently, the crew should be composed of a pilot and an observer. The helicopter performing the patrols is operated in an environment full of obstacles and at low altitudes, which significantly increases the possibility of collision with the distribution system or terrain. At the low speed and altitude of the flight, it is necessary for the pilot and crew to be extremely focused, maintaining situational awareness, having knowledge of the area of operation, maintaining effective communication, and having established clear roles and responsibilities of individual members.

Based on the previous methods, risks have been identified, which are assessed in terms of their acceptability in Table 5. Mitigation measures are proposed in Chapter 4 of this paper, along with tables containing original and adjusted risk assessment values.

The FAA website was used to search for aviation incidents to determine the likelihood of their occurrence, which allows to search through the NTSB accident and incident report database. The database was used mainly due to a huge number of aviation accidents related to aerial work in the US and abroad, which gives us a more objective view of the occurrence of individual risks. The NTSB database contained 17 reports of accidents and incidents during pipeline inspections from 1984 to 2018 [6]. Degradation of helicopter performance was mentioned in seven cases. Incomplete planning, pilot occupancy or technical problems occurred in six reports. Entering an area of bad weather was mentioned in five reports, with weather information missing in three cases. Violation of the safety distance from obstacles and subsequent collision with the obstacle occurred in three cases and unintentional deviation from the planned route in one case.

4.2.2. High voltage power line inspection flights

Helicopter power line inspections provide an effective way of visually inspecting the structure of electrical networks, conductors and identifying elements that pose a threat to the reliability of the electrical systems. Together with pipeline inspections, when performing the task, the aircraft flies through a hazardous environment full of obstacles, which greatly increases possible collision with infrastructure or terrain. This type of aerial work also requires a crew of at least two people – an observer and a pilot – to perform the task in an efficient and safe manner. To reduce the risk of a collision, crew must identify potential hazards and take corrective action well in advance. Failing to do so, the pilot can only take very limited measures to avoid collision due to a very close distance to obstacles.

Risks have been identified and are assessed in Table 6. The main way to prevent a helicopter from colliding with power lines is crew understanding and knowledge of the characteristics of the system. This gives crew members an opportunity to anticipate locations of overhead lines, thus avoiding complete reliance on visual contact only. However, despite familiarizing themselves with the system, it is important for crew to remain vigilant throughout the mission.

The NTSB database contained 18 reports from 1983 to 2015 concerning power line inspections. Degradation of the helicopter's performance was mentioned in nine cases, mainly due to improper maintenance, failure, fatigue of the helicopter's main and tail rotor systems, weather, or pilot human factor. Collision with an obstacle (especially with wires, poles, trees, or terrain) was mentioned eight times, which was caused by disorientation, insufficient training, technical failure, turbulence, pilot's reduced attention or a flight into unsuitable weather. Unfamiliarity with power line systems was mentioned five times, which was caused by poor planning, incorrect distance estimation or pilot inexperience. Lastly, emergency landing into terrain occurred in four reports.

4.2.3. Aerial transport of external cargo

Various types of external cargo can be transported by helicopter, anything from building materials to harvested wood from forests. Helicopter logging is a method of removing felled and uprooted trees by helicopter. This external freight transport is a complex activity in which many events take place simultaneously or in quick succession. To ensure the safety of all involved and the efficient operation, it is necessary that all staff are well acquainted with the task, effective coordination of all activities and appropriate planning are in place.

The following risks have been identified when using helicopters in the forest industry:

- downwash / vertical airflow from the rotor can cause weak or damaged trees and other debris to fall and can create dusty conditions that reduce visibility for both ground staff and the pilot,
- transported material may come loose and fall to the ground if it is not properly secured. This may endanger people under the helicopter's flight path, or in the event of material falling and getting stuck on trees, it can become hazardous for people who will be in the area in the future.

The NTSB database contained 79 accidents and incidents that occurred during logging operations from 1983 to 2019. A technical failure resulting from insufficient maintenance or material fatigue and the subsequent forced landing in unsuitable terrain occurred in half of the cases. Inaccurate fuel calculations and insufficient flight preparation occurred in eight cases. Human factor such as inattention, mismanagement, or misestimation of obstacle location occurred in fifteen cases. Load and obstacle collision was identified in thirteen cases and disconnection of the rope / load dropping occurred three times. Third-party errors were mentioned three times and downwash and its consequences occurred in one report.

In addition, there were 31 accident reports from construction and assembly flights during 1983 and 2020 and 15 reports for flights with other external loads (1992-2020). The most common was a forced landing in unsuitable terrain, which was mainly caused by technological or human factor failure. The second most frequently mentioned risk factor was collision of the load-bearing rope / load with an obstacle, resp. fall of the burden. Other frequent risks included insufficient fixation or uncontrolled rotation of the load, falling parts or collision of the tow rope with tail rotor. Risks that have been identified are summarized in Table 7.

4.2.4. Photographic and film flights

According to NTSB reports, from 1988 to 2018, 27 accidents or incidents occurred during photographic or film flights. The most common factor in the accidents was the pilot's risky behavior to achieve the desired shot, whether by flying near the photographed objects, putting the helicopter in an inappropriate flight mode, or continuing the flight despite adverse weather conditions. Flights in excessive proximity to terrain, whether mountains or water, and resulting risks occurred as the second most frequent accident contributing factor. Improper arrangement of objects in the cabin, exceeding the weight and balance limits, or even accidentally dropping passengers during open door flights occurred in five cases. Landings in unsuitable terrain or forced landings in populated areas were mentioned four times. The risks are assessed in table 8.

4.2.5. Adventure flights

Adventure flights have recently become a popular activity offered on the internet. Offers include sightseeing flights, aerobatic flights or even offers for enthusiasts to try piloting the aircraft. The passenger is usually a layman who may have never experienced the forces of helicopter flight or has never flown even in an airliner. The passenger is also not subject to medical examination, which may result in the various risks listed in Table 9. 107 accidents and incidents from 1983 to 2021 related to adventure flights were found in the NTSB database. The most common risk factor was pilot's risky behavior to meet the often-inappropriate requirements of passengers. This usually involved flying outside the helicopter's flight envelope at a low altitude and near terrain or doing abrupt maneuvers. In several cases, kinetosis (motion sickness) also occurred in the pilots, which had serious consequences in two cases. Unintentional interference with controls by an unqualified passenger during difficult maneuvers may have catastrophic consequences, especially in cases when the pilot is unaware of such situation. However, none of the 107 accidents mentioned such event, so we can assess the probability of occurrence as unlikely.

4.2.6. Helicopter firefighting

Helicopters are mainly used to extinguish fires in inaccessible mountain and forest terrain, which poses many risks. Between 1996 and 2021, the NTSB database contained 39 reports of accidents and incidents that occurred during flights with a bambi bucket, which is used to bring water to the affected areas. According to the reports, the most common risk factor was a technical failure, which was caused not only by improper maintenance by corrosion or material fatigue, but also by the bag or helicopter colliding with trees, suction of tree parts and other foreign objects into the engine, failure of bucket rope system or tangling of rope to the undercarriage, which shifted the helicopter's center of gravity outside of set limits. Encounter with the water surface when filling the bucket was also mentioned, or a technical failure directly above the water surface. It is necessary to operate the helicopter with an external load within the permitted weight and balance values, considering the meteorological conditions in the area. The pilot must also not forget to maintain the safety distance of the main or tail rotor from obstacles in densely forested areas when trying to correctly place the water bucket between the trees. Reduced visibility due to smoke and consequent loss of spatial orientation was a factor in ten cases, and the impact of high temperatures on the helicopter's performance was mentioned in 5 reports. Assessed risks can be found in Table 10.

5. MITIGATION MEASURES PROPOSAL

Risk mitigation measures are actions or changes, for example in the organization's operating procedures, equipment or infrastructure that reduce the likelihood and / or severity of the risk.

5.1. Pipeline inspection

In an event of time-related stress during pre-flight preparation and possible incomplete planning, the operator shall ensure that crew has sufficient time for pre-flight preparation. The operator shall ensure that no task is scheduled in which the maximum total mass of the helicopter is exceeded in relation to the altitude density at the mission location.

Pilot busy with other tasks, distracted from proper operation of the helicopter – the proposed measure is to assign a multi-member crew to the task, so that the pilot can focus on the proper operation of the helicopter.

Technical problems – the pilot will ensure that all maintenance irregularities are corrected before the flight and that the helicopter is airworthy. In a case of non-functional equipment, check that it is not included in the approved minimum equipment list.

Degradation of helicopter performance, failure to ensure adequate power reserve, loss of control – to avoid failure to ensure adequate power reserve due to lack of pilot's attention, a multi-member crew assigned to the task should reduce this probability. Should performance degradation occur due to a sudden change in wind speed or direction, it is necessary to define the necessary power reserves for operators in different weather conditions. Operations should stop when wind gusts exceed the specified limit, or at lower values at pilot discretion. It is necessary to create a company environment in which pilots would not be afraid to end the task prematurely in the interest of safety. The customer must also be familiar with and understand the importance of maintaining safety.

Unintentional flight into bad weather – operation should cease when the cloud ceiling or visibility values are below the minimum specified values for the pilot performing the task, helicopter, or the company. To reduce the likelihood of terrain collision after entering IMC conditions, the company should consider installing radio altimeters to helicopters.

TABLE V. RESIDUAL RISK LEVEL DURING PIPELINE INSPECTIONS

Risk	Probability	Severity	Risk level	Adjusted probability	Severity	Residual risk level
Time stress, incomplete planning	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Pilot distracted from proper operation of helicopter	Occasional	Hazardous	Intolerable	Unlikely	Hazardous	Tolerable
Technical issues	Remote	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable
Degradation of helicopter performance	Occasional	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable
Unintentional entry into bad weather	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Inaccurate / missing weather information	Remote	Hazardous	Tolerable	Unlikely	Hazardous	Tolerable
Violation of safety distances	Remote	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable
Unintentional deviation from route	Remote	Major	Tolerable	Unlikely	Major	Acceptable

Inaccurate / missing weather information – although the level of risk has been determined to be acceptable, it is necessary to ensure that pilots have all available weather data on the route and at the mission location during pre-flight preparation. The operator should ensure the availability of such data. However, weather forecast data is not always completely accurate, so the risk of inaccurate data cannot be eliminated completely.

Violation of safety distance from obstacles – the pilot should be familiar with the terrain characteristics of the pipeline area he surveys (rising terrain, etc.). Installing a radio altimeter in a helicopter can also be beneficial.

Unintentional deviation from the planned route – the level of risk was determined to be permissible, but to reduce the probability of an event, the flight path could be entered into the on-board navigation GPS system, if the helicopter has such a system. This would allow the pilot to be able to quickly check any deviation from the planned flight route.

5.2. High voltage power line inspection

Collision with obstacles – to mitigate the consequences, the use of a helmet with goggles, leather gloves, boots and fireproof clothing is proposed, as well as mandatory use of seat belts and other available protective equipment. To reduce the likelihood of an obstacle encounter occurrence, the pilot should inform all crew members to be vigilant and to monitor for any obstacles around the helicopter. A more expensive but beneficial measure could be to install a wire strike protection system.

Emergency landing into unsuitable terrain – the proposed measure to reduce the likelihood is active involvement of all crew members in emergency situations, such as vigilance and monitoring of any obstacles and objects that could endanger the safety of the crew.

Degradation of helicopter performance – proposed measures include the use of safety procedures, such as autorotation landings. To avoid degradation of performance due to pilot lack of attention or a sudden change in wind speed / direction, it is necessary to define the necessary power reserves that must be maintained. Operation will stop when wind gusts exceed the specified limit, or at lower value at pilot discretion. To prevent degradation due to a technical failure, the pilot must check that the helicopter has no maintenance irregularities before the flight.

Unfamiliarity with power lines being controlled – the proposed measure here is inclusion of power line maps in the pre-flight preparation and pre-flight briefings with employees of the distribution company.

TABLE VI. RESIDUAL RISK LEVEL DURING POWER LINE INSPECTIONS

Risk	Probability	Severity	Risk level	Adjusted probability	Adjusted severity	Residual risk level
Collision with obstacles	Occasional	Catastrophic	Intolerable	Remote	Hazardous	Tolerable
Emergency landing into terrain	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Degradation of helicopter performance	Occasional	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable
Unfamiliarity with power line systems	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable

5.3. Aerial transport of external cargo

Forced landing in unsuitable terrain – it is recommended to use a helmet and protective suit to mitigate the possible consequences. Another proposed action is to inform all crew members of emergency landing procedures and alert them to actively monitor any obstacles around the helicopter, such as trees, towers, or power lines. Before mission start, it is necessary to determine a suitable place for landing and a suitable area for possible dropping of external cargo in an event of emergency.

Downwash – the proposed measure here is alerting the ground crew of the event possibility, requiring wearing of protective clothing, helmets and goggles by ground personnel, and warning them to secure any loose objects in the area under the helicopter.

Electrostatic charge from the suspension – the employer should ensure that its employees adhere to safety principles and are regularly trained and encouraged to exercise caution when handling the suspension. Before lifting or unloading the cargo, the electrostatic charge must be discharged from the helicopter, load, or load lifting device by ensuring that the helicopter or load lifting device is in contact with the ground or that the load is gripped with a sufficiently grounded hook.

Load contact with obstacles, load falling, cargo damage – PIC should carefully examine the maps and / or conduct a flight survey of the area at safe altitude during pre-flight preparation to identify all obstacles and possible flight hazards. The pilot must also ensure that the rope is long enough to maintain a safety distance from obstacles when attaching / disconnecting the load.

Rope contact with tail rotor – this event can occur if the rope is unloaded and towed behind the helicopter. Setting the maximum permitted helicopter speed when flying with an unloaded rope is proposed, so that at high speed no excessive drag on the rope is created, which would reduce the distance between the rope and the tail rotor. In addition to the speed of the helicopter, the direction and strength of the wind should be considered, so that the the operation with an unloaded rope is safe.

Dangerous external cargo spinning – some loads tend to rotate during the flight, which can lead to damage to the rope and excessive stress on the primary hook or its attachment to the helicopter. This can lead to unintentional release of the load. The proposed measure is the installation of a rotating device in the helicopter suspension system for loads that are known to tend to rotate during flight, and for all loads whose flight characteristics are not known.

Falling fragments, danger to third parties – all persons working near the helicopter must wear hearing protection in addition to protective clothing, and it is also appropriate to wear a vest or high visibility clothing. The pilot shall ensure that the aircraft is operated at an altitude which, in the event of a failure of the critical helicopter system, will allow an emergency landing without undue danger to persons or property on ground. If cargo is damaged during transport and debris falls from the cargo, the cargo must be disconnected at a suitable place immediately.

Insufficient load securing – the ground staff employer should be checked by the customer to ensure that only the appropriate material and procedures are used to secure the cargo. The aerial work provider should appoint a person to oversee the appropriate securing of cargo from the ground. The load capacity of the attachment device must correspond to the weight of the load.

Before starting the task, the pilot will make sure that the appropriate type of helicopter and carrying ropes, hooks or other special equipment are used for the task. Prior to take-off, the pilot shall ensure that the hooks and ropes are properly attached and secured to the helicopter and that the rope is not accidentally tangled in any part of the landing gear. During the pre-flight briefing, the pilot shall inform the ground staff of the emergency procedures, communications, and measures to be taken by the staff in an event of an emergency.

TABLE VII. RESIDUAL RISK LEVEL DURING EXTERNAL CARGO TRANSPORT

Risk	Probability	Severity	Risk level	Adjusted probability	Adjusted severity	Residual risk level
Emergency landing into terrain	Frequent	Catastrophic	Intolerable	Remote	Hazardous	Tolerable
Downwash	Occasional	Major	Intolerable	Remote	Major	Tolerable
Electrostatic discharge from suspension	Remote	Major	Tolerable	Remote	Major	Tolerable
Load contact with obstacles / load falling	Frequent	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Load-bearing rope collision with obstacles	Frequent	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Contact of rope with tail rotor	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
External cargo spinning	Occasional	Hazardous	Intolerable	Unlikely	Hazardous	Tolerable
External load damage	Occasional	Major	Intolerable	Remote	Major	Tolerable
Falling fragments, danger to third parties	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Insufficient load securing	Occasional	Hazardous	Intolerable	Unlikely	Hazardous	Tolerable

5.4. Photographic and film flights

Take-offs and landings on uneven terrain – the PIC will check that there are no hazards such as power lines or other obstacles near the approach or departure routes of the landing / take-off area.

Flights in excessive proximity to terrain obstacles – in all circumstances, the safe height above the terrain and obstacles must be maintained and the pilot must take care to maintain an adequate power reserve. Installing a radio altimeter could help prevent the helicopter from descending below a set level. To mitigate the effects of an accident in mountainous terrain, all crew members should wear a helmet, be properly bucked up and have survival equipment and an ELT emergency transmitter on board.

Inadequate demands from filming personnel, inappropriate helicopter operation and risk-taking to achieve a desired shot – during pre-flight training, pilots shall inform photographers / filmmakers of the importance of safe helicopter operation. The film staff and the pilot must agree on the activities they plan to take and the shots they plan to achieve before the flight. Prior to assigning the task, the pilot must be checked by the operator that none of the contributing factors in his previous incidents was incorrect decision-making or excessive self-confidence. If it is the case, another pilot must be assigned to the task.

Improper arrangement of objects in the cabin, the possibility of objects falling out during flight without doors – proposed measure is a mandatory securing of all loose objects or film equipment inside the helicopter. All internal cargo must be secured in the cabin so that crew members and other passengers cannot be endangered or injured during normal flight operations or emergency landings. Any object taken into the helicopter cabin must be adequately secured against unintentional movement. The position of the center of gravity with the load on board and the calculations of the fastening forces must be calculated according to the requirements of the helicopter flight manual and must allow safe operation. During doors-off flights, the door must be properly secured or removed. Flying with the door open is only permitted if described in the flight manual.

Technical failure during flights above populated areas – the pilot will ensure that all maintenance irregularities are corrected before the flight and that the aircraft is airworthy. Pilot will also check that the required equipment is in working order and that any non-functional equipment is not included in the minimum equipment list. The pilot shall ensure that he / she always flies at a sufficient height above the populated areas in order to be able to land the helicopter safely if any failure should occur.

TABLE VIII. RESIDUAL RISK LEVEL DURING PHOTOGRAPHIC FLIGHTS

Risk	Probability	Severity	Risk level	Adjusted probability	Adjusted severity	Residual risk level
Take-offs and landings on uneven terrain	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Excessive proximity to obstacles	Occasional	Catastrophic	Intolerable	Remote	Hazardous	Tolerable
Inadequate filming demands and risk-taking	Frequent	Hazardous	Intolerable	Remote	Hazardous	Tolerable
Improper cabin object arrangement, objects falling out	Occasional	Major	Intolerable	Remote	Major	Tolerable
Technical failure above populated areas	Occasional	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable

5.5. Adventure flights

In an event of pilot kinetosis, the operator shall ensure that the pilot performing the task is in a satisfactory physical condition and has not experienced nausea during maneuver performing in the past.

Danger to third parties on the ground (possibility of damage to health or property) – when performing aerobatic maneuvers, it is necessary to select a suitable area under the helicopter, where no people or property on the ground that could be damaged are present should the helicopter become uncontrolled. Only a pilot who has sufficient experience with the maneuvers should be assigned to the task by the operator.

Unintentional interference to flight controls from an unskilled passenger during difficult maneuvers – for helicopters with dual control, it is necessary to explain the principles of controls during pre-flight briefing with passengers and emphasize dangers of potential interference of the passenger. For helicopters with more passenger seats, it is recommended to seat passengers primarily at the rear of the aircraft.

Risky pilot behavior to meet inadequate passenger requirements – the operator shall ensure that the pilot selected for the task has not had an incident in the past, where the risk factor was poor decision-making, excessive confidence or risk-taking.

TABLE IX. RESIDUAL RISK LEVEL DURING ADVENTURE FLIGHTS

Risk	Probability	Severity	Risk level	Adjusted probability	Severity	Residual risk level
Pilot kinetosis	Occasional	Major	Intolerable	Unlikely	Major	Acceptable
Passenger kinetosis, fear of flying and heights	Remote	Negligible	Acceptable	Remote	Negligible	Acceptable
Danger to third parties	Occasional	Major	Intolerable	Remote	Major	Tolerable
Interference of unqualified passenger	Unlikely	Catastrophic	Tolerable	Extremely unlikely	Catastrophic	Tolerable
Risky pilot behavior	Occasional	Catastrophic	Intolerable	Unlikely	Catastrophic	Tolerable

5.6. Helicopter firefighting

Technical failure during flight over the affected area – before the flight, the pilot must check that the helicopter has no maintenance irregularities, and all the necessary equipment is in working order. To mitigate the consequences of risk, the pilot must wear a protective suit with fire-resistant material, a helmet and leather gloves. If any possible problems are observed with the handling of the bambi bucket, they should be reported to the pilot by radio immediately. The crew must identify safety zones and potential escape routes near the fire or the burned area. However, special care must be taken when landing in burned areas to avoid exposure to excessive heat and the possibility of fuel ignition.

Reduced visibility due to smoke – the pilot must ensure maximum co-operation of the crew in observing and reporting any obstacles, such as trees or power lines. Before approaching the fire area, it is necessary to check the airspace for other aircraft. Before descending to a low altitude, it is recommended to conduct a survey flight at a higher altitude above the obstacles to identify possible dangers.

High temperatures due to fire – the pilot must have altitude and temperature data at the point of intervention before the flight to ensure that the payload is within the allowable values and does not exceed the weight limits.

TABLE X. RESIDUAL RISK LEVEL DURING AERIAL FIREFIGHTING

Risk	Probability	Severity	Risk level	Adjusted probability	Adjusted severity	Residual risk level
Technical failure above affected areas	Frequent	Catastrophic	Intolerable	Remote	Hazardous	Tolerable
Reduced visibility due to smoke	Occasional	Hazardous	Intolerable	Remote	Hazardous	Tolerable
High temperatures due to fire	Remote	Hazardous	Tolerable	Remote	Major	Tolerable

6. CONCLUSION

The aim of the paper was to identify hazards and determine risks that could occur during aerial work performed by helicopters, to evaluate the risks and propose measures to bring them to an acceptable level. This paper dealt with six different types of aerial work in which different risks were found. Subsequently, corrective measures were proposed for situations with an unacceptable level of risk to bring them to the minimum acceptable level of risk, which was successful for each defined event.

Tens or even hundreds of risks could be potentially found for individual types of work, but only a few of them were identified for each type. Estimation or evaluation of probability or severity of the risk involved may depend on the personal experience and sensitivity of the assessor. Therefore, due to lack of experience, the probability of occurrence was based on the NTSB accident database, but it also has its limits. For some activities, only a few accident reports were available, but dozens or hundreds for others, which significantly distorted the probability of occurrence. However, some helicopter aviation activities are more widespread than others. The probability could be better determined if, for example, the numbers of flights performing the activities were available and they could then be compared with the number of incidents and accidents. Additional measures could be proposed when proposing mitigation measures, but these would require more experience in the field and would be more time consuming. Findings suggest that a complete risk elimination is not possible. The human factor remains the most common risk factor in air accidents and incidents, but human cannot be completely removed from the process. A more suitable term in this case is mitigation.

ACKNOWLEDGMENT

This work was supported under the project of Operational Programme Integrated Infrastructure: "Research and development of contactless methods for obtaining geospatial data for forest monitoring to improve forest management and enhance forest protection", ITMS code 313011V465. The project is co-funding by European Regional Development Fund.

REFERENCES

[1] TRANSPORT AUTHORITY. Certificate holders – aerial work SK | Civil aviation. [online] Available at: http://letectvo.nsat.sk/letova-prevadzka/osvedcenie-letovej-sposobilosti/formulare/drzitelia-osvedcenia-sk/.

[2] Act no. 143/1998 Coll. §44. [online] Available at: https://www.zakonypreludi.sk/zz/1998-143.

[3] SNYDER, R.L. AND PAULO, J. (2005). Frost protection. Volume 1. [online] Rome: Food and Agriculture Organization of the United Nations. ISBN: 92-5-105328-6. Available at: https://www.fao.org/3/y7223e/y7223e.pdf.

[4] INTERNATIONAL CIVIL AVIATION ORGANIZATION (2018). Doc 9859, Safety management manual. Fourth edition. [online] Montréal, Quebec, Canada: International Civil Aviation Organization. ISBN: 978-92-9258-552-5. Available at: https://skybrary.aero/sites/default/files/bookshelf/5863.pdf.

[5] NÆVESTAD, T.-O., BYE, R.J., ANTONSEN, S., BERGE, S.H., HESJEVOLL, I.S. AND ELVEBAKK, B. (2021). Examining the most accident-prone sector within commercial aviation: Why do accidents with light inland helicopters occur, and how can we improve safety? Safety Science, 139, p.105235.

[6] FAA.GOV (2021). FAA Aviation Safety Information Analysis and Sharing (ASIAS). NTSB Aviation Accident and Incident Data System (NTSB). [online] faa.gov. Available at: https://www.asias.faa.gov.

[7] NOVÁK SEDLÁČKOVÁ, A., PITOR, J., MRÁZOVÁ, M. 2015. Crisis management in aviation. 1. vyd. - Bratislava : DOLIS, 2015. - 152 s., ilustr. - ISBN 978-80-8181-000-8.

[8] GALIERIKOVA, A., MATERNA, M., SOSEDOVA, J. 2018. Analysis of risks in aviation. Transport Means - Proceedings of the International Conference, 2018, 2018-October, pp. 1427–1431

https://doi.org/10.26552/ pas.Z.2022.2.24

AIRCRAFT RECYCLING SYSTEM OPTIMALIZATION AND AIRCRAFT SECTIONS RE-USE POSSIBILITIES AFTER THE END OF THEIR ECONOMIC LIFE

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Abstract

Purpose of this article is to evaluate re-use of sections from retired aicraft for further usage and additional optimalization of recycling and re-use of materials used in aircraft construction. With hundreds of commercial airplanes retired every year, the need for innovative approaches in recycling process rises. The concept of re-using parts from retired aircraft is not new. Before scrapping, valuable parts are of course stripped of the airplane. The article assesses if there is possibility to re-use parts and sections that usually end up scrapped in aviation and under which circumstances. Its first part is focused on analysis of procedures currently utilized during aircraft recycling, including brief description of decomissioning process, current state aircraft recycling in general, processes of disassembly and dismantle, existing facilities, description of recycling of alloys and composite materials. Second part deals with legislative, technical and environmental options of aircraft recycling and re-using aircraft sections. Third part focuses describes current parts market, together with proposal how to make it more efficient, current and possible future trends concerning aircraft recycling and re-use of materials and comparison of recycling between USA and Europe

Keywords

Aircraft recycling, Parts reclamation, Aerospace industry, Composites, Optimalization of recycling

1. INTRODUCTION

Airplanes are rightfully considered one of the most technologically impressive inventions designed by man. In over a century of existence, they have gone through many evolutionary stages. Far less emphasis has been placed on issues relating to the handling of end of life aircraft. These often ended up abandoned at remote airfields. It was not until the advent of the new millennium, when it became apparent that alternative uses would be found for the materials used in their construction and the recycling of aircraft on an industrial scale began to be discussed. This article will describe the current recycling issues, its advantages and obstacles. In addition, it will also deal with the situation in the used parts market, but also with the issue of recycling composite structures, which are increasingly serving as a substitute for aluminium alloys and presenting new challenges in the sector. It will also outline possible alternatives for the reuse of units that have not yet reached the end of their technical life and ideas for streamlining some of the processes on the market. It is divided into three chapters. The first is an introduction to the subject, containing factors leading to scrapping, a description of dismantling and disassembly, the situation with parts, equipment and an approach to recycling the most commonly used materials. The second chapter deals with legislation and recommendations related to the processes, addresses the environmental impact of aircraft recycling and presents solution of the use of decommissioned machines in the armed forces as a possible model for civil aviation. The third describes the sale of used parts with ideas for further improvement, future trends in the use of recycled materials, and comparisons aircraft recycling between the US and Europe.

2. ANALYSIS OF PROCESSES THAT ARE CURRENTLY USED IN AIRCRAFT RECYCLATION

This chapter describes the methods currently used to recycle aircraft parts and assemblies. Every year, hundreds of transport aircraft are retired by operators around the world as they reach the end of their technical service life or it is no longer economically viable to operate them. According to the International Air Transport Association (IATA), the average age of transport aircraft at the time of retirement is 27 years. Given the constant growth in air traffic in the years prior to the outbreak of the COVID-19 pandemic, it is estimated that the number of retired aircraft will increase in the coming years. A small proportion are being converted to carry cargo after retirement by passenger carriers, with subsequent operation by freight carriers. Most of them, however, are decommissioned and gradually dismantled by specialized firms. In today's world, the emphasis on recycling is considerable in all sectors and will grow in the future. The concept of recycling in the aerospace industry is a relatively new, it began to emerge in a larger degree at the turn of the millennium, in connection with the activity of the world's largest commercial transport aircraft manufacturers at the time, Airbus and Boeing. The aim was to prevent the trend of aircraft languishing at various airports after being retired and stripped of usable parts. The European company Airbus founded the Process for Advanced Management of End of Life Aircraft (PAMELA) project, while the American Boeing came up with AFRA - Aircraft Fleet Recycling Association - in 2005. AFRA, which includes aircraft manufacturers such as Boeing and Embraer, engine manufacturers such as Rolls-Royce, as well as companies specialising in aircraft disassembly and parts distribution, recycling companies, leasing companies and research and development centres, has published a series of guidelines known as BMPs, which have become the industry standard in the United States and Europe. Companies specializing in dismantling and recycling that are certified according to them are considered a reliable source of quality parts. The Association provides the procedures and tools necessary to increase the economic return on scrapped aircraft and contributes to the further expansion of recycling by making it an attractive option for a greater number of operators who, until recently, have preferred to simply park scrapped aircraft in desert areas. Its European equivalent, the PAMELA is supported by the European Commission. The aim at its inception in 2005 was to demonstrate that a greater proportion of scrapped aircraft are recyclable than the previously stated 50%. As part of the experiment, Airbus carried out a complete disassembly and recycling of an Airbus A300 transport aircraft, proving that up to 85% of the total weight of the machine could be reused or recycled. Less emphasis was placed on the quality and purity of the material recovered, but according to Airbus, most of the recovered material and parts could be reused in the aerospace sector.

2.1. Decomissioning, Disassembly, Dismantling

Operators usually take the decision to retire an aircraft when the machine is approaching the end of its service life. For commercial carriers, this is usually divided into technical and economic. Technical service life is determined by the manufacturer on the basis of fatigue tests that are part of the type certification of a given type when it enters service. The economic lifetime is not defined. If the operator considers that it is more economically viable to acquire a new aircraft due to rising operating costs, and there is no interest in the market for a given aircraft, it will be retired. If the owner decides to sell it to an aircraft dismantling company, several options are possible, such as selling the entire aircraft in the condition it is in, at the location where it is located, which imposes minimal time and logistical requirements on the owner, with the dismantled parts already being the property of the new owner. A more time-consuming method is to disassemble higher value parts such as engines, auxiliary power units or landing gear, in-house with subsequent sale. If it has sufficient space, the company can decommission the aircraft and gradually dismantle the parts it installs in the remaining aircraft in its own fleet or for resale

Disassembly means the removal of components and parts that will subsequently be reused as spare parts on the aircraft. After removing the usable parts, the rest of the machine is dismantled. The main objective is to recover part of the money spent together with a positive environmental impact of the recycling process. This process must be carried out by an approved maintenance organisation. Parts dismantled by an organisation without the necessary approval cannot be used as spare parts. Airlines having their own MRO organisation, can handle the process independently. As mentioned above, parts must have records of their history, called logbooks, must be removed and subsequently stored in accordance with the regulations. Typically, the process involves the removal of engines, auxiliary power unit (APU), ram air turbine (RAT), avionics, flight control systems and engines, hydraulic systems, landing gear including wheels and brakes, pumps and electric motors.

At the start of dismantling, there are no parts in the machine that could be installed on another airworthy aircraft. The reuse of any parts is strictly prohibited. The process is not required to be carried out by an approved maintenance organisation. It will normally start after the aircraft has been removed from the aircraft register. Prepare Your Paper Before Styling

2.2. Current state of aircraft recycling

Recycling can be defined as the process of collecting, sorting and reprocessing used materials for further use. It therefore reduces the demand for extraction of natural resources, the energy consumed for it and prevents waste of resources. Its main objective in the manufacturing industry, which includes aerospace, is to save the environment by reducing greenhouse gas emissions, preventing water and soil pollution and, last but not least, contributing to the creation of employment opportunities. There is currently no legislation on procedures for dealing with end-of-life aircraft. Recycling is therefore voluntary. This probably has something to do with the relatively small number of aircraft involved until recently. The vast majority of recyclable components from aircraft are composed of valuable metals and alloys which, once recycled, become materials that can be reused. Nowadays, it is mainly metals that are recycled from aircraft, which are available in large quantities, while the less abundant ones end up as waste. The quality of recovered materials also varies, as the emphasis is on quick and inexpensive dismantling of the aircraft rather than on the separation of the individual materials. The alloys that are used in aircraft construction are aluminium, magnesium, nickel, cobalt, steel and titanium. Nickel and titanium alloys are mainly used in engine parts. Aluminium alloys clearly have the largest share.

2.2.1. Recycling of aluminium alloys

For decades, aluminium alloys have been used as the primary structural element of major aircraft parts, both military and civilian. Advantages include relatively light weight, combined with sufficient temperature resistance. Their manufacture is mastered, established and relatively inexpensive. Due to the not entirely advantageous properties of pure aluminium alloys, other elements such as copper, zinc, manganese, silicon and magnesium are commonly added. Of all the aluminium alloys, those used in aerospace have the highest volume of alloying and are the most expensive. Alloy grades 7000, 6000, 2000 and 5000 are used in aircraft, most commonly with the specific designations EN 7075, EN 6061, EN 6063, EN 2024 and EN 5052. It has been reported that, compared to the processing of raw material, the use of recycled aluminium alloys saves up to 90% of the energy otherwise spent on the electrolysis of liquid aluminium. The recycling of aluminium alloys begins with sorting based on piece size and grade composition. Pieces with a matching grade guarantee high purity of the resulting material, free of contaminants. These are crushed, melted and then formed into cast parts during refining. They are easier to mix during repeated melting. Laser spectrometry labeled LIBS is widely used in the recycling of large aircraft assemblies and components. It allows the elemental content of an alloy to be accurately classified and thus the specific designation of that alloy to be determined. It is not only used for aluminium alloys, it can reliably determine any type of alloy.

2.2.2. Recycling of titanium alloys

Titanium alloys are widely used in aerospace due to their high strength, good corrosion resistance and high heat resistance. Unlike other commonly used structural materials, the manufacturing process is complicated and lengthy, which also results in its higher cost. The titanium extraction process begins with its identification, classification, surface cleaning and separation from the residue. Depending on the composition of the individual alloys in relation to the elements added, these are then remelted and recycled. The most widely used titanium alloy in aerospace applications is Ti-6Al-4V, which has a high proportion of aluminium.

2.3. Issues with composite materials recycling

In recent years, there has been a significant increase in the use of composites in the construction of both civil and military aircraft. Their main advantage is weight reduction. Boeing has saved up to 20% percent of the weight of its 787 Dreamliner by replacing aluminium alloys with composites. Other advantages include their flexibility, reduced maintenance requirements, reduced number of parts, and they are not subject to corrosion and expansion at high temperatures. While the advantages of their use are obvious, the subject of their disposal or recycling presents new challenges for the industry. Of course, composites were also used in older aircraft, but with their proportion of the structure being around 10 to 15%, the issue of recycling was not as important. This will, of course, change in the future. Compared to previous materials, composite waste is already generated in the manufacturing process. Glass and carbon fibre are most commonly used in aircraft construction. Carbon/glass fibres and epoxy resins are the two main components of composites, which are present in the form of a pre-impregnated roll of material prior to the manufacturing process. In the past, this roll was cut by hand, resulting in a very low material recovery rate of only around 40%. With the use of automation, it has been possible to increase the accuracy considerably, as well as to reduce the time required for production. At the same time, today's automated trimming machines are able to mark the piece to facilitate identification at later stages of the process. These rolls have a specified lifetime in their raw state, beyond which they cannot be used again without a recertification process, which, however, further increases the cost of production. Despite advances in manufacturing, the proportion of used material relative to waste is still relatively high. As the use of composites grows, so will composite waste. As already indicated, recyclers face a major challenge in terms of cost and time efficient recycling of composites. There are currently a number of approaches to recycling composites.

2.3.1. Mechanical recycling

The simplest method is mechanical recycling. It can be used for almost all composite materials, but it is mainly used for glass fibres, its technology is well mastered and it is available at a relatively low initial cost. Pieces of materials are first cut or crushed to reduce them to a size of about 50-100 mm. These are then further reduced to dimensions on the order of tens of µm by high-speed shredders. After shrinking, they are separated by sieves into parts with a higher fibre content and parts with a higher resin content. In the case of glass fibre reinforced polymers, these fibres are crushed once more after sorting. These are already considered as raw materials which can be further used. No chemicals or high temperatures are required for mechanical recycling. Compared to newly produced fibres, recycled fibres have lower strength as well as weaker molecular bonds as a result of the fact that the fibres are broken. The reduction in mechanical properties, which can be in the range of 18-30 %, is a major obstacle to the use of recycled fibres. Recycled fibres are therefore only subsequently used in lower grades of composites.

2.3.2. Thermal recycling

Two thermal methods are used for material extraction. The first is the fluidized bed method. It also involves combustion, but allows the material to be extracted in the form of fibres, while the burning of the resin matrix produces energy from which heat or electricity can then be generated. It can be used with both glass and carbon fibres. Initially, the composite material is mechanically cut into smaller pieces, which are then used to fill the fluid bed reactor. The device heats up fresh air that needs to be brought in. Epoxy resins require 550 °C, while polyester resins require 450 °C. When heated to 450°C, glass fibres lose up to 50 % of their tensile strength, while carbon fibres resist even higher temperatures better. The hot air stream breaks down the matrix and separates the fibres, which are then separated from the matrix by a swirling motion. Heavier materials such as metal pieces cannot be separated by the hot air. The resin from the matrix completely oxidizes (burns), generating energy. The surface properties of recycled fibres can be similar to newly produced fibres, but their overall characteristics can lead to limitations in further use.

The second thermal method is pyrolysis, which takes place at temperatures between 350 and 800 °C, without the presence of oxygen, when the organic part of the composite material is broken down into smaller molecules by the supply of hot air. These are converted into a gaseous or liquid state. Inorganic parts such as fibres, fillers or possibly small carbon particles remain in the solid state. By oxidation of the incoming air, these particles are burned off, resulting in clean fibres and fillings. It can also be combined with incineration to remove residual materials.

2.3.3. Chemical recycling

In chemical recycling of composites, the matrix degradation is carried out using chemicals and solvents such as methanol, propanol, but also water and others. Fibres extracted by chemical recycling should retain most of their original mechanical properties. On the other hand, being quite energy intensive, any research in this area is likely to focus on this area, in order to increase the economic attractiveness of solvolysis, which is already a newer and thus not fully explored/adopted approach in the field of composites recycling. Current developments are focused on experiments with different substances used both as solutions and as catalysts.

3. LEGISLATIVE, TECHNICAL AND ENVIRONMENTAL OPTIONS OF AIRCRAFT RECYCLING AND RE-USING AIRCRAFT SECTIONS

The second chapter of the article deals with the possibilities of reuse of aircraft units. As mentioned in the previous chapter, a large number of parts and components can be used from a scrapped aircraft. However, after their disassembly, a large part of the aircraft remains in one piece. This is made up of recyclable material and waste. After dismantling, some of the planes are parked and languishes somewhere on the periphery of airports, some are dismantled in order to recover the materials used in the construction. The challenges already described in the recycling process prevent the possibility of these materials being reused in the construction of newly manufactured aircraft. A small part may be converted to other uses such as various attractions, museum exhibits, restaurants and so on. The re-use of aircraft assemblies from retired planes is virtually non-existent in commercial aviation.

3.1. *Examples of aircraft sections re-use from military aviation*

However, if the issue of reuse of units is examined not only from the perspective of commercial/civil aviation, but also from the military perspective, it becomes clear that practical cases already exist around the world. The military aviation sphere is not only not subject to civil aviation regulations, but may have its own specificities in each country. With the end of the Cold War, defence budgets declined significantly, which in the vast majority of countries at the time affected both the numbers of aircraft in service and the numbers of new ones being purchased. This situation essentially persisted until the annexation of the Ukrainian peninsula of Crimea by the Russian Federation in 2014. When the United States armed forces are taken into account, a large number of aircraft that had not yet reached the end of their service life were decommissioned and stored in this context, victims of budget cuts due to their advanced age or the fact that they represented older modifications. The US armed forces have a very efficient system for dealing with unused aircraft. Most are flown or ground-transported to Davis-Monthan Air Force Base, Arizona, home of the 309th Aircraft Maintenance and Regeneration Group. Upon arrival here, the aircraft are preserved and stored so that they can be returned to service if required, with approximately 25 % of the machines actually returning to service. About 300 aircraft are disposed of each year. Compared to civilian aircraft after the disassembly, a considerably higher degree of disassembly is visible here. In addition to the normally disassemblied engines, landing gear, instrumentation, control systems, etc., there are missing forward fuselage sections, cabin overlays, wings or tail control surfaces. This may be due in part to the need to remove sensitive military systems before scrapping and recycling, which is provided by contracted civilian firms. The main reason lies in the aforementioned reduction in defence budgets. In the new millennium, it was to replace the current generation of US aircraft such as the General Dynamics (now Lockheed Martin) F-16 Fighting Falcon, the McDonell Douglas (Boeing) F/A-18A/B/C/D Hornet, the Fairchild Republic A-10 Thunderbolt II and, in part, the McDonell Douglas (Boeing) F-15C/D Eagle, the Lockheed Martin F-35 Lighting II family of aircraft. For a number of reasons, this program has suffered from significant increases in development costs and unit price as well as significant delays. As a result, the decision was made to extend the service life of the in-service equipment. Given the interim nature of this solution, the logical requirement was to keep the cost as low as possible. This was to be achieved by utilising units from stored aircraft that had lower sorties and were stored and maintained in ideal desert conditions. It is usually conducted as part of scheduled maintenance and is carried out by the component's own maintenance units, with the removal of parts from parked aircraft being carried out by members of 309th Group. The project is considered a success, the savings in time and money when compared to newly manufactured parts are not insignificant.

From a technical perspective, a similar approach could be applied to the repair of damaged civil aircraft, for example. Of course, this would require considerable financial and labour effort, multiplied by the fact that commercial aircraft significantly outnumber the above-mentioned examples of military machines in terms of size, and thus the actual execution could be even more technically challenging, depending on the damage and the extent of repair required. In such a case, it would be up to the operator to assess whether it is more economically viable to scrap the machine or to attempt to repair it.

3.2. *Legislative aspects of recycling and used parts*

There is currently no binding, internationally recognised legislation that mandates aircraft to be dismantled and recycled after scrapping. It is logical to assume that any future regulations should be under the umbrella of ICAO, which is currently responsible for international coordination in the field of civil aviation. Although ICAO has recently put the aircraft retirement process and its challenges on its agenda, it also believes that the established so-called Industry Best Practices represent a better alternatives to regulations, either governmental or through ICAO. Nevertheless, it participates in the aircraft retirement process through the Standard and Recommended Practices (SARPs) contained in the Annexes. For example, the procedures contained in Annex 6 (aircraft operations), Annex 8 (aircraft airworthiness) or ICAO document 9760 (airworthiness manual) are important in terms of handling parts that will be reused. Other regulatory authorities involved in the retirement and dismantling of aircraft are national or regional environmental authorities and national/regional aviation authorities, represented by EASA in Europe and FAA in the United States. Their competence in the scrapping process mainly extends to the reuse of disassemblied parts. From a European Union perspective, it is important that the disassembly of the aircraft and the maintenance of the parts is carried out by a company certified by EASA as an approved maintenance organisation. The Agency has issued 5 regulations concerning maintenance organisations. All salvaged parts are subject to a regulation known as EASA Part M- Continuing airworthiness requirements, which is basically the requirements for maintaining the airworthiness of an aircraft, including all its parts and airframe assemblies. The next regulation is known as EASA Part 145 and relates directly to the performance of maintenance. It is the European standard for the certification of organisations providing design, manufacture, operation and maintenance of aircraft and their components. Although it falls under EASA, Part 145 is also aligned with FAA standards, so a company that is based in both the United States and Canada and is certified by the FAA as a maintenance center can also obtain Part 145 and improve its market position. In addition to the participation of the regulatory authorities, whose powers are mainly concentrated on the dismantling process, associations formed by companies in the industry, such as AFRA or IATA, are also involved in the retirement of aircraft. They are also involved in the dismantling process and the procedures set out by them are also recommended by regulatory bodies such as ICAO. IATA has developed guidance that guarantees operators and owners an economical, environmentally friendly scrapping of the aircraft that meets all legislative requirements. The document is entitled Best Practices for Aircraft Abandonment (BIPAD) It does not represent binding regulations. It is aimed at aircraft operators to give them a coherent picture and to motivate them to scrap the aircraft according to IATA procedures. Given that business and operating conditions differ from company to company and that the relevant laws also differ from country/region to country, it is not possible to create standard procedures that are applicable in every situation. The document is therefore mostly focused on general procedures, description of processes and information on applicable legislation. Another association is AFRA, which was created as an initiative of Boeing. Although it currently has dozens of members, there are no air carriers or regulators among them. It provides certification/accreditation to companies in the industry on a voluntary basis, which makes either mined parts or materials better priced. It is the leading international association in the recycling industry and the author of a document known as Best Management Practices, which is mainly aimed at companies specialising in aircraft dismantling, disassembly and recycling. It is appropriately complementing IATA's BIPAD, together they form an environmentally acceptable solution to aircraft scrapping.

4. DESIGN OF APPLICABLE SOLUTION FOR RECYCLED MATERIALS

4.1. Re-certified parts market

The current situation in the commercial aviation sector is marked by the ongoing COVID-19 pandemic and, more recently, the aggression of the Russian Federation against Ukraine, which has led to the announcement of trade sanctions by the European Union, the United States of America, Canada, Australia, New Zealand and Japan, with the civil aviation sector being one of the affected areas. Airbus and Boeing have already announced that they are suspending support for their products, including the supply of spare parts in the Russian Federation. Given the fact that these make up a large proportion of the country's civil transport aircraft, the decision will have consequences. Paradoxically, this may contribute to the growth of the used parts market, which Russian operators may seek to purchase through various intermediaries in the future. Any reciprocal action from the Russian side will have a limited effect, due to the fact that the Russian share of the global market is minimal, even negligible in the countries mentioned. However, at the time of writing, active fighting is still ongoing and negotiations between the involved parties are not yielding any practical results, so it is too early to draw any conclusions. In contrast, the impact of the COVID-19 pandemic on the sector is clear. Compared to its early days, it is easier to predict developments and operators can plan more effectively on this basis. Significant numbers of aircraft stored and subsequently dismantled have resulted in the market being flooded with large numbers of used parts. This, together with the low demand caused by the fact that the remaining aircraft were operated at a significantly lower level of activity, resulted in a significant drop in the value of the parts. The existence of the Internet has greatly simplified, accelerated, and globalized the parts sales process, while significantly reducing the possibility of an aircraft remaining grounded due to an unavailable parts. However, it is not possible to completely prevent the latter situation. New innovations in the way spare parts are procured could further reduce the likelihood of this phenomenon, which usually results in flight delays, cancellations or the need to lease a replacement aircraft. A potential solution could be to access the maintenance of selected used parts on the basis of a service contract with the parts owner. Similar contracts exist with parts manufacturers. In principle, this would work by the aircraft operator paying a monthly lump sum to the parts owner. In addition to the value of the part itself, this could also be based on the number of aircraft of a given model in the operator's fleet. In this case, the owner would have the parts ready in stock and they would be dispatched to the operator as soon as possible if needed. Such an approach is of course particularly suitable for airlines serving shorter routes or a defined region where the part can be delivered cheaply and quickly. Otherwise, the parts owner would probably have to operate a network of warehouses, but such a solution means high costs associated with transport, area and staff. A more cost-effective alternative would be a pool approach. This would consist of the owner providing the aircraft operator with a pool of spare parts that are immediately available. However, the monthly fees for this option will understandably be higher. The other option is an exchange in the sense that the spare parts supplier sends the operator a new or repaired part, the operator sends the non-functioning part to be repaired at the operator's expense in a shop. If the part is irreparably damaged or has reached the end of its manufacturer's service life, it must be destroyed in accordance with the regulations. Some parts may continue to be used for non-flight activities, e.g. as teaching aids in the training process of personnel, whether flight or ground. In this case, the part must be visibly damaged e.g. notched, marked 'non-serviceable' and/or distinctively colour coded to prevent its intentional or unintentional reuse on an active aircraft, as this constitutes a major flight safety violation.

4.2. Trends in aircraft recycling and future development

Currently, the concept of the so-called circular economy, an alternative to the traditional economy, is gaining prominence in various industries. It places great emphasis on minimising waste and preserving the long-term value of materials. This approach is driven by resource constraints, pollution, production limits, etc., which have made the original 'take, make, dispose' approach unsustainable. Used products quickly lose most of their value and end up as waste in landfills or simply abandoned in various places. Given that aircraft are built from expensive and high quality materials, they should be at the forefront of interest. While aircraft recycling is still a relatively new process, building parts and components for the aerospace industry from recycled materials is currently virtually non-existent. The challenges of the recycling process that cause this have already been described and are mainly related to the quality of the recovered materials. However, these materials can be used in other areas and sectors. In the future, it is expected that there will be a cost-effective separation of individual alloy layers and materials during recycling, which could allow aluminium alloys to be reused in the aircraft structure for less critical parts with lower or medium loads, such as flaps. Recycled plastics have degraded properties compared to newly produced ones, which limits their further use and understandably prevents reuse in the aerospace sector. At the same time, it should be added that the plastic components used on aircraft, especially in the interior, are not very critical from the point of view of flight safety, and therefore recycled materials may be used in the future. The reuse of composite materials faces similar challenges as plastics. For both, waste is already generated during the production process. Carbon fibre is increasing in aircraft construction at the expense of aluminium alloys, where both the manufacturing process (no waste) and the recycling issue are better managed. Uses are mainly sought for carbon/glass fibres as the resin is removed in the recycling process. There is currently little interest in recycled glass fibres and their price is low, so it is not economically viable to recycle them. With carbon fibres the situation is different. Because they are cut into smaller pieces when recycled, they cannot be reused to produce products of comparable quality to those made from non-recycled materials, and the situation is very similar to the recycling of plastics. Today, recycled fibres can be used, for example, as reinforcement in concrete structures. Another trend for the future may be the use of recycled carbon fibres as body parts on cars. Carbon fibres have been used in cars for a long time both in the interior and exterior due to their lighter weight and their distinctive appearance. In the more distant future, it can be expected that a high emphasis will already be placed on the recoverability and usability of materials at the end of a flying career in the development of new generations of aircraft. Manufacturers could opt for materials that are more easily recyclable. Such an approach could be key in addressing current recycling issues such as the quality of materials and the economic efficiency of the process. The activity of the current giants in the transport aircraft market, Boeing and Airbus, has already been described and is expected to grow further in the future.

4.3. Analysis of the current state of aircraft recycling in North America and Europe

When comparing aircraft recycling, the focus will be on the regions of Europe and North America, given their dominant position in the aircraft recycling industry. In the future, with the further development of air transport, we can expect a wider involvement of companies based in powerful Asian economies such as India, Japan, South Korea or China. The latter has considerable potential, not only in terms of the number of aircraft operated and the workforce, but also thanks to its domestic transport aircraft programme, which can be expected to expand considerably once development problems have been overcome.

4.3.1. Locations

Natural conditions are one of the important factors primarily in storage and dismantling, but also in disassembly. The aim is to keep the humidity and the salt content of the air as low as possible in order to reduce the formation of corrosion. In this respect, the United States has a clear advantage, thanks to the dry desert areas in the south-west of the country, such as the states of Arizona and California. Western Europe, where the entire European aircraft recycling system is concentrated, is characterised by a wetter climate thanks to the Gulf Stream. In this respect, Spain has the most ideal conditions in the region.

Indeed, in the United States, the greater part of the facilities are located at airports in these areas. In Arizona there is the aforementioned Davis-Monthan military base, as well as Phoenix Airport, Kingman Airport and Marana Airport. Compared to the rest of the world, this is a significant concentration of these specialised facilities in a relatively small area, which is both an indication of ideal conditions and of an established and proven system. In California, there are San Bernardino, Mojave and Victorville airports. Las Vegas Airport in Nevada and Roswell Airport in New Mexico are also located in these convenient conditions. In the state of Texas, in the south of the country, there is Hondo Airport. A relatively large part of the industry, is located in the state of Florida in the south-east of the country which has the less suitable conditions,. The level of precipitation is relatively high, and Florida is also a peninsula, so the small distance from the sea guarantees a higher level of salt in the air. In addition, the area is one of those with a higher risk of hurricanes. Although these can be predicted fairly well, the problem lies in the fact that aircraft that are unable to fly cannot be evacuated in time. The choice of this location can probably be justified by the large number of aircraft operating in the area, which the companies want to satisfy. Airports in the area include Miami, Fort Lauderdale and Wellington. North of Florida in the state of Arkansas are the Blytheville and Stuttgart airports, and there is a larger facility at the Memphis, Tennessee airport. Although Canada is the largest country in the North American region by area, the challenging natural conditions, the short distance from southern Canada where the majority of the population is concentrated to the US have meant that there is a significantly smaller market for aircraft recycling in the country. The main centre is located at the Montreal airport.

As mentioned, Spain has the most suitable conditions in Europe, with Zaragoza, Valencia, Teruel and Madrid airports, used as dismantling facilities are located. However, the United Kingdom ranks first in terms of the number of companies and facilities in the area. As an island with high levels of rainfall, it has less suitable conditions. Airfields used include the Cotswold, St Athan, Caerphilly, Birmingham, Norwich or Barry. The remaining European airports are located in Ireland (Dublin), France (Tarbes, Chateauroux), the Netherlands (Enschede) and Germany (Hamburg).

4.3.2. Existing companies

There are dozens of companies in both regions involved in the handling of scrapped aircraft, whether in the form of dismantling, disassembly or the sale of spare parts. Each usually has a large area allowing the aircraft to be parked for long periods at one of the less frequented airports, staff and the necessary equipment; if the company disassembly and then sells certified parts, it must have suitable storage facilities. Most of these companies are located in two countries, namely the United States of America and the United Kingdom. For example, Kingman Aviation Parts (disassembly and parts sales) and Kingman Airline Services (MRO, disassembly) are located at Kingman Airport, Ascent Aviation Services (MRO, both disassembly and teardown), Jet Yard Solutions (storage, disassembly and teardown and recycling) are located at Marana Airport in Arizona. In California, First Class MRO (storage, disassembly), Aircraft Recycling Corporation, and ComAv Technical Services (both disassembly, recycling) are located at the Victorville Airport. The Las Vegas airport in Nevada is home to Scroggins Aviation, which, in addition to its traditional activities of storage and dismantling, also provides props for the film industry and benefits from its convenient location. General Airframe Support (both aircraft and powerplant storage and disassembly) is based at Roswell Airport in New Mexico.Hondo Aerospace and the propulsion-only firms BP Aerospace and Conescus Aerospace are also based in Texas. Others are GA Telesis at the Fort Lauderdale airport and AerSale, which is one of the largest firms in the industry. Both are located in the state of Florida and are MRO organizations, but are also involved in disassembly and parts sales. ADI- Aircraft Demolition and Recycling at Wellington Airport (disassembly and recycling) and MD-Turbines in Miami, which is a powerplant disassembly company, are also based here. Blytheville and Stuttgart airports in Arkansas are home to Aviation Repair Technologies (MRO, dismantling storage) and Cavu Aerospace (maintenance, both dismantling and disassembly), respectively. In Canada, Aerocycle, based at the Montreal airport, is the only Canadian company with accreditation from both AFRA and ASA. However, a local aircraft manufacturer, Bombardier, is also involved in disassembly and recycling.

In Spain, at Zaragoza Airport, there is a company called Aviation International Recycling, which dismantles and recycles aircraft. Others are Jet Aircraft Services in Madrid, which is an MRO organisation, also offering both dismantling and recycling services, MAGMA in Valencia, which does not have a narrow specialism in aircraft directly but is focused on the wider industry. Teruel Airport is the largest aircraft storage facility in Europe, some of which is dismantled and recycled here. It is operated by Tarmac Aerosave. In the UK there is Air Salvage International (Cotswold Airport), which dismantles, disassembles and recycles aircraft; eCube Solutions at St Athan Airport in Wales, which disassembles, disassembles and recycles aircraft; AerFin at Caerphilly Airport, which is in the leasing business but also disassembles engines; and STS Aviation Services UK at Birmingham Airport, whose portfolio includes dismantling, disassembly and recycling, Orange Aero Limited, which disassembles and recycles power units, KLM UK Engineering, which is a maintenance organisation at Norwich Airport, where it also disassembles, dismantles and recycles aircraft, or GJD Services at Barry Airport (disassembly, disassembly and recycling of both aircraft and engines). In neighbouring Ireland, EirTrade Aviation Ireland Limited is based at Dublin Airport and dismantles and disassembles aircraft. It is best known for its scrapping of Air France's A380 aircraft. In France, there are Tarmac Aerosave at Tarbes airport, which also operates in Teruel in Spain, and Vallair in Chateauroux (a company with a wide range of activities, including dismantling and recycling). There is also Aircraft End-of-Life Solutions, described above, in Enschede, the Netherlands, and More Aero (dismantling and recycling) in Hamburg, Germany.

4.3.3. Qualitative and environmental factors

A number of factors must be taken into account when assessing quality and ecology. The main ones in this case include legislation issued by both aviation authorities and government regulations that affect the wider industry. First and foremost is the ICAO, which brings together all the independent states of the world, and so from its point of view, standards should not differ. Its jurisdiction in the subject is primarily concerned with the use of spare parts, largely in general terms. In the area of maintenance, national or regional aviation authorities have more competence. In the territories compared, three regional aviation authorities have authority, namely the European EASA, the US FAA and the Canadian TCCA. As already mentioned, their authority extends almost exclusively to the process of dismantling and subsequent handling of parts. In Europe this is mainly Part 145, its equivalent in America is Code of Federal Regulations (CFR) 25. Based on bilateral agreements that have been concluded between the three entities, EASA, for example, recognises procedures certified by the FAA and TCCA and vice versa. This applies to routine maintenance as well as to disassembly, repair and any subsequent recertification of used parts, which, in addition to greatly simplifying bureaucratic procedures in practice, also points to similar quality and safety standards in these processes. This contributes to the high quality and transparency of the extracted parts, which are more affordable compared to new production parts. At the same time, U.S. maintenance organizations can directly obtain Part 145 certification from EASA, further simplifying the parts re-export process considerably. As for the subsequent dismantle and recycling process, these are currently not under aeronautical oversight, but under environmental and ecological authorities. In view of this, they may differ not only in terms of Europe-America regions, but also within a single country. They may vary depending on the population density, emission and noise standards in the area. In general, laws in this respect are stricter in the European Union than in the USA, where in some regions such facilities have the support of local authorities due to the fact that they are among the valued employment providers in sparsely populated areas. The government's favourable policy on importing aircraft from abroad has further contributed to the development of the local aircraft recycling industry. In terms of the quality of materials recovered in dismantling and recycling, the situation can also be complex, even though essentially the two most developed regions in the industry are being compared. In fact, there are no regulations in force in this respect yet, apart from legislation on the handling and disposal of hazardous substances. In current recycling, the aim is to find a compromise between the quality of the material and the resources needed to extract it. Therefore, the decision is essentially up to the individual company or the buyers of the recovered material. Certain voluntary quality standards in this area are set out in the AFRA Best Management Practices document. Although this is an initiative of the American Boeing company, it brings together companies from several regions of the world.

4.3.4. Summary

The North American and European regions are currently leading the industry and setting the standard for other regions. The leader among countries is the United States followed by the United Kingdom. Companies from these regions represent the best options for aircraft operators who do not have their own MRO organisation. As these are, without exception, advanced economies, the cost of the work itself may be higher here than elsewhere, but the result is the reliability and quality of certified and proven parts, which can save considerable money while contributing to flight safety. Minimal environmental impact is guaranteed when disassembled and then recycled according to AFRA procedures. This could be further reduced by the development of binding legislation on aircraft recycling.

5. CONCLUSION

The aim of the article was to evaluate the current state of the processes that the decommissioned aircraft is going through and to suggest possible improvements. Although aircraft are amongst the most expensive products to manufacture and one would expect that the effort to recover and reuse the material should be as old as aviation itself, this is not the case. It is only in the new millennium that it has been discussed at an industrial level.

The main obstacle that has made the possibility of recycling ignored for a long time is the quality of the materials. The problem is that economically viable separation of individual layers of materials at the required quality persists to the present day. A new challenge in terms of recycling is posed by the increasing share of new materials, such as mainly composites. Although these have been in use for some time, due to their low share to date, coupled with a general lack of interest in aircraft recycling in general, the issue of their reuse has not been addressed. A further complication is the absence of regulations in the area of disassembly, which nowadays prevents the use of larger structural units, and in the area of recycling, where operators are not forced to recover the materials used to build the aircraft.

Although the industry is currently recovering from the effects of the COVID-19 pandemic, it is expected to grow and develop again. At the same time, its environmental impact, which is not insignificant, needs to be comprehensively eliminated.

Greater use of mechanisation in aircraft recycling would contribute to a more efficient selection of the materials of current alloys. Intensive research into increasingly efficient recycling methods will be key to the reuse of materials that could eventually be reused in aircraft manufacture. Manufacturers could also make a major contribution to this, starting at the design and development stage itself. If binding legislation were to be adopted requiring aircraft owners to dismantle and recycle their aircraft, it would be possible to proceed in a similar way to the automotive industry. A proactive approach to recycling by Western aircraft manufacturers is already evident and could be further extended, for example by providing benefits to operators who take a proactive and responsible approach to recycling. Based on the initiative of the aircraft manufacturers themselves, aircraft recycling is a relatively prestigious industry, which is generally located only in the most advanced countries with available technologies and facilities. The United States currently has the largest market presence, followed by the United Kingdom.

It is safe to say that the future of aircraft recycling will be positive, despite the current crises. Even the current state of affairs, with energy and material costs rising significantly, will have a positive impact on this, which will not only affect the environment, but will also contribute to the creation of new jobs and could further improve the image of aviation in the eyes of the general public, as well as environmentalists, who have long been critical of the negative impact of aviation on the environment.

REFERENCES

[1] INTERNATIONAL AIR TRANSPORT ASSOCIATION. 2018. Best Industry Practices for Aircraft Decomissioning (BIPAD) 1st Edition. [online]. 2018. 101p.[cit. 2022-03-22]. Available on the internet: https://www.scribd.com/document/420730740/BIPAD . ISBN: 978-92-9229-827-2.

[2] INTERNATIONAL AIR TRANSPORT ASSOCIATION. 2020. Guidance for Managing Aircraft Airworthiness for Operations During and Post Pandemic. [online]. 2020. Available on the internet: https://www.iata.org/contentassets/d0e499e4b2824d4d867a8e07800b14bd/iata-guidance-managing-aircraft-airworthiness-during-post-pandemic.pdf.

[3] SGI AVIATION. 2018. Aircraft Decomissioning Study. [online]. 2018. 80 p. [cit. 2022-03-28]. Available on the internet: https://www.sgiaviation.com/wp-content/uploads/2020/03/IATA_Aircraft_Decommissioning_Study_May-2018.pdf .

[4] AUSTRALIAN TRANSPORT SAFETY BUREAU. 2007. How Old is Too Old? The impact of ageing aicraft on aviation safety. [online]. 2007, 78 p. [cit. 2022-04-08]. Available on the internet: https://www.atsb.gov.au/media/29959/b20050205.pdf. ISBN: 1-921-164-39-5.

[5] RIBEIRO, J. S. - GOMES. J. O. 2015. Proposed framework for End-of-Life aircraft recycling. In Procedia CIRP Volume 26. [online]. 2015, vol. 26, p. 311-316. [cit. 2022-03-22]. Available on the internet: https://www.sciencedirect.com/science/article/pii/S2212827114008610 .

[6] ASMATULU, E. - OVERCASH, M. - TWOMEY, J. 2013. Recycling of Aircraft: State of the Art in 2011. In Journal of Industrial Engineering. [online]. 2013, vol. 2013, 8 p. [cit. 2022-03-23]. Available on the internet: https://www.hindawi.com/journals/jie/2013/960581/ .

[7] SZABO, S. - KOBLEN, I. - VAJDOVÁ, I. 2015. Aviation Tehnology Life Cycle Stages. In eXclusive e- JOUNAL. [online]. 2015, 8 p. [cit. 2022-04-10]. Available on the internet: https://www.researchgate.net/publication/306165621_Aviation_Technology_Life_Cycle_Stages. ISSN: 1339-4509.

[8] SABAGHI, M. - CAI, Y. - MASCLE, CH. - BAPTISTE, P. 2015. Sustainability assessment of dismantling strategies for end-of-life aircraft recycling. In Resources, Conservation and Recycling. [online]. 2015, vol.102. p. 163-169. [cit. 2022-03-26]. Available on the internet: https://www.sciencedirect.com/science/article/pii/S0921344915300653.

[9] ZHAO, D. - GUO, Z. - XUE, J. 2020. Research on Scrap Recycling of Retired Civil Aircraft. In IOP Conference Series: Earth and Environmental Science [online]. 2020, vol. 657. 10 p. [cit 2022-03-26]. Available on the internet: https://iopscience.iop.org/article/10.1088/1755-1315/657/1/012062/pdf.

[10] WONG, K. - RUDD, CH. - PICKERING, S. - LIU, X. 2017. Composites recycling solutions for the aviation industry. In Science China Technological Sciences. [online]. 2017, vol. 60, 10 p. [cit. 2022-03-26]. Available on the internet: https://www.researchgate.net/publication/317973117_Composites_recycling_solutions_for_the_aviation_industry. ISSN: 1674-7321.

[11] KHAN, W. - SOLTANI, S. - ASMATULU, E. – ASMATULU, R. 2013. Aircraft recycling: A review of current issues and perspectives. [online]. Wichita. 2013, 11 p. [cit. 2022-03-26]. Available on the internet: https://www.researchgate.net/publication/289031934_A

ircraft_recycling_A_review_of_current_issues_and_perspectives.

[12] KRAUKLIS, A. – KARL, CH. – GAGANI, A. – JORGENSSEN, J. 2021. Composite Material Recycling Technology—State-of-the-Artand Sustainable Development for the 2020s. [online]. 2021, 33 p. [cit. 2022-04-01]. Available on the internet: https://www.researchgate.net/publication/348529249_Composite_Material_Recycling_Technology-State-of-the-Art_and_Sustainable_Development_for_the_2020s.

[13] MAAß, S. 2020. Aircraft Recycling – A Literature Review. [online]. Hamburg. 2020, 61 p. [cit. 2022-04-07 Available on the internet: https://www.fzt.haw-hamburg.de/pers/Scholz/arbeiten/TextMaass.pdf.

[14] BRUIJNS, E. – GREEUW, M. 2017. AMARG je víc než jen hřbitov. In Letectví + Kosmonautika. 2017, vol. 3, p.50-55. ISSN: 0024-1156

[15] LAKE. J. 2019. Keeping the legacy alive- part one: US operators. In Air Forces Monthly. 2019, vol. 4, p. 50-55.

[16] INTERNATIONAL CIVIL AVIATION ORGANIZATION. 1969. Annex 6 to the Convention on International Civil Aviation-Operation of Aircraft. [online] Montreal. 2018, 10th edition, 188 p. [cit. 2022-04-14]. Available on the internet: http://www.icscc.org.cn/upload/file/20210603/20210603132536_27477.pdf.

[17] INTERNATIONAL CIVIL AVIATION ORGANIZATION. 2005. Annex 8 to the Convention on International Civil Aviation-Airworthiness of Aircraft. [online] Montreal. 2005, 5th edition, 124 p. [cit. 2022-04-14]. Available on the internet: https://aviation-is.better-than.tv/icaodocs/Annex%208%20-%20Airworthiness%20of%20Aircraft/Annex%2008,%2010%20edition.pdf.

[18] EUROPEAN AVIATION SAFETY AGENCY. 2015. Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex II (PART-145) to Regulation (EU) No 1321/2014. [online]. 2015, 2nd edition, 82 p. [cit. 2022-04-13]. Available on the internet: https://www.easa.europa.eu/sites/default/files/dfu/Annex%20II%20to%20Decision%202015-029-R%20-%20%28AMC-GM%20Part-145%29.pdf.

[19] EUROPEAN AVIATION SAFETY AGENCY. 2015. Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex I (PART-M) toRegulation (EU) No 1321/2014. [online]. 2015, 2nd edition, 253 p. [cit. 2022-04-13 Available on the internet: https://www.easa.europa.eu/downloads/20260/en.

[20] ELSAYED, A. – ROETGER, T. – BANN, A. 2019. Best Practices and Standards in Aircraft End-of-Life and Recycling. In Destination Green. [online]. 2019, p. 279-284. [cit. 2022-04-14]. Available on the internet: https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg279-284.pdf.

[21] Meet the Israel Air Force unit that frankensteined a totaled F-15 [online]. Available on the internet: https://www.defensenews.com/air/2017/05/15/meet-the-israel-air-force-unit-that-frankensteined-a-totaled-f-15/ (cited 2022-04-07)

[22] Fighter Jet Crashes in Forest [online]. Available on the internet: https://yle.fi/news/3-5495390 (cited 2022-04-07)

[23] Aircraft Recycling Market Report [online]. Available on the internet: https://www.gminsights.com/industry-analysis/aircraft-recycling-market (cited 2022-04-20)

[24] Commercial aircraft disassembly, dismantling & recycling market size [online]. Available on the internet: https://www.fortunebusinessinsights.com/commercial-aircraft-disassembly-dismantling-and-recycling-market-103584 (cited 2022-04-20)

[25] We Finally Know How Many F-22s Were Left Behind At Tyndall AFB During Hurricane Michael [online]. Available on the internet: https://www.thedrive.com/the-war-zone/24442/we-finally-know-how-many-f-22s-were-left-behind-at-tyndall-afb-during-hurricane-michael (cited 2022-04-20)

[26] AFRA Members [online]. Available on the internet: https://afraassociation.org/accreditation/directory-of-accredited-companies/ (cited 2022-04-20)

[27] Dismantling and recycling [online]. Available on the internet: https://www.myairtrade.com/resources/dismantling (cited 2022-04-20)

[28] BUGAJ, M., NOVÁK, A. 2010. Všeobecné znalosti o lietadle : drak a systémy, elektrický systém. - 1. vyd. - Žilina : Žilinská univerzita, 2004. - 247 s. - ISBN 80-8070-210-1.

[29] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

[30] BUGAJ, M., URMINSKÝ, T., ROSTÁŠ, J., PECHO, P. 2019. Aircraft maintenance reserves - New approach to optimization. Transportation Research Procedia, 2019, 43, pp. 31–40. ISSN 23521457.

https://doi.org/10.26552/ pas.Z.2022.2.25

NOISE OPTIMISATION OF AIRCRAFT JET ENGINES

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Abstract

Aviation industry is source of noise, which has negative impact to human health and significantly influences surrounding fauna and flora. Nowadays tendency and also a need of higher care about environment concerns the aviation sector as well, which has eminent negative aspects to environment. This study is concentrated on concept solution of changes of jet engine´s output parameters, especially focused on noise emissions, using shape changes of nozzle of created 3D jet engine model, what allows simpler, economic undemanding, but relevant resulting analyse of fluid flow through the engine. Object of the research is influence of the nozzle shape to the created noise effect, which was made by fluid flow going through this shape. The goal of the study is to make and analyse as much as possible ideal shape characteristics of jet engines with the reference to the noise. The result is evaluation of possibility to do some kinds of research and analysis of jet engines on 3D models of jet engines, their comparison with reference to another parameters, such as: thrust or fuel consumption. To completing research were used facilities, devices and places of Air Department, also necessary tools and other stuff which belongs to the owner of this study. For modelling 3D model of engine and nozzle shapes, was used computer software and production of these shapes allows 3D printer. Used methods for creating nozzles are with regards to real shapes of engine. Results and conclusions of this research are appropriate to be used in praxis of air or another industry, whose purpose is utilizing thrust units. With application of these data is possible the achieve reduced noise of certain unit, with some changes of other parameters, such as: increased or decreased fuel consumption or thrust, according to the initial requirements. Moreover, these results can be used not only for industrial purposes, but also are relevant for economics.

Keywords

jet engine, noise emissions, fluid flow, shape, shape characteristcs

1. INTRODUCTION

Aviation industry is a subject of many studies, including various aspects. One of them is called emission mitigation. Mostly, the studies are focused on carbon emissions, which are linked with global situation, rising sea levels, melting of glaziers and many more. On the other hand, there are also emissions called noise emissions. People are not usually familiarized with effects of noise.

2. HEALTH ISSUES

According to the part of introduction, noise causes a health issues, which are more dangerous than is public known. Between the biggest belongs annoyance, sleep issues, ischemic heart disease, cognitive disorders and more. Few studies claim that children rising in the vicinity of the airport, where is high negative impact of a noise, have slower development. [1] [2] [3] [4] [5]

3. SOURCE OF NOISE

The source of noise may be distinguished into 2 parts. First part is generation on noise due to interaction of an air with a plane. The second, and the topic of this research, is the noise generated by the engine.

Noise created by the engine is sort out to the next sub-parts. Here belongs jet noise, noise of combustion chamber, turbomachinery noise.

Depending on the position of the engine towards to the noise measure facility, each of mentioned source of noises supreme.

Noise is measured in many unites, mostly used is a scale of dB (deciBel). Moreover, there are many variations of this scale, sometimes used so called PNdB, what is Perceived Noise in dB. Figure 1 shows the impact of a position of an engine to the value of noise.

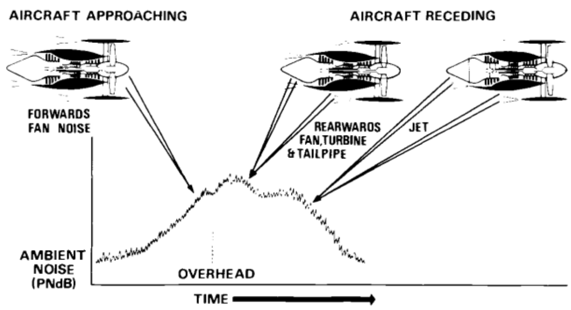


Figure 1 Dependency of a position of the engine to the impact of noise

Exist several of possibilities how to diminish the noise. However, aviation industry is a very specific sector, where all optimizations must be considered as appropriated, since one of the privileges of the aviation is sustainable economy. Any modifications cannot have negative impact, f.e. higher weight or increased aerodynamic drag. [6]

4. REGULATIONS

In regards of Annex 16, Volume II, which describes the regulations of noise impact, each aircraft must have certification which agrees with current regulations.

From the very beginning of aviation, nowadays certification requirements are stricter, and pressure of public forces those regulations to be more. On the next figure are shown chapters, which describes the noise limitations throughout the time. Each color represents one chapter. In past, the regulations were not so strict, but nowadays are. The last, the green shape also the smallest one, shows chapter from the year 2018 comparing to the past.

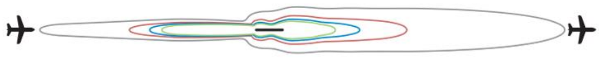


Figure 2 Chapters

Currently exists many manners of regulating noise. F.e. the airports use noise taxes, anti-noise walls, improved air procedures and many more, which could be sort as active or passive.

Between active diminishing belongs eliminating the noise in source of the noise, method of disposition, method of isolation, method of using material absorbing the noise, method using personal protecting equipment. [7]

The intensity of noise is measured in various units, mostly commonly used is decibel. For imagination of level of intensity, is Table, which shows different intensities regarding to the public known sounds.

Table 1 Comparing the intensity of noise to the public known sounds

Level of sound (dB)	Comparing
0	Audibility threshold
20	Wind lessness in the environment
40	Normal background noise
60	Slightly louder communication
70	Applause in the hall (from this level, the long-term effect has a negative effect on health)
75	Flushing the toilet
80	Going passenger car
90	Going train
100	Maximum power of the chainsaw
110	Rock concert
130	Jet start (pain threshold)

5. SOUND GENERATING MECHANISM

To diminish the noise of the aircraft, was introduced the mechanism, which simulates the flow of the air through the engine. This mechanism was created to replace a real jet engine, which would be financial unavailable. Sound mechanism could generate the flow of the air and simulates the real stream without a need to own a jet engine. Modifying nozzles influences this stream and noise generated by the interaction of the air with a construction of the engine is changed. Thus, this mechanism is designed to provide a flow, and to easily change the nozzles, to measure and evaluate the change of noise.

Figure 3 Constant, convergent and divergent shape of nozzle

Figure 4 Constant, convergent and divergent shape of nozzle with special shaped edge

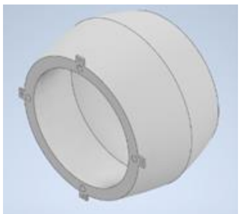


Figure 5 Divergent-convergent shape

Firstly, sound generating mechanism must be designed. In order to do it, Autodesk Inventor 2021 software was used. To create similar conditions as in a real jet engine, shapes and sizes ratios have been preserved. The final size must have been minimalized to the appropriate dimensions. The mechanism was made using 3D printer, and its size limits determined the final size of mechanism.

The fan was designed to provide air flow through the mechanism. It is conducted by the electromotor, put into the construction, and wires are led out of it using designed shell. Electromotor is connected to the remote control to operate it from the distance, so measuring of noise is not negatively impacted.

Besides the sound mechanism, the nozzles were designed and created. To secure easy and fast replacement of them, was designed a manner of pin connection with possibility to reach higher rigidity, using a screw connection.

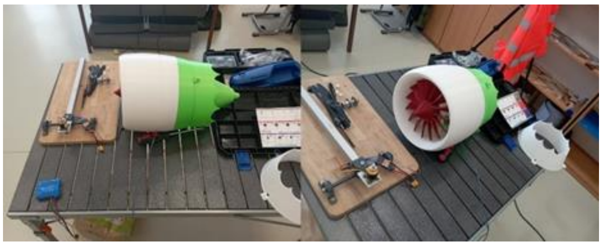


Figure 6 Created sound mechanism

Were printed the most basic shapes of nozzles, to observe the impact of shapes to the air flow, containing constant, divergent, and convergent shapes constructions, their mixing and special outlet shapes. Overall were made 7 shapes. Divergent and divergent with special shaped edge, convergent and convergent with special shaped edge, constant and constant with special shaped edge and divergent-convergent shape. Divergent-convergent shape varies from the others by the longitudinal length.

6. SIMULATIONS

Except for noise measurement, is important to do other measurements. Noise optimization, as was mentioned, must preserve another engine parameters, such as thrust or fuel consumption. Noise optimization, which would case lower thrust, higher fuel consumption or would have negative impact on the other engine parameters, could be considered as ineffective.

To prove, that sound generating mechanism is relevant manner how to measure and optimize noise characteristics of jet engines, computer simulations must be done.

For computer simulation was used CFD simulating software, which allows to observe air flow parameters. Designed sound mechanism was put in, and were set parameters to simulate air flow. For each nozzle was made simulation and values were written into the table to see with an ease the results.

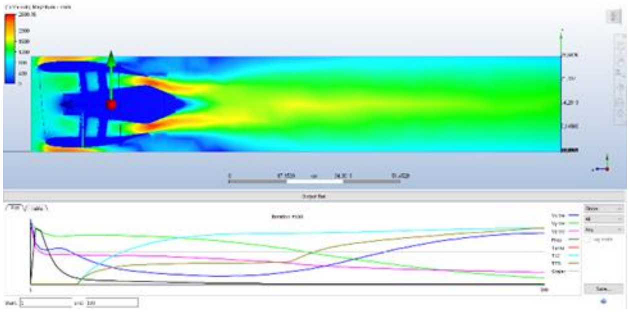


Figure 7 Demonstration of convergent nozzle using simulating software

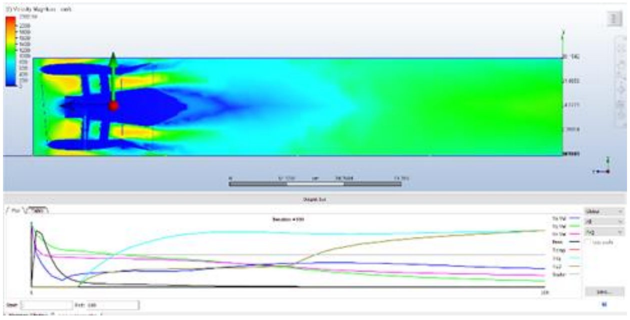


Figure 8 Demonstration of divergent shape of nozzle

Each simulation shows color resolution, as can be seen in Figure 7 and Figure 8, what represents the change of speed of the air through mechanism and beyond it.

Comparing Figure 7 and Figure 8, the change in flowing air through and beyond the engine is markable. The airflow hit the furthest part of the simulation in case of convergent nozzle, on the other hand, the divergent nozzle has only small impact in the further distances. However, the cone, which is created beyond the engine, is in case of divergent shape wider, what could affect another axes.

All parameters are also written under the simulation and graphs are made of it. Regarding to the results of simulation, a table of the most important parameters is made. Maximum speed is measured in m/s (meter per second) and turbulence in Mega Joules.

Table 2 Air parameters of CFD simulation

Shape	**Maximum speed (m/s)**	**Amount of accelerated air**	**Turbulence (MJ)**
Constant	22	Regular	2,86
Constant with special shaped edge	20	Regular	5,34
Convergent	25,5	Regular	3,15
Convergent with special shaped edge	25,6	Regular	5,27
Divergent	21	Small	8,22
Divergent with special shaped edge	20	Small	6,13
Divergent-convergent	21	High	3,5

Following the Table 2, the best nozzle for the created speed are convergent shapes. These results are logic, since they follow the Bernoulli equation of flowing fluid. The amount of accelerated air is also very important, and it can be seen, except of divergent shapes, all of them are appropriate. In this case, divergent-convergent shape is influenced by the dimension of it since the longitudinal axis of this shape is longer than the others. Optimal shape regards to the created turbulence is constant shape. However, this is not the only parameter which impact the generated noise, and the real experiment must be done.

After the simulations using the CFD software, the real experiments were done. First, the thrust measurement was performed. Sound generating mechanism was hanging in vertical axis, attached to the sensor of weight using lean ropes. Sensor of weight is connected to the computer, to write down all outputs. After turning on the fan of the mechanism, it started to generate thrust, which caused the change of weight in vertical axis. This change was processed in computer. The results were evaluated and graphs for each nozzle was made and so was a table. Thrust force is measured and processed in Newton unit.

*Table 3 Thrust me**asurement results***

Shape	**Thrust force in N**
Constant	35,34
Constant with special shaped edge	20,88
Convergent	29,72
Convergent with special shaped edge	20,1
Divergent	19,22
Divergent with special shaped edge	8,74
Divergent-convergent	1,66

Table 3 shows that, the highest thrust is achieved using constant shape, but the convergent shapes also achieve high values. The lowest thrust values are recorded using divergent shapes and divergent-convergent shape.

Observing the animations, that are the output of CFD simulation provide visual analyzing. Each shape of nozzle changes the air, which flows through the mechanism. As the flow is altered, engine parameters are altered as well. That means, that noise optimization must be considered with other engine characteristics, to preserve another values appropriate to be used in the airplane.

There is a difference between a simulation and real experiment. Divergent-convergent shape produce the least thrust and it is caused by low speed of air flowing through the mechanism produced by the fan. Other results are comparable, and to get better results, the method of thrust measuring might by improved.

Before the noise measurement are done, the conditions of this procedure must be set. Following the instructions of Annex 16, Volume II, correct procedures can be done. It describes very specifically the correct conditions under which the measurement must be done. First of all, choosing the right location is defined. Terrain, such as grass has special condition which allows to provide noise measurement, since the grass could absorb a part of noise energy. Another, such as snow or water must be cleaned out. Clay or sand have also special conditions under which could be measurement done.

Annex also defined obstacles, which are in the vicinity of measurement. Building, walls, trees, cars are unacceptable due to absorbing or reflecting the sounds waves.

Weather, such as rain, fog, drizzle has also negative impact on noise measuring.

Conditions for noise measuring are highly limited to ensure seamless process. Besides environment conditions, also another things are defined. Arrangement of microphones, the path of flying plane, the height of measuring point from the ground are also set. It is important to obtain some data from the engine or airplane, which is under measurement, to collect precise data of position above the microphone, also about engine rotation, attitude of the airplane and more.

Noise measurement of this research are done under specific conditions. F.e. the microphone with filter D, which is for aircraft noise measuring is, replaced with the filter A. In this case, it is not important to get the specific real values of noise, but to see the difference between these values according to the used shape. Also the hierarchy of microphone layout must be preserved to secure all numbers are measured at the same place relative to the sound generator.

The hierarchy layout of microphones consists of 3 axes. Longitudinal engine axis, the second axis at the angle of 30° and the last at the angle of 17,5° from the second axis. Microphones lay at the distances 1 meter from each other in each axis. The first is set 1 meter from the output of sound generator. Maximum distance of the last microphone is 3 meters. The high of microphone is the same as the center point of the output cone of the mechanism.

Measuring took place during the night to minimize the noise of the environment. The underlay was concrete, so noise energy was reflected, not absorbed. The temperature reaches 8,5°C and relative humidity was 65%. To measure all parameters was used multifunctional environmental meter MS6300.

Since, there are 3 axes, and 3 measuring distances in each axis, the results are for each nozzle very comprehensive. For reaching values which could be compared simpler, the average values are taken.

Besides the acoustic measurements, the measurements of air flow velocity were made. The speed of air and the amount of air are recorded by the MS6300 as well. The hierarchy of this air flow measurement is a bit changed. It also consists of 3 axes at the same angle as in previous instance, but the distances between measuring points are shortened in to the 0,5 m and the first point is 0,5 m from the output of the engine and the last in distance of 2 meters. The high of measurement point is the same as previous cause. The temperature and relative humidity are changed, due to measuring provided during the day. Temperature was 12,4°C and relative humidity was 65%.

Next tables show the results of measuring those parameters in separated axes.

Table 4 Results of measuring noise and other air flow parameters in longitudinal axis

Highest velocity	Constant shape
Lowest velocity	Divergent shape
Highest amount of flow	Constant shape with special shaped edge
Lowest amount of flow	Divergent shape
Highest intensity of noise	Divergent shape with special shaped edge
Lowest intensity of noise	Convergent shape with special shaped edge

Table 5 Results of measuring noise and other air flow parameters in second axis

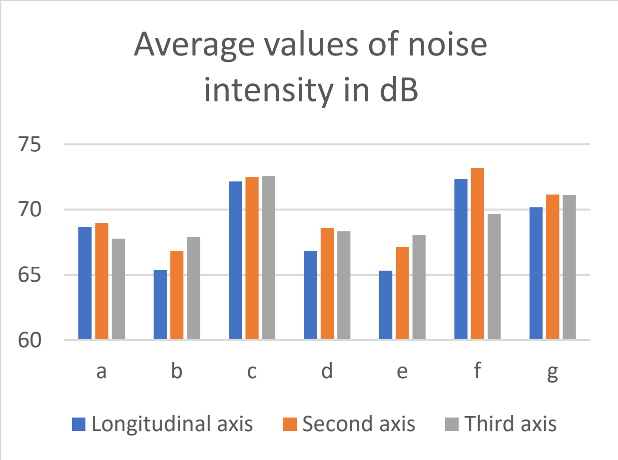
Highest velocity	Convergent shape with special shaped edge
Lowest velocity	Constant shape and divergent shape, both with special shaped edge
Highest amount of flow	Divergent shape
Lowest amount of flow	Divergent shape with special shaped edge and constant shape
Highest intensity of noise	Divergent shape with special shaped edge
Lowest intensity of noise	Convergent shape

Table 6 Results of measuring noise and other air parameters in third axis

Highest velocity	-
Lowest velocity	-
Highest amount of flow	-
Lowest amount of flow	-
Highest intensity of noise	Divergent shape
Lowest intensity of noise	Constant shape

In the next Graph 1 are marked the nozzle shapes using letters of alphabet to simplify the clarity.

a – constant shape, b – convergent shape, c – divergent shape, d – constant shape with special shaped edge, e – convergent shape with special shaped edge, f – divergent shape with special shaped edge, g – divergent-convergent shape.



Graf 1 Average noise intensities for each shape in each axis

Depending on the axis, the results vary. The best shapes for reaching the highest velocity of the air are constant and convergent. Lowest velocities are in different axis and in different distance are reached by using divergent shapes. Amount of flow varies in each axis and distance.

The highest intensity of noise is generated by divergent shapes, specially when uses shaped edge. The best shape for minimalizing noise is depending on the axis convergent or constant shape.

In the third axis, no air flow was measured for any shape.

7. COMPARING THE EXPERIMENT WITH THE SIMULATION

Comparing the results of the experiment and the computer simulation, allows to evaluate, whether is sound generating mechanism relevant for measuring of noise.

Simulation proved, that the highest velocity was reached by convergent shaped, following by the constant one. Experiment, on the other hand proved, that depending on the axis, the results are the same, and thus, convergent, and constant shapes reached the highest velocities. So thus, it proved same results for the lowest velocities.

Amount of flow showed that the minimum is created by divergent shape. Both, the simulation, and the experiment coincide. Maximum flow varies in this case comparing simulation and the real experiment.

Intensity of noise may be compared with the simulation turbulence. In this case, both showed the maximum intensity using divergent shapes.

In simulation, the minimum turbulence was reached by constant and convergent shapes. Measuring the real experiment proved similar results depending on the axis and the distance from the source of noise.

8. CONCLUSION

This research described the way of creating the sound generating mechanism, which after all measurements is considered as relevant. Simulation done using computer and real experiment are mostly coincided.

The best shape optimization for minimizing the noise generated by the flow, which interact with the construction, is the nozzle of convergent shape with special shaped edge, which preserves the engine most important parameters, such as thrust, and diminish the impact of noise.

Future improvement could achieve better results, closer reaching the real jet engine characteristics, by increasing the velocity of the air in the engine. Also, could be improved the method of measuring. Another improvement, such as adding the primary flow or the flow around the engine could cause more relevant results.

REFERENCES

[1] EASA, EEA, EUROCONTROL, „Air Quality," European Aviation Environmental Report - 2019, pp. 85-86, 2019.

[2] WHO, „Environmental Noise Guidelines for the European Region," WHO, 2018. [Online]. Available: https://www.euro.who.int/__data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf.

[3] WHO, „Evidence of health outcomes," Environmental Noise Guidelines for the European region, pp. 63-71, 2020.

[4] WHO, „Relevant risk increase of adverse health effects," Environmental Noise Guidelines for the European region, pp. 22-23, 2020.

[5] WHO, „Selection of priority health outcome," Environmental Noise Guidelines for the European region, pp. 17-19, 2020.

[6] N. A. Cumpsty, „Chapter 7. Engine Noise".

[7] Ú. f. a. m. inženýřství, „Akustika, základní pojmy a veličiny v akustice," Univerzita Tomáše Bati ve Zlíne, Zlín.

[8] ČERŇAN, J., HOCKO, M. 2020. Turbínový motor I. 1. vyd. Žilina : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 335 s.ISBN 978-80-554-1673-1.

[9] ČERNAN, J., ŠKULTÉTY, F. 2020. Design of the air velocity measuring inlet channel for the small jet engine. Transport Means - Proceedings of the International Conference, 2020, 2020-September, pp. 942–945. ISSN 1822296X.

https://doi.org/10.26552/ pas.Z.2022.2.26

THE IMPACT OF THE COVID-19 PANDEMIC ON THE ECONOMIC PERFORMANCE OF EUROPEAN AIR NAVIGATION PROVIDERS

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Abstract

The main objective of paper, is to evaluate the effects of the Covid-19 pandemic on the economic results of European air navigation service providers. The paper provides a set of information; the impact of the pandemic on air traffic in Europe, funding and forms of financial assistance to air navigation service providers in Europe. The findings are based on the synthesis of the knowledge from the research. Two analyses are carried out to achieve the goal. The first analysis focuses on selected financial and economic indicators for all 37 air navigation service providers and concentrates on the pre covid period. Due to the limited data availability, second analysis looks at the three selected European air navigation service providers and compares the financial analysis indicators for 2019, i.e. the year before the outbreak of the pandemic. It also includes 2020, 2021, while the Covid outbreak persisted in Europe. The findings of the paper confirm the stable development of financial and economic indicators in the pre-recession period and also the deteriorating situation during the Covid period. In the conclusion, recommendations are proposed to help to identify more comprehensively the impact of crises such as the Covid-19 crisis on the financial situation of air navigation service providers in order to create a more resilient funding system.

Keywords

air navigation service providers, air navigation services, COVID-19, economic performance, financial analysis

1. INTRODUCTION

The Covid-19 pandemic, which erupted in Europe in early 2020, has hit the aviation sector much harder than other sectors. This impact was mainly due to a decrease in air traffic due to the introduction of government travel restrictions. The decline in traffic is also linked to the decline in air navigation services provided, leading to gate-to-gate revenue, which is the primary component of funding for European air navigation service providers.

Given the timeliness, the article looks at the impact of the Covid-19 crisis on the economic performance of European ANS providers, given that this pandemic still persists and that the aviation industry, and therefore the air navigation service provider, was not prepared for the crisis. The main information bases of the research were data from the ACE Benchmarking Report as well as data from the annual reports of individual European ANS providers, which quantified the effects of the Covid-19 pandemic on selected financial and economic indicators and selected indicators of financial European air navigation service providers.

There are many studies and expert studies that look at the impact of the Covid-19 pandemic articles on European air navigation service providers. However, the articles focus mainly on the demand for transport services, the financial assistance that individual ANS providers have received, but are not focused on research by ANS providers as financial-economic entities. None of the articles analyzed used the same research to determine the impact of the Covid-19 pandemic on the economic performance of European air navigation service providers as used in this article.

2. LITERATURE REVIEW

The individual expert articles cover in particular the operational and, to a lesser extent, the financial and economic impact of Covid-19 on air navigation service providers in Europe. Although more than two years have passed since the outbreak of the pandemic in Europe, the question of the impact of the pandemic on this aviation sector is not fully answered. Therefore, more and more experts and institutions are commenting on this topic in order to assess the real impact of the pandemic on this aviation sector.

The decrease in air traffic in individual airspace caused a decrease in revenues from route and terminal charges and thus affected the economic area of providing air navigation services. In 2020, air traffic in Europe fell by 55% compared to 2019, representing a loss of € 4.9 billion [1]. In 2021, there was a 44% drop in operations, so the loss was € 3.7 billion. Just as there was a decrease in traffic in the airspace, there was also a decrease in traffic in the area control centers. The busiest area control center in European airspace was the control center in the upper airspace of Karlsruhe UAC in Germany, with a decrease in traffic of 44% compared to 2019 [2]. Jobs and wages have been reduced due to cost reductions. The staff who remained in office were properly cared for and created an environment in which they did not tolerate or feel the consequences of the pandemic [3]. On the other hand, the positive news was that the high level of delays in European airspace, due to insufficient capacity in 2019 from April to 2020 due to pandemic reductions, has almost disappeared [4]. The articles focused on the issue of economics only in the impact of the Covid-19 pandemic on revenues, which have seen a significant decline, and on the forms of state aid provided to them. Last but not least, the articles focused on the issue of future funding for the sector, where GATCO and DATCA suggested two options for future funding, public tax funding or hybrid funding, where air navigation service providers would finance the state at 50% and the remaining 50 as a percentage of airspace users [5].

3. RESEARCH GOAL AND METHODOLOGY

The research applied in this article is divided into two parts and, since the covid period has affected European ANS providers, especially in terms of revenue generation, it quantifies the effects of the Covid-19 pandemic on selected financial and economic indicators of European ANS providers.

The first part of the research is devoted to the pre-covid period and its aim is to characterize the structure and dynamics of selected financial and economic indicators of European air navigation service providers. The data of selected financial indicators of European air navigation service providers for the implementation of the first part of the research come from the reports ACE Benchmarking Reports 2019, 2018, 2017, 2016 and all 37 European air navigation service providers are included in this part. It is important to note that these reports, published annually by Eurocontrol, focus mainly on cost-effectiveness as a key benchmarking indicator in terms of ATM/CNS costs and do not address the issue of financial indicators in a comprehensive way.

The second part of the research consists of performing a financial analysis of selected European air navigation service providers according to Zalai et al. [6]. As not all European air navigation service providers have published annual reports dating back to 2021, 2020 and 2019, only three European air navigation service providers were included in this financial analysis. These three European ANS providers include the Norwegian ANS provider Avinor, the British ANS providers NATS provider and the Swiss ANS provider Skyguide.

4. RESEARCH RESULTS

4.1. Before the covid period

The pre-covid period was analyzed on the basis of selected financial and economic indicators, the data of which come from the ACE Benchmarking Report and from which the article generates indicators of structure, growth rate and calculated values of average, median and standard deviation comprehensively for European air navigation service providers. The individual European ANS providers were grouped in this analysis. The breakdown of groups A, B, C, D and E is taken from Commission Implementing Decision (EU) 2019/903 [7]. The breakdown of Non-SES 1 and Non-SES 2 does not come from Commission Implementing Regulation (EU) 2019/903, but was created by merging these groups, with which the ACE Benchmarking Report works.

The values of the mean, median and standard deviation did not change significantly for the analyzed four-year period before the outbreak of the Covid-19 pandemic for all analyzed financial and economic indicators. This fact confirms the stable development of the individual indicators analyzed in the pre-covid period for European ANS providers as a whole.

In terms of structure indicators, we focused mainly on the share of gate-to-gate revenues, which are formed by revenues from route and terminal charges to total revenues from the provision of air navigation services due to the fact that the decrease in air traffic during the pandemic decreased this financial-economic indicator the financial situation of European ANS providers was significantly affected. We focused on other selected indicators of the pre-covid period.

Based on the data, we found that route fee revenues total approximately 80 percent or more of total gate-to-gate revenues, and the remaining percentages account for up to 100 percent of terminal revenues. Revenues from gate-to-gate account for more than 80% of total revenues from ANS provision for most ANS providers. The exceptions are the Norwegian provider ANS Avinor for the whole period (49.74% in 2016; 50.03% in 2019) and the Swiss provider ANS Skygiude for the whole period (66.75% in 2016, 68.63% in 2019). The Estonian provider ANS EANS and the Ukrainian provider ANS UkSATSE with the highest value of 100% for all four years analyzed and the Bulgarian provider ANS BULATSA and the Moldovan provider ANS MOLDATSA with the highest value of 100% of the share of gate-to-gate ANS revenues in the total ANS provision for 2019, 2018 and 2017. The results of this structure indicator show that gate-to-gate ANS revenues, which are made up of line and terminal revenues, are key to financing European ANS providers. Based on Table 1, we can see that for groups A, C, D and group Non-SES 1, Non-SES 2, the values of this structure indicator are very homogeneous and reach more than 80%, in group B the exception is mentioned Avinor and in Group E Swiss provider ANS Skyguide.

TABLE 1 SHARE OF GATE-TO-GATE ANS REVENUE IN TOTAL REVENUE FROM ANS PROVISION [SOURCE: 10,11,12,13,14]

ANSPs	2019	2018	2017	2016
Albcontrol	99,89	99,73	99,86	99,83
ANS CR	98,61	98,68	98,34	98,11
ANS Finland	85,27	85,23	84,80	97,94
ARMATS	99,96	99,97	99,98	99,95
Austro Control	97,77	97,90	98,96	98,74
Avinor	50,03	51,56	51,48	49,74
BULATSA	100,00	100,00	100,00	99,61
Croatia Control	93,05	90,95	90,27	92,68
DCAC Cyprus	88,77	89,18	89,29	88,06
DFS	84,24	90,89	91,76	92,77
DHMI	99,51	99,53	99,30	99,16
DSNA	94,15	93,82	93,85	95,74
EANS	100,00	100,00	100,00	100,00
ENAIRE	83,93	84,66	78,65	81,02
ENAV	95,12	94,52	94,83	93,93
HCAA	99,03	99,09	98,58	98,11
HungaroControl	96,66	97,28	95,61	95,41
IAA	99,11	99,10	98,82	98,76
LFV	92,79	93,63	93,67	93,12
LGS	98,01	98,19	97,27	97,88
LPS	96,82	96,64	95,46	95,02
LVNL	91,82	93,68	94,70	95,18
MATS	88,06	82,81	88,38	90,00
M-NAV	99,94	99,94	99,88	99,86
MOLDATSA	100,00	100,00	100,00	89,31
NATS	83,26	83,12	81,17	78,84
NAV Portugal	99,04	99,38	99,12	97,58
NAVAIR	90,25	90,12	92,51	93,70
Oro navigacija	95,22	97,66	98,20	96,82
PANSA	98,51	98,20	98,56	98,12
ROMATSA	97,07	97,87	95,61	95,35
Sakaeronavigatsia	96,70	94,60	90,93	88,90
skeyes	81,82	83,68	84,42	83,58
Skyguide	68,63	68,94	67,00	66,75
Slovenia Control	94,67	95,34	95,08	94,23
SMATSA	89,76	91,36	84,93	86,43
UkSATSE	100,00	100,00	100,00	100,00

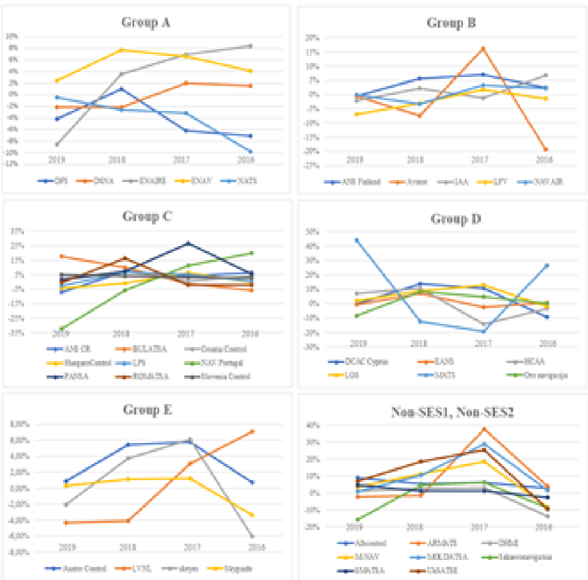
(Group A is marked in yellow, group B in blue, group C in green, group D in orange, group E in red and group Non-SES1, Non-SES 2 in gray).

Based on other analyzed structure indicators, we found the following facts in the research:

- For most European ANS providers, ATM/CNS provision costs account for more than 85% of the ANS provider's total gate-to-gate costs.
- The average percentage value of the share of air traffic controllers in the total number of employees was 31,88% in 2016, 32,04% in 2017, 31,39% in 2018 and 31 % in 2019.
- The share of the sum of the net book value of fixed assets in operation and the net book value of fixed assets under construction in total assets was in only a few cases higher than 70%.
- The share of the sum of long-term and short-term liabilities in total liabilities represented variable values ranging from three to one hundred percent.

In the analysis of growth rate indicators, as with the structure indicators, we focused mainly on gate-to-gate ANS revenues.

Graph 1 describes the growth rate of gate-to-gate ANS revenues of individual European ANS providers. Most European ANS providers have had a similar growth rate of this revenue indicator. The highest value was for the provider ANS MATS, where the growth rate in 2019 was over 40%. The lowest growth rate of 0.07% was with the Cypriot ANS provider DCAC Cyprus in 2019. European ANS providers in Group A and Group E had the lowest values of this indicator (Group A: -9.76% in 2016 for UkSATSE, 8.39% in 2016 for ENAIRE, Group E: -6.08% in 2016 for Skeyes, 6.15% in 2017 also for Skeyes). The highest value of the gate-to-gate ANS revenue growth rate indicator was 63.6% for the ANS MATS provider from group D (44.34% in 2019; -19.26% in 2017).



GRAPH 1 RATE GROWTH OF GATE-TO-GATE ANS REVENUES OF EUROPEAN ANS PROVIDERS BROKEN DOWN BY GROUP [SOURCE: OWN PROCESSING BASED ON DATA FROM ACE AND 2015BENCHMARKING REPORTS 2019, 2018, 2017, 2016, 2015]

Despite various developments in the years analyzed, selected financial and economic indicators of growth rates and structures confirm the relative stability of the air navigation services sector before the Covid-19 pandemic. This is also justified by the focus of ACE Bechmarking Reports on cost-effectiveness as a major problem for the economy of European air navigation service providers, not the sources of funding and capital structure of these ANS providers.

4.2. Covid-19 period

The data needed to calculate the financial analysis indicators, which are the debt ratio and the profitability indicators, come from the consolidated financial statements and the consolidated balance sheets of the selected ANS providers. For Avinor and NATS, the individual data are provided for the whole group and not only for the ANS provider itself, as is the case for Skyguide.

4.2.1. Debt ratio

For the Norwegian provider ANS, the total indebtedness of assets in 2019 reached 65.403%. In 2020, when the Covid-19 pandemic broke out, the value of this debt ratio increased by 8,037 percentage points and thus exceeded 70%, which represents the company's high debt. In 2021, this value did not change significantly compared to 2020, but there was a decrease of 0.284 percentage points.

For the UK provider ANS NATS, it is important to note that the fiscal year ends on the last day of March. The mass disruption of flights in the United Kingdom took place as early as March 2020. This means that the impact of the Covid-19 pandemic on this ANS provider can only be comprehensively assessed in the annual report from 2021. rising character. Compared to 2019, growth of 4,59 percentage points was recorded in 2020. In 2021, the growth of this debt ratio was higher than in the previous year. The value of total asset indebtedness rose by 8,873 percentage points in 2021. All three values were higher than the recommended values, which represents a higher indebtedness of this provider.

The total indebtedness of assets with the Swiss provider ANS in 2019 was 52,594%. In 2020, this value fell by 0,239 percentage points, but in 2021 it rose by as much as 14,293 percentage points. None of the values during the analyzed three-year period exceeded the value of 70%, which represents the limit value of this indebtedness indicator in terms of recommended values.

TABLE 2 VALUES OF THE DEBT INDICATOR OF ANS AVINOR, NATS AND SKYGUIDE PROVIDERS [SOURCE: DATA OF ANNUAL REPORTS OF ANS AVINOR, NATS AND SKYGUIDE PROVIDERS FOR 2021, 2020 AND 2019]

		Avinor	NATS	Skyguide
Debt ratio	2021	73,156 %	70,508 %	66,648 %
	2020	73,440 %	61,635 %	52,355 %
	2019	65,403 %	57,045 %	52,594 %

4.2.2. Profitability indicators

For the Norwegian ANS provider, the return on total assets reached a negative value of -0.019 during the three-year period in 2020. The negative value of this profitability indicator indicates the worst situation of the provider in the three-year analysis period. In 2019 and 2021, the values of this indicator were positive. The highest value of this indicator was achieved by the provider in 2019, and thus this year it brought 2 øre net profit to the provider of each Norwegian kroner of total assets. Even in 2021, this indicator brought the provider a profit, but 0.14 øre less than in 2019. The value of the return on equity of the Norwegian provider ANS in 2019 was 0.046. In 2020, this dropped to a negative value of -0.055, and in 2021 the value of this indicator returned to positive values. The negative value of this profitability indicator indicates that in 2020 the ANS provider made a loss of 5.5 øre net profit. In 2019, Avinor achieved a profit of 4.6 øre per crown of net profit, and in 2021 it was a profit 3 øre lower than in 2019.

For the British provider ANS NATS, the value of return on total assets was positive in two years, in 2019 and in 2020. In 2021, this value was negative. In 2019, the provider made a loss of 5.4 pence of net profit for each pound of total assets, and in 2020 it was 4.3 pence less than in the previous year. The value of return on equity decreased from 2019 to 2021 by 0.189. Already in 2020, the value of this profitability indicator reached negative numbers, when in 2020 it reported a loss of 0.1 pence of net profit for every pound of equity and in 2021 this loss was higher by 8.2 pence than in the previous year. The best return on equity was in 2019, when one pound of equity was produced by 10.6 pence of net profit.

Both profitability indicators of the Swiss LAS provider reach negative values throughout the three-year analysis period. In the case of return on total assets, this means that the Swiss ANS provider did not make any net profit on the company's total assets. However, the values of this profitability indicator increased in 2021 compared to the previous year, namely by 0.041. The value of return on equity decreased by 0.628 from 2019 to 2021, when it reached even greater negative values. These negative values tell us that for every single franc of equity, the Swiss ANS provider made a loss in all three periods analyzed. In 2019, this loss was 1.4 rapen net profit, in 2020 53.7 rapen net profit and in 2021 64.2 rapen net profit. Based on data from the annual report of the Swiss provider ANS from 2018, we found that in this year the values of both profitability indicators did not reach negative values, because the values of profit before tax and profit after tax were positive.

TABLE 3 VALUES OF CALCULATIONS OF ANS AVINOR, NATS AND SKYGUIDE RENTABILITY INDICATORS [SOURCE: DATA OF ANNUAL REPORTS OF ANS AVINOR, NATS AND SKYGUIDE PROVIDERS FOR 2021, 2020 AND 2019]

		Avinor	**NATS**	**Skyguide**
Return on Assets	**2021**	0,006	-0,018	-0,214
	2020	- 0,019	0,011	-0,255
	2019	0,020	0,054	-0,006
Return on Equity	**2021**	0,016	-0,083	-0,642
	2020	- 0,055	-0,001	-0,537
	2019	0,046	0,106	-0,014

5. CONCLUSION

The aim of this article was to analyze the financial situation of European air navigation service providers in the run-up to the Covid-19 pandemic in Europe and the outbreak and persistence of the pandemic and to identify the impact of selected pandemics on the economic performance of European ANS providers.

Although many experts and organizations are working on the impact of the Covid-19 pandemic on ANS providers, this article uses a different methodology to determine the impact of the Covid-19 pandemic on the economic performance of European ANS providers. Two parts of the research were conducted in the article. The first part, a four-year pre-peace analysis, included all 37 European providers and the data for this research come from the ACE Benchmarking Report. Due to the unavailability of the necessary data, only three European ANS providers were included in the second part of the research, the covid period analysis. The data for this analysis come from the available annual reports for 2021, 2020 and 2019.

In the analysis of the pre-covid period, the values of selected financial and economic indicators did not change significantly, which indicates the stability of this period. Through an analysis of the pre-covid period, we found that gate-to-gate revenues, which are made up of line and terminal revenues, account for the largest share of total ANS revenues from European providers. As travel restrictions introduced in response to the outbreak of the pandemic have led to a decline in air traffic and thus a drop in gate-to-gate revenues, a change in the financing model of European ANS providers will be needed to make it easier for ANS providers to manage crises such as crisis associated with the outbreak of the Covid-19 pandemic.

During the analysis of the covid period, a change in selected indicators of the financial analysis was visible. The calculation of the indebtedness indicator showed a higher indebtedness of the company during the Covid-19 pandemic. The values of the profitability indicators were very diverse, which points to the different impact of the Covid-19 pandemic on selected European ANS providers. Both analyzed profitability indicators showed negative values in the covid period and thus reached a loss for the provider. Profitability manifested itself in these profitability indicators in the pre-ancillary year, but in the year when the pandemic broke out, a certain degree of loss was observed in these profitability indicators. For Skyguide, profitability was recorded in 2018, and a loss rate was reported throughout the period analyzed. The Norwegian provider ANS Avinor showed positive values for both profitability indicators in 2021, which can be assessed as an improving situation.

The mentioned processes of commercialization and corporatization could also be reflected in the consolidated financial statements. All three ANS providers Avinor, NATS and Skyguide have liberalized terminal air navigation services, which affects the economies of these providers not only in terms of cost but also in terms of revenue.

Given that the ACE Benchmarking report focuses only on the cost of ANS providers, which is undoubtedly a financial indicator, this report ignores the revenue aspect of the economy, which has become more significant due to the change in the unit rate method from the full cost method to the fixed method. costs and revenue shortfalls from the provision of ANS due to the Covid-19 pandemic. To comprehensively assess the impact of crises, in our case the impact of the Covid-19 pandemic on the economic performance of European ANS providers, it would be necessary to produce reports that have the same or at least similar accounting standards and without data restrictions and specifically address the financial health of providers. ANS in the regulated part of the industry, not their whole group. This is likely to be accompanied in the future by a structural reform in the provision of ANS, which may contribute to transparency in the reporting of accounting information (SES2 + recast 2020).

It is important to note that individual airspace blocks are being phased out due to non-fulfillment of their purpose, despite the many successes they have achieved through the cooperation of individual ANS providers within a functional block. The outbreak of the Covid-19 pandemic, which caused a sharp drop in air traffic, has shown that a single European or not resilient enough, as the provision of services is difficult to adapt to transport developments. In September 2020, the European Commission drafted a recast of the 2013 European Parliament and Council Regulation on the implementation of the Single European Sky. services from line services. Thus, the decision whether to purchase individual CNS, AIS, ADS, MET and terminal services on a commercial basis will be up to the provider itself. If it decides to purchase through a tender, the performance plans that are developed for the reference period in the key performance areas and key performance indicators will not apply to this. It follows that the ANS provider can decide whether to go through the market mechanism or be pushed by transnational regulation. Airports will also decide for themselves from whom to purchase terminal services through the market mechanism. As a result of these changes, new market entrants will emerge and therefore the provision of ANS should be conditional on compliance with the defined requirements in this Regulation regarding financial soundness, liability and insurance coverage. For this purpose, a proposal is made for the issuance of an economic certificate, which will be issued by individual national supervisory authorities. Article 8 of that recast, which is renumbered Article 6, contains the following wording: 'In addition to the certificates they must hold in accordance with Article 41 of Regulation (EU) 2018/1139, air navigation service providers shall also hold an economic certificate. This economic certificatef shall be issued on application, provided that the applicant has demonstrated sufficient financial soundness and has obtained adequate liability and insurance coverage”[8]. The wording of this article supports the basic idea and conclusions of this article that ANS providers should be seen as financial entities and that the future development of ANS providers in Europe will require a structural reform that separates the provision of core services from organizational and accounting services. support services, as well as the organizational and accounting separation of the provision of terminal services from the core services. . The proposed structural reform does not envisage the creation of a transnational fund to finance the provision of ANS, which appears to be an alternative to structural reform. It is also possible to set up such a fund, which could financially rehabilitate the system in the event of major crises and which would be a support instrument for financing such crises.

REFERENCES

[1] Eurocontrol. Charting the European Aviation recovery: 2020 COVID-19 impacts and 2021 outlook [online]. 2021. https://www.eraa.org/system/files/think_paper_8_-impact_of_covid19_on_european_aviation_in_2020_and_outlook_2021.pdf.

[2] Eurocontrol. Charting the European Aviation recovery: 2021 COVID-19 impacts and 2022 outlook [online]. 2022. https://www.eurocontrol.int/sites/default/files/2022-01/eurocontrol-think-paper-15-2021- review-2022-outlook_0.pdf

[3] Internation Labour Organization. COVID-19 and civil aviation [online]. 2020. https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/briefingnote/wcms_741466.pdf

[4] European Commision, Eurocontrol, FAA. Special report on the impact of the COVID19 pandemic on the U.S. and European ANS systems. 2021

[5] Barbero L., Laursen T. A New Normal for Air Navigation Services [online]. https://www.atmpolicy.aero/wp-content/uploads/2020/07/ATT05020.pdf

[6] Zalai a kol. 2016. Finančo-ekonomická analýza podniku. 9. vyd. Bratislava: Sprint 2 s.r.o., 2016, 487 s. ISBN 978-80-89710-22-5.

[7] Európska komisia. VYKONÁVACIE ROZHODNUTIE KOMISIE (EÚ) 2019/903 [online]. 2019. Dostupné na internete: https://eur-lex.europa.eu/legal-content/SK/TXT/PDF/?uri=CELEX:32019D0903&from=EN

[8] 8 Európska komisia. Zmenený návrh NARIADENIE EURÓPSKEHO PARLAMENTU A RADY o implementácii jednotného európskeho neba (prepracované znenie) [online], 2020. Dostupné na internete: https://eur-lex.europa.eu/resource.html?uri=cellar:095951f7-fcb5-11ea-b44f-01aa75ed71a1.0003.02/DOC_1&format=PDF

[9] Tomová A. 2014. Economics of air navigation services. 1. vyd. Žilinská univerzita v Žiline/EDIS-vydavateľské centrum ŽU. 154 s. ISBN 978-80-554-0905-4.

[10] Eurocontrol. ATM Cost-Effectiveness (ACE) 2019 Benchmarking Report with Special Focus on COVID-19 Impacts in 2020 [online], 2021. https://www.eurocontrol.int/sites/default/files/2021-06/eurocontrol-ace-2019-benchmarking-report.pdf

[11] Eurocontrol. ATM Cost-Effectiveness (ACE) 2018 Benchmarking Report [online], 2020. https://www.eurocontrol.int/sites/default/files/2020-06/eurocontrol-ace-2018-benchmarking-report.pdf

[12] Eurocontrol. ATM Cost-Effectiveness (ACE) 2017 Benchmarking Report with 2018-2022 outlook [online], 2019. https://www.eurocontrol.int/ACE/ACE-Reports/ACE2017.pdf

[13] Eurocontrol. ATM Cost-Effectiveness (ACE) 2016 Benchmarking Report with 2017-2021 outlook [online], 2018https://www.eurocontrol.int/sites/default/files/2019-08/ace-2016-benchmarking-report-upd.pdf

[14] Eurocontrol. ATM Cost-Effectiveness (ACE) 2015 Benchmarking Report with 2016-2020 outlook [online], 2017. https://www.eurocontrol.int/sites/default/files/2019-08/ace-2015-benchmarking-report-upd.pdf

[15] Avinor. INTERIM FINANCIAL REPORT 4th quarter 2021 [online]. 2022. https://avinor.no/contentassets/b7c5fc18e6824abbb7612e688ce72c12/avinor_q4-rapport2021_en.pdf

[16] Avinor. Annual and Sustainability Report 2020 [online]. 2021. https://avinor.no/globalassets/_konsern/om-oss/rapporter/en/avinors-annual-report2020.pdf

[17] Avinor. Annual and Sustainability Report 2019 [online]. 2020. https://avinor.no/globalassets/_konsern/om-oss/rapporter/en/avinors-annual-report2019_en.pdf

[18] NATS Holding Limited. Annual Report and Accounts 2021 [online]. 2022. https://www.nats.aero/wp-content/uploads/2021/07/NATS-Holdings-Ltd2021.pdf

[19] NATS Holding Limited. Annual Report and Accounts Year ended 31 March 2020 [online]. 2021. https://www.nats.aero/wpcontent/uploads/2020/10/NATS-Holdings-Ltd-2020.pdf

[20] NATS Holding Limited. Annual Report and Accounts 2019 [online]. 2020. https://www.nats.aero/wpcontent/uploads/2019/07/NATS7555_AnnualReport-2019_AW_Full.pdf

[21] Skyguide. Annual report 2021 [online]. 2022. https://api.skyguide.ch/wp-content/uploads/2022/02/Skyguide_AnnualReport2021_E-1.pdf

[22] Skyguide. Annual report 2020 [online]. 2021. https://api.skyguide.ch/wpcontent/uploads/2021/03/SKY_Annual_Report_2020_EN_Final. pdf

[23] Skyguide. Annual report 2019 [online]. 2020. https://api.skyguide.ch/wp-content/uploads/2020/03/E-sky-RA-2019-LR-v2.pdf

[24] Skyguide. Annual report 2018 [online]. 2019. https://api.skyguide.ch/wp-content/uploads/2019/03/E-sky-RA-2018-LR-1.pd

https://doi.org/10.26552/ pas.Z.2022.2.27

QUALITY OF SERVICES PROVIDED BY BORYSPIL AIRPORT

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Abstract

The aim of the diploma thesis is to develop a proposal for the implementation of the SmartGate system to improve the passport control process in international passenger transport services at the Boryspil Airport. The theoretical part deals with the existing methods of evaluating the quality of airport services and offers an algorithm for airport service quality indicators stigmatization. The analytical part of the work is devoted to the analysis of production and financial activities and competitive advantages of Boryspil Airport. In the project part, modern information technologies of air transport services at the world's leading airports were considered and the efficiency of the SmartGate system implementation at Boryspil Airport was calculated.

Keywords

airport, airport services, quality, methods, SmartGate system.

1. INTRODUCTION

To increase competitiveness in the air transport services market, companies need to pay special attention to quality issues. Although airport service standards have always existed, modern conditions require a change of a specific way of managing airports, focusing on two main objectives: quality and passengers. The high quality of services for all categories of passengers and other means meeting their expectations and at the same time creating an advantage over competitors, which is the key to a long-term partnership with them.

The level of customer satisfaction is affected by the quality of services provided, which leads to market expansion, the emergence of new customers and long-term cooperation with them. The combined effect of the above factors results in quality at the system level, which applies not only to the management system but also to the company as a whole. This allows us to talk about the concept of "airport quality of work", which guarantees an increase in workload, increased profits and a reduction in the airport's economic risks.

Every airport is more or less in a competitive environment. ACI - Airport Council International - identifies the following forms of competition between airports:

- competition to attract new airlines, passengers and cargo;
- competition between airports with overlapping airport catchment areas;
- competition for the role of hubs between airports and for transit traffic flows between hubs;
- competition between airports located in one metropolis;
- competition between airport terminals;
- competition for the right to provide ground handling by airlines.

Awareness of the airport in a competitive environment always leads to the understanding that quality is one of the basic elements in the management system and its measurement is a key element in improving the efficiency of its operation. The aim of the diploma thesis is to develop a proposal for the implementation of the SmartGate system to improve the passport control process in international passenger transport services at Boryspil Airport. (1)

Based on the goal, we can formulate the following goals of this work:

- get acquainted with the methods of evaluation of airport service quality indicators;
- develop an algorithm for evaluating airport service quality indicators;
- analyze the main production and financial results of Boryspil airport and identify shortcomings in the work of the airport operator;
- consider modern information technologies for air transport services at the world's leading airports;
- develop a project proposal to improve the passport control process in international passenger flow at Boryspil Airport.

2. CURRENT METHODS FOR ASSESSING THE QUALITY OF SERVICES PROVIDED BY AIRPORTS

2.1. Methodical approaches to the analysis of the quality of airport services

Creating the conditions for the development of the aviation industry, increasing the quality of transport and the competitiveness of air transport in accordance with the concept of its reform requires research into the quality of airport services. Addressing this issue requires, first and foremost, the evaluation and development of methodological approaches to airport service quality management, considering their characteristics, identifying the organizational and economic components of airport service quality management, due to both organizational factors that take into account management functions and economic part of the cost of shaping the quality of services.

In the diploma thesis the quality management of airport services are considered as a separate system that provides an optimal ratio of its components. This will create a rational process for managing the quality of airport services and identify a set of factors that affect the quality of services depending on the conditions of their creation and provision.

Quality management of airport services is a set of organizational and economic parameters and indicators that ensure effective quality management of services through modern passenger service organization, ticket records, computer technology for consumer screening and customs control; The result is ensuring the development of technical equipment in the process of providing services, increasing quality, achieving regulation and reducing costs, improving the economic efficiency of implemented measures. (2)

Airport service quality management is a set of interconnected principles, methods, subjective and objective factors and management functions aimed at developing and meeting quality requirements and reducing quality costs. Managing the quality of airport services therefore means ensuring an optimal ratio of their components. At the same time, efforts are being made to achieve priority objectives such as improving quality levels, reducing operating costs and ensuring efficiency.

For the quality process of airport services, it is necessary to determine the organizational and economic parameters and factors that will ensure the correct quality of airport services.

Organizational and economic assurance of airport service quality management is a set of organizational and economic parameters of ensuring the quality of service management through passenger transport organization, ticket registration, passenger screening technology, customs services organization, quality assurance of airport services, organization of customs services, organization of customs offices, quality control of services, management and control of quality of services, ensuring the development of technical equipment of the service provision process, organization of work to improve airport services and regulation and reduction of costs for the quality of airport services.

Ensuring the quality of airport services is implemented through a combination of organizational and economic factors.

2.2. Analysis of airport service quality assessment methods

Growing demand in the air transport market is leading to new requirements for airport service quality management systems. The high level of airport services determines the efficiency of the airport, which is reflected in attracting additional funding by opening new flights, increasing capacity, expanding the list of services provided and attracting new airlines.

Therefore, to function effectively and assess the prospects of future management, they must have information on the level of quality of services, which will identify their strengths and weaknesses, choose the optimal direction of development. It is therefore necessary to assess the level of quality of services provided by the airport. However, there are currently no centralized rules governing the quality of airport services as well as quality control systems for airport infrastructure.

The main elements of the service quality management system are evaluation and quality control. The service quality control system at airports is based on the standards, recommendations, approaches, methods, and techniques of ICAO, ACI, IATA and the independent UK agency Skytrax.

The most important part of a quality management system is its evaluation, which provides information for analysis and allows you to control the quality of services provided and allows management to make the most appropriate management decisions.

Airport market players have faced the problem of the lack of uniform approaches, criteria, and methods for assessing the level of quality of airport services, and thus the need for the independent development of mechanisms for the regulation of service activities. For this reason, it is important to develop common approaches and methods for assessing the quality of airport services, the results of which are needed when planning measures to improve the quality of services provided by airports.

To determine the methods of assessing the quality of airport services, it is important to understand what indicators can be used to assess the level of quality of service at airports. The main indicators of service quality at airports are:

- speed of passenger registration at the checkpoint (passport control on arrival);
- passenger check-in time;
- waiting time in the registration line;
- the time of delivery of the first piece of luggage

Regularity of flights means strict adherence to the flight schedule of scheduled, charter and additional flights, no delays of departures due to airport staff. Regularity of flights is achieved through the main measures:

1) provision of relevant information to passengers:

- flight arrival / departure time;
- flight delay / delay explaining the reasons;
- any changes to flights and passenger services;

2) professional performance of airport staff, namely:

- high level of knowledge, training;
- desire to provide assistance in customer service.
- self-control and politeness in case of disagreements in the dialogue with clients.

3) storage of luggage, cargo and mail handed over for transport.

The level of services at the airport will be ensured by a comprehensive and high-quality provision of services, namely:

- reduction of formalities before and after departure;
- reduction of waiting time for disembarking the aircraft (timely arrival of boarding / exiting stairs and buses);
- minimum waiting time for luggage;
- terminal information security;
- convenience of transferring passengers between terminals;
- convenience of access and availability of parking;
- availability of additional services: post office, banks, cafes, restaurants, Duty Free shops;
- availability of rest rooms and areas for mothers with children;
- internet security of the airport;
- services for passengers with disabilities, etc.

The issue of the quality of services provided at the airport as one of the participants in the air transport process should be addressed by a comprehensive combination of quality of service measures, taking into account the main and complementary quality indicators.

After the analysis of all available sources of information, which consisted of the work of V.V. Kubicheck, A.V. Andreev, Airport Service Quality measurement methodologists, O.Attalik, Seung Chang Lee and others it can therefore be said that there is a lack of sophistication of approaches and methods for assessing the quality of airport services and the need to create a uniform universal system for assessing the quality of airport services. (3) (4)

Within the problem, the work offers a comprehensive algorithm for evaluating the quality of airport services, which includes a professional assessment of the importance of factors affecting the quality of services, as well as the degree of satisfaction with these factors in a particular airline. The choice of an expert method for assessing the level of service quality is due to the impossibility of using methods of objective determination of the values of individual or complex quality indicators by such methods as instrumental, empirical or computational. The key groups of consumers of airport products are airlines that generate revenue from air transport activities, as well as passengers, so the proposed quality of service algorithm will be based on indicators that determine the quality of service for these two groups. The algorithm is based on the development of questionnaires that contain a list of factors that affect the quality of services at the airport. Factors are developed with a classification by groups to identify the main areas for improvement in airport services.

3. ANALYSIS OF OPERATION AND SERVICES PROVIDED BY BORYSPIL AIRPORT

Boryspil International Airport is a Central Asian state-owned trading enterprise under the administration of the Ministry of Infrastructure of Ukraine. 100% of the share capital of the state enterprise Boryspil belongs to the state represented by the Ministry of Infrastructure of Ukraine. Management is performed by the CEO in the person of Pavel Riabikin. The main tasks of the state enterprise "Boryspil" are:

- timely satisfaction of economic demand and social needs in the provision of air transport services;
- ensuring aviation and flight safety.

Boryspil International Airport is the subject of natural monopolies in terms of ensuring the landing and take-off of aircraft, ensuring aviation safety, ensuring excessive parking of aircraft, providing services at the airport.

Boryspil Airport is the only airport in Ukraine that successfully competes with major European airports. According to the International Airports Council (ACI EUROPE), Boryspil led a growth rating among major airports in Europe in 2018 (first in the group of European airports serving 10 to 25 million passengers). According to the results for 2018, the credit rating of Boryspil International Airport reached the maximum level of uaAAA, the forecast is "stable". The company with a rating of uaAAA has the highest credit rating compared to other Ukrainian companies or debt instruments. The airport is a member of relevant international and national associations: the International Airport Council of the European Region, the Ukrainian Air Transport Association (UATA), the Chamber of Commerce and Industry of Ukraine, the Ukrainian Quality Association, the Employers 'Transport Services Employers' Association, the Association of Taxpayers of Ukraine, etc., and is governed by the standards and procedures of the International Air Transport Association (IATA) and the International Civil Aviation Organization (ICAO). Boryspil Airport is the only airport in Ukraine from which scheduled intercontinental flights operate.

Because of an active policy of attracting airlines, the airport operates more than 40 national and foreign airlines, including: Air Arabia, Air Astana, Air Baltic, Air France, Air Malta, Air Moldova, Adria Airways, Atlasjet Ukraine, Azerbaijan Airlines, Azur Air, Austrian Airlines , Belavia, British Airways, Bravo Airways, Brussels Airlines, Bukovyna, Czech Airlines, Ellinair, Flydubai, Georgian Airways, Iraqi Airways, KLM, LOT, Lufthansa, Myway Airlines, Qatar Airways, Ryanair, SkyUp, SWISS, Turkish Airlines, Ukraine International Airlines, Wind Rose, YanAir, etc. (5)

Demand for airport services is supported by the advantageous location at the intersection of several interstate transport routes (connecting Asia with Europe and America), the proximity of the capital, the availability of modern infrastructure and the implementation of a mushroom development strategy.

The airport infrastructure includes two runways (4 km and 3.5 km long), which allow the reception of aircraft of any type, without limiting weather and light conditions, as well as 2 terminals (D and F). The second runway 18R/36L is currently in limited mode on the sides of terminal F.

Boryspil Airport is constantly striving to improve - developing infrastructure, attracting new airlines, and improving service quality. In 2019, the Cabinet of Ministers of Ukraine approved the Concept for the Development of Boryspil International Airport for the period up to 2045, the main priorities of which are the development of infrastructure and the introduction of modern services.

Boryspil has its core business in three segments: air services, auxiliary air services and commercial services.

Boryspil Airport is the only one in Ukraine with regular transcontinental flights. In line with the airport's "hub" development strategy, implemented since 2015, all international and domestic flights have been relocated to Terminal D, which reduces passenger handling time and significantly reduces the airport's costs for maintaining terminals B and F, which have been temporarily suspended. Exhibitions, presentations, and other events were held regularly in Terminal F, the proceeds of which covered the costs of its maintenance. In 2018, Terminal F was preparing to resume operations as an air passenger terminal from March 2019 due to a significant increase in passenger traffic attracted by the airport. In addition to passenger terminals, there is also a freight terminal.

For a more convenient transfer to the airport was launched in November 2018 Kyiv Boryspil Express - it is a specialized express connecting the main railway station in Kiev with the state enterprise "Boryspil".

The SARS-CoV coronavirus pandemic in 2019 began in December 2019 in Wuhan, Hubei, China. As of March 20, 2022, 470 million people worldwide were ill.

The COVID-19 pandemic also hit the air force hard - since February 2020, and especially in the spring, airlines have significantly reduced the number of flights or suspended flights altogether. As a result of the government's decisions on quarantine, closure and banning or restricting entry, the pandemic crisis in aviation has been the deepest since World War II. In April 2020, the number of flights (compared to April 2019) in the world decreased by 80% and in Europe by 90%.

In the spring of 2020, a complete lockdown was introduced to stop the COVID-19 coronavirus infection. During this period, scheduled flights to Ukraine and abroad were suspended, so the management of the airline UIA based at Boryspil Airport introduced an anti-crisis program to restructure costs, optimize staff and minimize airline costs.

On December 31, 2021, Boryspil International Airport opened its gates to all visitors after a period of restrictions imposed because of the proliferation of COVID-19.

On the morning of February 24, 2022, Russia launched a large-scale war against Ukraine. Missile attacks were launched on several military facilities in Kyiv, Kharkov and Dnipro. Boryspil Airport is said to resume its usual activities as soon as possible after a war.

3.1. Analysis of the production and financial performance of Boryspil Airport

It should be noted that since 2016, the passenger air transport market has been developing relatively dynamically. The number of passengers who have used the services of Ukrainian Airlines has grown by an average of a quarter each year.

Commercial flights of domestic and foreign airlines were served by 20 Ukrainian airports, during the period under review the total number of aircraft departing and arriving reached 182.8 thousand, which is 14.3% more than in 2017. At the same time passenger transport through Ukrainian airports, which crossed the border 20 million, reached 20,545.4 thousand people, which ensured growth of 24.5%. Freight transport increased by 7.8% to 56.4 thousand. tons.

According to statistics for 2018, there was a significant increase in the number of passengers handled at all major airports: Kyiv (Zhulyany) (by 51.9%), Lviv (by 47.9%), Boryspil (by 19.4%), Kharkiv (by 19.3%), Odesa (by 17.8%) Zaporizhzhia (by 14.9%) and Dnipro (by 8.1%). A significant increase in passenger traffic was also recorded at Chernivtsi (by 53%) and Kherson (by 41.8%) airports. (1)

It should be noted that today almost 98% of total passenger traffic and 99% of postal traffic is concentrated at 7 airports in the country - "Boryspil", "Kyiv (Zhulyany)", "Lviv", "Odesa", "Kharkiv", " Zaporizhzhia "And" Dnipro ".

Boryspil Airport is the first state-owned enterprise to make an effective transformation of its business model and in a few years has transformed itself from a stagnant and unprofitable to a highly efficient and highly profitable European leader in terms of growth.

The strategy of building the so-called collection airport (type "hub"), implemented since 2015, is aimed at attracting additional transfer passengers from foreign markets.

At present, the share of transfer passengers reaches almost 30% of the total passenger traffic at Boryspil Airport. Attracting a significant number of additional transfer passengers reduces the cost of serving a single passenger, thus reducing the cost of airport services and making them more attractive to airlines and passengers.

Boryspil Airport, together with the airlines based in it, thus create an aviation product that is attractive on the Ukrainian and international markets. This strategy has ensured a significant increase in the number of passengers attracted to the airport.

Boryspil International Airport handled 9.433 million passengers in 2021 (of which 8.798 million regular passengers, 635.2 thousand non-scheduled passengers), bringing passenger traffic back to 62% of the 2019 level.

According to the website, the airport recorded 75.8 thousand movements in 2021 (of which 64.5 thousand international and 11.3 thousand national), which is 68.5% from 2019.

According to a report by the International Airports Association (ACI Europe), Boryspil led a growth rating in 2021 among major European airports. The airport Boryspil occupied the fourth place in the group of European airports handling 10 to 25 million passengers.

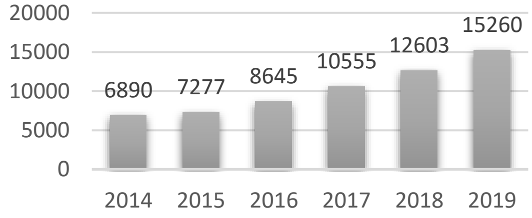

Figure 1. Dynamics of the number of passengers handled at Boryspil Airport during the years 2014-2019. Source: Author's

Stable growth of passenger transport is ensured not only by cooperation with the largest carrier of Boryspil Airport, Ukraine International Airlines (UIA), but also by acquiring new carriers. During 2018, the airport welcomed 10 new airlines. Collaborated with Ryanair, Brussels Airlines, Iraqi Airways, Myway Airlines, Ellinair, Air Malta and Sky Up, renewed its partnership with SWISS, FlyDubai, Air Moldova. The growth of all categories of passengers was ensured, the largest increase was in the category of transfer passengers. In total, more than 50 powerful international airlines fly to the airport. Airlines and passengers at Boryspil Airport are mainly attracted by:

- competitive costs of the company's services provided by transparent "Regulations on the application of reduction factors to airport charges";
- wide geography of Boryspil airport routes;
- according to ACI Europe 2018, the airport is one of the 30 best airports in Europe for the quality of transfer flights;
- high quality of the company's services.

The main part of Boryspil International Airport's revenues (about 59%) consists of revenues from airport fees (passenger fee, aircraft take-off and landing fee, aviation security fee, parking fee). Airport charges are regulated by government agencies, which reduces the flexibility of the airport's pricing policy. (6)

Revenues from airport charges grew at a slower pace than other revenue items in 2018 due to a reduction in the passenger tax rate under the Ministry of Transport and Infrastructure Regulation and the extension of incentives (discounts) to airport charges by 80% for all carriers as recommended by the Antimonopoly Committee of Ukraine.

Other revenue segments of the airport show a very high positive dynamics, mainly due to increased passenger traffic due to reduced profitability of airport charges. Boryspil Airport thus provides an effective profitability management policy that ensures an increase in financial results (revenues and profits) and an increase in passenger transport (satisfaction of social needs and economic demand in the development of air transport).

By summarizing the activities of Boryspil International Enterprise in 2019, we observe stable growth of key indicators.

3.2. Analysis of the current state of activities of Boryspil Airport

Boryspil Airport successfully competes with the leading airports in Europe, so it must meet the latest international criteria and quality standards. To explore and implement best practices and innovations, relevant airport specialists participate in industry exhibitions and conferences, study the latest ICAO and IATA recommendations, and actively participate in the preparation of relevant amendments to national regulations to improve standards and international standards.

Research and implementation of innovations at the airport is taking place in all major areas. According to the results of the research in the years 2017-2018, several innovative technologies were put into operation, which enabled:

- an increase in the capacity of security checkpoints by 40% without increasing the number of staff;
- reorganization of the aircraft parking system on the apron and increase of the number of taxiways;
- shortening the time of inter-flight check-in of passengers, passengers and luggage and increasing the use of parking spaces for aircraft;
- shortening the runway cleaning time in severe weather conditions by 30% and increasing the number of flights served due to the introduction of new high-performance snow removal equipment;
- increasing the number of self-service kiosks for passengers and luggage;
- speeding up the passenger check-in process via Fast Lanes;
- renewal of rescue equipment, which ensured the implementation of recommended international standards and created the possibility of operating modern wide-body aircraft, which are used to develop promising long-distance routes.

Research on best practices and implementation of innovative sectoral and inter-functional solutions at Boryspil Airport is aimed primarily at increasing runway, terminal and transfer zone capacity, reducing passenger and baggage handling times, reducing flight time and number, reducing wage and financial costs per flight. and passenger services. As a result, Boryspil Airport increases labor productivity and reduces unit costs every year.

Boryspil operates in Ukraine, where the political and economic situation in the country in 2018 was largely determined by factors that emerged in 2014-2015. It was characterized by instability, which led to a deterioration of public finances, volatility of financial markets, illiquidity of capital markets, instability of the national currency against major foreign currencies. These factors negatively affect the socio-political, financial and market risks that affect the company's operations.

Boryspil International Airport also operates in the context of sectoral (technical and operational) risks, environmental risks and other risks (cyber threats, public nuisance, terrorism, etc.).

Boryspil Airport identifies and manages risks to ensure its continuity and fulfill its statutory tasks (profit from economic activity, timely satisfaction of economic demand and public needs in the provision of air transport services, safety).

Most of the identified risks are provided with a qualitative assessment based on an expert analysis of the probability of their occurrence and their impact on the company. For each identified risk, a formalized or informal policy will be developed to reduce the potential negative effect. The main provisions of some risk management principles are disclosed (for example, financial risk management policy - in the financial statements together with the independent auditor's report, environmental risk management - in relevant reports, etc.), but some policies (operational, cyber threat prevention, public order prevention, fight against terrorism, etc.) cannot be published.

However, Boryspil Airport systematically publishes the results of the risk management system - production, business, financial, environmental, social, flight safety reports and more. The results confirm that the airport takes all measures necessary to maintain the stable operation and development of the company.

Decree of the President of Ukraine of 04.09.2015 №535 / 2015 "On the decision of the National Security and Defense Council of Ukraine of 20.07.2015" on measures to protect the national interests of Ukraine in the field of aviation "provides for the establishment of an international hub airport (hereinafter" hub "). Pursuant to that decision, the Austrian company Airport Consulting Vienna GmbH has drawn up an updated Boryspil Airport Development Concept. The document was approved by all interested central executive bodies and sent for approval to the Cabinet of Ministers of Ukraine.

The purpose of the concept is:

- ensuring the sustainable development of the airport as an international hub;
- increasing the level of flight safety and aviation security;
- increasing the level of passenger services;
- creating a favorable investment climate for the development of airport infrastructure, including minimizing the use of public funds;
- overcoming growing competition from European airports.

The implementation of the Concept is planned for the period up to 2045 and consists of seven main stages, each of which is determined by the volume of projected air traffic. In implementing the measures defined by the Concept, Boryspil Airport can provide the following traffic volumes: in 2019 - 14.4 million passengers, in 2030 - 28 million, in 2040 - 44 million, in 2045 - about 54 million passengers.

In order to determine the detailed tasks and measures necessary for the implementation of the first stage of the concept Ministry of Infrastructure of Ukraine no. 289 of 28.07.2015 approved the Strategic Development Plan of the state enterprise SE "Boryspil" for the period 2015. -2019. By Regulation of the Ministry of Infrastructure of Ukraine no. 500 of October 29, 2018, the plan changed. The strategic plan corresponds to the "National Transport Strategy of Ukraine until 2030". (6)

According to the Strategic Plan, the factors that will ensure the high competitiveness of the airport in the coming years are:

- the presence of a strong base airline operating on a "hub & spoke" model;
- the availability of a transparent and flexible system of incentives for air carriers, aimed at increasing passenger transport (direct and transfer) and developing a network of routes;
- development of non-aviation activities;
- development of airport infrastructure (terminals, platforms, runways, service systems, etc.) for the provision of comfortable services to passengers and air carriers in conditions of dynamically growing demand and development of the network of routes.

World experience shows that any airport can only become a "hub" through cooperation with basic airlines, which have an extensive network of routes. The synergy between airlines and airports creates a common product that is competitive in terms of "price and quality". Fulfillment of the Development Concept and the Strategic Plan will ensure stable growth of the airport's revenues and the profitability of its activities in the conditions of cheaper air transport.

4. PROPOSAL AND RECOMMENDATIONS FOR IMPROVING BORYSPIL AIRPORT SERVICES

4.1. Research of modern passenger check-in technologies at the airport

Over the last 10 years, the process of passenger transport at the airport has changed dramatically as a result of the introduction of biometric control systems as well as mobile check-in and baggage tracking services. According to SITA forecasts, the development is expected to accelerate in the next 10 years. With the advent of digital transformation in the aviation industry, passengers will discover the endless possibilities of advanced technologies - from taxi flights to airports with their own intelligent system. SITA claims that major changes will affect almost all airport systems.

In a modern world there are many passport control systems. The most common among them are:

- BorderXpress Kiosks
- Global Entry
- Automated Passport Control (APC)

However, the disadvantage of these systems is that passengers must enter data about themselves, but the most effective technology today is the automated passport control system "SmartGate", because this system does not require any additional data.

SmartGate (eGate in New Zealand) is an automated self-service border control system operated by the Australian Border Forces and the New Zealand Customs Service and is located at immigration checkpoints in departure and arrival halls at ten Australian international airports and 4 international airports such as New Zealand. SmartGate enables Australian ePassport holders and ePassport holders from many other countries to go through immigration control more quickly and increase travel security by conducting passport checks electronically. The SmartGate system uses face recognition technology to verify the identity of the passenger against the data stored in the chip in his biometric passport. (7)

With the number of passengers around the borders with Australia and New Zealand continuing to grow, SmartGate systems provide a viable means of coping with this increased burden. The system provides passengers with a more convenient and faster way to get through customs at the airport. (8)

Increased security is also a key feature of the SmartGate system. The use of SmartGate biometric gateways helps ensure that those who should not be in the country and those who should not leave the country do not enter the country, and also helps to limit the use of stolen passports as a means of identity theft.

According to Janet Tyson, of the Australian and New Zealand School of Government, all passengers at Australian airports have benefited from faster handling with SmartGate - on average it took 16 minutes from arrival to customs compared to more than 20 minutes for passengers outside SmartGate who they also benefited from shorter queues. (9)

The SmartGate system was chosen for this diploma thesis, as the airports of New Zealand or Australia are easily compared to the Ukrainian airport Boryspil in terms of the number of handled passengers. Given the work of David K. Kneale from Australia, who conducted research and surveys on passenger satisfaction with SmartGate, we can state that SmartGate could be installed at a Ukrainian airport, as more than 70% of passengers of different ages are satisfied with it. (10)

4.2. Development of project proposals to improve passport control at Boryspil airport

The SmartGate system is automated and allows you to shorten the time when passing passport control, then considering all the results can be calculated how much time in the queue is reduced when using this system.

When using the "SmartGate" system, the passage of the passport control of one passenger takes 18 seconds [17], while in the normal passage of the passport control, this time is 5 minutes. This result can be grounded by taking the average value of a passenger standing in line for a passport control. Naturally, the one who is first in line will pass passport control much faster than the one at the end of the line itself.

Due to the formula for the average request time during service, we will make changes in connection with the introduction of an automated passport control desk.

The task of the Queueing theory is to create recommendations for the rational construction of transmission systems, rational organization of their work and regulation of the flow of requirements in order to ensure high efficiency of service with minimal costs for system design and operation.

The method of the Queueing theory provides the best option for passenger transport, where service time will be minimal and quality - high, without additional costs.

The Queueing theory makes it possible to obtain more accurate calculations to improve the passage of passport control. (11)

Based on the results obtained, it can be stated that the time that passengers spend in a row will be significantly reduced, which has a positive effect on the quality of airport formalities in general.

The Queueing theory thus reaffirms the need to implement the automated passport control system "SmartGate".

4.3. Economic efficiency of SmartGate system implementation at Boryspil airport

Boryspil Airport will be able to automate the processing of passenger data through the installation of "SmartGate" electronic turnstiles based on face recognition. Such turnstiles can be installed in departure and arrival halls in self-service mode without the participation of border guards.

The technical result is an increase in the reliability of the identity verification system by implementing exercises of automatic control of biometric characteristics and documentary data of an individual.

The technical result is achieved by the fact that the system contains the following blocks:

- reception of visual passport scanning data;
- identification of reference addresses of the database of endangered citizens;
- data selection;
- creation of addresses of the database of endangered citizens;
- identification of data of vulnerable citizens;
- receiving data from the database of vulnerable citizens;
- receiving data from the electronic passport integrated circuit;
- identification of visual reading data;
- identification of biological personality parameters;
- receiving fingerprint data;
- task type data records;
- selection of data record types;
- selection of reference addresses of data record types;
- editing of addresses for recording and reading data;
- integration of data recording and reading signals.

Using this system will be useful to save space at the airport. Thanks to the SmartGate system, passenger service time is reduced compared to standard passenger passport control, which improves passenger service and at the same time saves not only time during rush hour, but also money.

4.4. Investment calculation

In the case of the implementation of SmartGate, Boryspil Airport will return the invested money in about 3 years, which is not a bad result in terms of time.

Installing the system will reduce international travel time by an average of 80%, as SmartGate will allow them to scan documents in person without having to spend time completing declarations, such as in other widely used existing systems.

Due to the introduction of the SmartGate system at the Ukrainian airport, it will be possible to save considerable funds from the cost indicators calculated by us, which will allow the airport to direct the saved money to the airport modernization, as originally planned by the Ukrainian modernization program.

As the issuance of biometric passports is gaining popularity today, it is possible to introduce an automated passport control system i.e., to use this system with the participation of a passport control worker. In this case, only holders of biometric passports will be able to pass the automated check. Other passports will be checked manually. Passport control services can also selectively check the passports of those using the automated system until the system is implemented and biometric passports are owned by all those who use air transport. The competent authorities of Boryspil Airport must also consider aviation security measures, border integrity measures, anti-drug measures and immigration controls when implementing SmartGate.

5. CONCLUSION

The work analyzes the main methods of evaluating the quality of airport services. As a result of the study and analysis of a large number of scientific publications, as well as an assessment of the situation in the airport services market, the document presents an algorithm for assessing the quality of airport services that facilitates monitoring of problem areas and making the right management decisions in this area. In addition, this algorithm can be applied to any company that provides airport services, regardless of the scope of activity, legal form of ownership or geographical location.

The analytical part of the thesis analyzed Boryspil Airport, its history and structure; geography of transport; main characteristics of terminals; information systems and technologies implemented at the airport; main production and financial indicators of the airport. Next, an analysis of the airport's revenue and expenditure structure is performed; business competitiveness; the main carriers operating flights to the airport are listed.

The project part of the work dealt with information systems and technologies implemented at the most modern airports in the world and the benefits of implementing SmartGate at Boryspil Airport.

The main purpose of introducing innovative technologies is to improve the quality of passenger services and increase the efficiency of airports and airlines.

Given the positive trends in the demand for air services around the world, the need to improve passenger services and thus streamline operations, the priority of foreign airport management is to optimize the use of available resources and effectively manage passenger flows using the concept of "smart airport".

One of the main stages that ensures the safety of the airport, and its flights is the completion of airport formalities.

The introduction of innovative passenger transport equipment at Boryspil Airport is not only cost-effective but will also help to improve passenger passport control services.The result of the diploma thesis is that by introducing the SmartGate system, Boryspil Airport can save money by reducing the number of employees and return the investment in about 3 years.

REFERENCES

[1] Malinoshevska, K. I. Quality management services at airports. [Online] 2015. [Cited: April 20, 2022.] https://www.econa.org.ua/index.php/econa/article/download/740/549.

[2] Sydorenko, K.V. Dissertation work. Forming the competitiveness of the production infrastructure of international airports. Oles Honchar National University in Dnipro. [Online] 2018. [Cited: April 25, 2022.] https://www.dnu.dp.ua/docs/ndc/dissertations/D08.051.03/dissertation_5bc88f1046198.pdf.

[3] Andreev, A.V. Methodological basis for creating indicators of airport competitiveness estimation. s.l. : Scientific Herald MSTU GA, 2012. pp. 13–19.

[4] Kubicheck, V. V. QUALITY RATING OF SERVICES OF AIRPORT INFRASTRUCTURE. [Online] 2011. [Cited: April 02, 2022.] https://pnu.edu.ru/media/ejournal/articles/2012/TGU_2_18.pdf.

[5] Official website Boryspil International Airport. Boryspil International Airport. [Online] April 10, 2022. [Cited: April 02, 2022.] https://kbp.aero/en/.

[6] Boryspil International Airport State Enterprise Management Report. [Online] February 02, 2020. [Cited: April 18, 2022.] https://kbp.aero/wp-content/uploads/2020/08/Zvit-pro-upravlinnya-DPMA-Boryspil-za-2019-rik.pdf.

[7] Trader, John. Biometric SmartGates Improve Border Security and Airport Efficiency. M2SYS Blog On Biometric Technology. [Online] Oktober 08, 2014. [Cited: April 23, 2022.] https://www.m2sys.com/blog/guest-blog-posts/biometric-smartgates-improve-border-security-airport-efficiency/.

[8] SMARTGATES. [Online] Australian Border Force. [Cited: April 19, 2022.] https://www.abf.gov.au/entering-and-leaving-australia/smartgates/arrivals.

[9] Tyson, Janet. Arriving at SmartGate: the automated passenger processing project. [Online] 2014. [Cited: April 18, 2022.] https://www.anzsog.edu.au/preview-documents/case-study-level-3/943-arriving-at-smartgate-the-automated-passenger-processing-project-b-2014-163-2/file.

[10] Kneale, David K., Baxter, Glenn S. and Wild, Graham. THE USE OF E-PASSPORTS FOR INBOUND AIRPORT BORDER SECURITY SCREENING: THE PASSENGER PERSPECTIVE. [Online] October 10, 2014. [Cited: April 11, 2022.] https://journals.vilniustech.lt/index.php/Aviation/article/view/2930/2408.

[11] KAZDA, A., CAVES, R.E. 2007. Airport Design and Operation. Bingley: Emerald Group Publishing Limited, 2007. 538 s. ISBN 978-0-08-045104-6.

[12] NOVÁK, A., MATAS, M. Models of processes as components of air passenger flow model. Communications-Scientific letters of the University of Zilina 10 (2), 50-54

https://doi.org/10.26552/ pas.Z.2022.2.28

PROBLEMATICS OF AIR TRAFFIC NOISE AROUND TRENČÍN AIRPORT

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Abstract

The choice of the topic reflects long-term need of municipalities around the Trenčín airport to handle the situation regarding noise exposure from air traffic. The main goal of the thesis is to evaluate and to design optimal flight procedures and practices to decrease noise polution in the vicinity of the airport. In thesis we analyze public and flight crew and airport operator opinion from multiple points of view. We compare the perception of the public, their social situation to the present air traffic operations and flight practices. The thesis includes analysis linked to the by-laws, regulations and standards and recommended practices on Public Health Authority of Slovak Republic and European union legislation with respect to public noise regulations, flight rules, air law, flight safety and aircraft noise certification. We compare the issue to similar examples of noise restrictions abroad.

Keywords

Aircraft operation, Traffic noise, Flight procedures, Noise reduction, Public opinion, Airport design

1. INTRODUCTION

In recent years, residents in the vicinity of Trenčín Airport have increasingly complained about increased traffic and thus increased environmental noise pollution from flight operations. At present, the airport is mainly used for the needs of aircraft repair shops, the Armed Forces of the Slovak Republic, the air ambulance service, private flight schools and the aeroclub. Trenčín Airport has historically had an important position in its area. In the past, the Trenčín Air Repair Works was one of the largest employers in the region. In this period, the airport was responsible for an incomparably higher number of aircraft sorties than at present. There were very few public complaints about noise from flight operations in those times. Numerous complaints from residents of the surrounding villages started to come in from 2010. People cited noise from aerobatic flying and noise from aerotow aircraft as the main reason for complaints.

To date, noise has been dealt with at the municipal level, without significant interference with air traffic. To date, there has been no wide-ranging and comprehensive public opinion survey to define more precisely the main reason for the complaints. The aim of this thesis is to analyse the source of noise, the needs and dissatisfaction of the inhabitants. This thesis summarizes the important points of the issue and provides suggestions and recommendations for partial reduction of the noise burden.

2. CURRENT LEGISLATION OF THE SLOVAK REPUBLIC IN THE FIELD O NOISE

The basic legal framework in the Slovak Republic for the establishment of details on the permissible values of noise, infrasound and vibration in the environment, and on their requirements for objectification, is the Decree of the Ministry of Health of the Slovak Republic No. 549/2007 Coll., No. 549/2007 Coll., No. 549/2007 Coll [1].

3. AIRPORT TRENČÍN

3.1. History and present

Trenčín Airport has historically played an important, not only strategic, but also social role in the Central Povazie region. It was founded in 1938. At the time of its greatest boom, the state-owned company Aircraft Repair Works Trenčín employed several thousand employees in various positions requiring a wide range of highly skilled and highly specialised personnel for the aviation and armaments industries. The factory also included a secondary vocational school of aerospace engineering, whose graduates found direct employment in the industry. The work associated with light and heavy maintenance of various types of aircraft has always been associated with a lot of ground and flight testing and sorties [2].

Currently, the main types of aircraft repaired at the Trenčín Aircraft Repair Plant include Mi-8/17/171 helicopters, L-39 jet trainer aircraft and L-410 transport aircraft. In 2021, an extensive modernisation of the main aircraft repair hangar was completed, which may mean a potential increase in the capacity of repaired aircraft in the future [2].

4. FLIGHT OPERATIONS AT TRENČÍN AIRPORT

The airport is equipped with two runways, one of which is a concrete runway and the other a grass runway. Concrete runway 04/22 with a length of 2000 metres is mainly used for the needs of the Slovak Army and training flights of flight schools operating at this airport. The grass runway 03/21 with a length of 1000 metres is mainly used by the Trenčín Aero Club for recreational and gliding flying.

Figure 1: VFR map of Trenčín Airport [3]

5. THE CURRENT SOLUTION TO THE PROBLEM

Trenčín Airport does not currently have any official published procedures to reduce noise in the vicinity of the airport.

Figure 2: LOTN [4]

The only, officially unpublished, restriction of the airport is a ban on aerobatic flights on Sundays, public holidays and public holidays. Notice TWR/10B/2017 is dated 06/26/2017. It comes into force on 1 July 2017 and until revoked, the aerobatic aircraft flying ban at Trenčín Airport is issued on Sundays, public holidays and public holidays. On weekdays and Saturdays, aerobatic aircraft operations are permitted between 08:00 and 18:00 LOC [5] [6].

6. OPERATORS

Private aircraft operators and flying clubs based at Trenčín Airport currently account for the largest part of the movements. The activities of these entities are mainly focused on the provision of both commercial and non-commercial services such as pilot training, aircraft rental, aerotaxi, aerial work and adventure flights. An important company-wide role is played by the air ambulance service. Most of them have a long-standing presence at Trenčín Airport.

7. THE MOST FREQUENTLY OPERATED AIRCRAFT TYPES

The following table shows the types of aircraft that are most frequently operated at Trenčín Airport. These are single-engine piston, twin-engine piston and twin-engine turboprop aircraft of various orientations. The table is aimed at comparing each aircraft in relation to the highest noise level generated during take-off mode together with the permissible noise values for the aircraft category.

Table 1: The types of aircraft that are most frequently operated at Trenčín Airport [7]

Typ lietadla	TCDSN	Motor	Vrtuľa	MTOW (kg)	Vzletový režim dB (A)	
					Level	Limit
Z-142	EASA.A.027	M337 AK	V 500 A	1090	72.4	74.5
Z-43	EASA.A.028	M337 AK	V 500 A	1350	77.7	78.0
Z-526F	EASA.A.353	M137 A	V 503 A	975	78.2	82.9
Z-226 MS	EASA.A.353	M137 A	V 503 A	890	81.6	81.6
C-152	C2079 10(10.4a)	O-235-L2C	1A 103/TCM6958	758	66.8	79.3
C-172	C5727 10(10.4a)	O-320-D2J	1C 160/DTM7557	998	75.8	83.8
DA-20 A1	EASA.A.223	Rotax 912 A3	HO-V352F-170FQ	730	64.8	78.8
DA-40	EASA.A.022	IO-360-M1A	MTV-12B/180-17	1200	78.7	81.5
DA-42	EASA.A.005	2xTAE 125-01	2xMTV-6ACF/CF187-129	1785	76.8	88.0
L-200A	EASA.A.043	2xM337 SH	2x410(A)T	1950	**	**
A-109K2	EASA.R.005	Arriel 1K1	2 x rotor	2850	91.7	94.6
EC-135 P2+	EASA.R.009	PW206B2	2 x rotor	2950	88.6	94.7
L-410 UVP E20	EASA.A.026	M601 E-21	V 510	6600	85.4	88.0
EA-300L	EASA.A.362	AEIO-540	MTV-14BC/C190-17	950	77.3	82.5
Z-50M	EASA.A.108	M137 AZ	V 503 A	700	**	**

The most frequent operating aircraft types at Trenčín Airport and their noise level comparison according to TCDSN [7]

All aircraft operated according to Table 1 meet the noise limits of Annex 16, VOLUME I. and thus do not violate international standards.

8. CURRENT SOCIAL SITUATION

According to the Trenčín Aircraft Repair Works, the most complaints related to noise from flight operations have been recorded from the municipalities of Trenčianska Turná and Trenčianske Stankovce, among the towns and villages around the airport. The inhabitants of these villages started to actively express their opinion in public groups on the social network Facebook. The most frequent complaints were noise from aerobatics and noise from aerotow aircraft. People were most unhappy about noise from flight operations on Saturdays, weekends and holidays. These are the days when the number of flights from Trenčín Airport is the busiest. The bulk of the activity is associated with leisure flying. Consequently, recreational, sport and pilots-in-training used their days off mainly for this kind of recreation.

9. COOPERATION WITH STAKEHOLDERS

As a first step, the airport operator, Letecké opravovne Trenčín, akciová společnost, was contacted. After an initial e-mail communication and a subsequent telephone contact, a first personal meeting was held with the CEO, Mr Ing. Juraj Lauš. At the initial meeting, the structure of the thesis and the expected objectives were presented to Mr. Lauš. He was very supportive of the idea and expressed his full support, patronage and cooperation in the development of the thesis. Mr. Ing. Lauš described the issue from the airport operator's point of view, the current situation within flight operations and also defined the most problematic places around the airport, from which the greatest number of complaints come from. These are the municipalities of Trenčianska Turna and Trenčianske Stankovce.

The telephone numbers of the mayors of the aforementioned municipalities have been traced via the official websites.

After an initial telephone contact and a brief explanation of the issue, we accepted an invitation to a personal meeting, which took place at the municipal office of the municipality of Trenčianska Turná. The meeting was attended by the mayor of the municipality of Trenčianska Turna, Mr Ing. Peter Mikula and the Mayor of Trenčianske Stankovce, Mr. JUDr. Martin Markech. At the beginning the basic objectives of the thesis were explained. Afterwards, a discussion on the topic took place in which the mayors of both municipalities expressed the long-term need to address the situation. Both of them unanimously confirmed the mass complaints of the inhabitants, especially during weekends and weekdays. At the same time, both are aware of the socio-economic benefits of the airport for the region, whether in terms of repair activities, strategic importance or leisure activities.

10. RESULTS OF THE QUESTIONNAIRE

According to the results of the questionnaire, the return rate of questionnaires was 61% from the municipality of Trenčianska Turna and 39% from the municipality of Trenčianske Stankovce. From the supplementary question, it can be stated that noise nuisance as a rule bothers more the inhabitants of the streets that are closer to the airport. 76% of the respondents have lived in their current place of residence for more than 10 years. Which did not support the theory that newly arrived residents are more susceptible to noise. According

to the results, noise is particularly bothersome to people who have been in the home for a long time or are unemployed, retired or housewives. Noise in the outdoor environment bothers most of the respondents. Air traffic bothers residents especially on Saturdays, Sundays, public holidays and public holidays. Noise is perceived as most disturbing by those without children or parents with children aged 6-12.

11. LAST NOISE POLLUTION MEASUREMENT IN THE VICINITY OF TRENČÍN AIRPORT 2021

On the basis of repeated complaints of residents living around Trenčín Airport and the subsequent suggestion of the Regional Hygienist Žilina, Office of the Chief Hygienist of the Ministry of Health of the Slovak Republic, No. 19466/2020/UVHR/71553 of 17 September 2020, the operator of Trenčín Airport ordered the measurement of the noise load in its surroundings. The measurement was carried out by the testing laboratory EUROAKUSTIK, s. r. o., Letisko M. R. Štefánika 69, Bratislava. The measurement was focused on the noise impact of the operation of aeroplanes during aerobatics training, for the requirements of the Act of the National Council of the Slovak Republic No. 355/2007 Coll., on the protection, promotion and development of public health and on the amendment and supplementation of certain acts, as amended.

For the purpose of the measurement, usually used aircraft for aerial acrobatics were deliberately selected. These aircraft are CAP 231, Zlín Z-50M, Zlín Z-142 and Zlín Z-526F. Most of them can be found in Table 2.

The test laboratory protocol No: SLE-200607/AK dated 28.06.2021 fully confirms compliance with the applicable legislation for aerobatic flight operations. At none of the six objectification points, including measurement point M3, were the permissible values of the determining variables exceeded in the reference time period of day and evening. The reference time period night was excluded because the monitored sound sources are not operating. [8].

12. RECOMMENDATIONS FOR NOISE REDUCTION AROUND TRENČÍN AIRPORT

VFR noise procedures - We propose to define arrival and departure VFR routes, which will be subsequently published to the aviation public via the Aeronautical Information Guide of the Slovak Republic (AIP SR). The aim of such routes is to ensure as far as possible that arriving and departing aircraft are routed away from populated areas and to draw the attention of pilots to places to avoid and thus reduce the noise pollution of the population. Such routes also include the need to use optimum flight regimes to reduce noise.

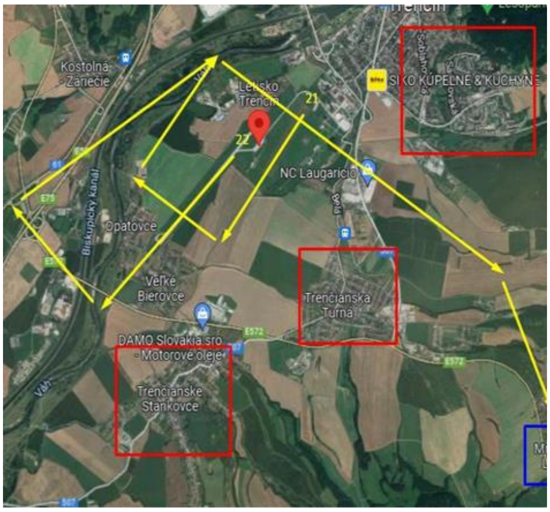

Figure 3: Departure tracks for runways 21 and 22 [9]

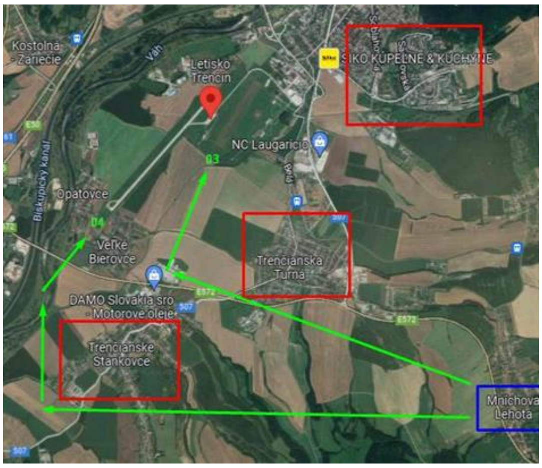

Figure 5: Arrival tracs for runways 03 and 04 [9]

12.1. Definition of an alternative flight box for aerobatics:

For the purpose of aerial acrobatics, the defined airspace already mentioned in this thesis is used. This box is located immediately above the aerodrome near the village of Trenčianska Turna. An alternative is to mark out a second flight box. In case of intensive training, two will be available, which can be alternated and thus the noise load can be distributed.

Figure 4: Alternative acrobatic box [9]

12.2. Defining noise restricted areas:

We propose to define noise restricted areas beyond the flying rules, which the pilot is obliged to avoid in case of local activity or overflight of Trenčín Airport. Such an area would extend from the ground to 2500 ft AGL, which is a prerequisite for noise abatement. Our recommendation is the areas over the villages of Trenčianska Turna, Trenčianske Stankovce and the Juh housing estate.

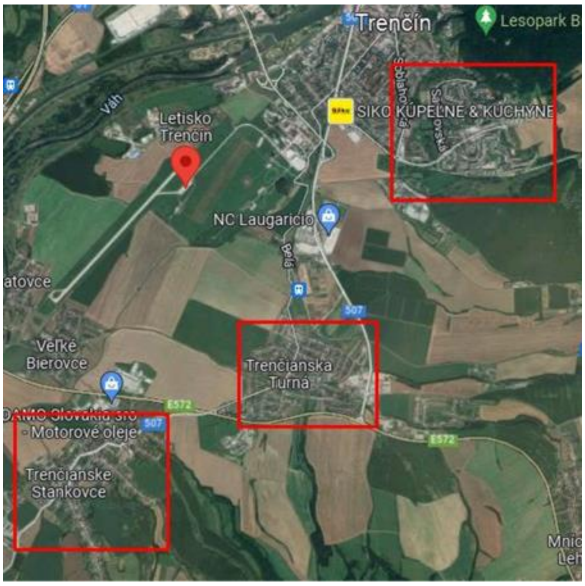

Figure 6: Noise restricted areas [9]

12.3. Adjustment of the permitted flight time for aerobatics:

Currently, aerobatic aircraft are prohibited to fly at Trenčín Airport during Sundays, public holidays and public holidays. On weekdays and Saturdays aerobatic aircraft operations are permitted between 08:00 and 18:00 LOC. We propose to amend such prohibition as follows. On weekdays and Saturdays, allow aerobatic aircraft operations from 09:00 to 17:30 LOC with a mandatory break between 11:00 and 13:00 LOC. Such a mandatory break will create space for a quiet lunch break for the residents of the airport vicinity. Such an arrangement could be partially relaxed with the agreement of the municipalities.

12.4. More active use of gliders' winch take-offs:

Winch take-offs of gliders are a common practicein gliding both at home and abroad. The Trenčín Aeroclub, as the only operator of gliding at the Trenčín airport, also has a winch in its equipment. Take-off with the help of a winch has undeniable advantages. First of all, it is a cheaper method of take-off compared to towing aircraft. Secondly, a shorter interval between two consecutive glider take-offs is ensured. In other words, there is no need to wait for the tow plane to return from the previous aerotow.

13. CONCLUSION

It is necessary to underline the fact that Trenčín Airport with its current number of movements is far behind the historical data. For continuous noise monitoring, it would be necessary to meet the requirement of at least 50 000 movements per year in accordance with Act 355/2007 Coll. on the Protection, Promotion and Development of Public Health and on Amendments and Additions to Certain Acts. At present, the number of movements is calculated at a maximum of two thousand per year. Even in the case of aerial acrobatics, the noise limits have not been confirmed by measurements to be exceeded. It should be noted that aerobatics training is carried out occasionally, several times a year. In order to take into account the real disturbance to the public, there would have to be 30 such flights per day. It can therefore be concluded that the occasional disturbance caused by aerobatic flights may be a nuisance, but is not subject to a total ban. Both direct and indirect methods have been proposed to reduce noise, which may help not only to reduce noise in the vicinity of the airport but also to increase the popularity of aviation.

REFERENCES

[1] Vyhláška č. 549/2007 Z. z. Vyhláška Ministerstva zdravotníctva Slovenskej republiky, ktorou sa ustanovujú podrobnosti o prípustných hodnotách hluku, infrazvuku a vibrácií a o požiadavkách na objektivizáciu hluku, infrazvuku a vibrácií v životnom prostredí v znení neskorších predpisov. [online]. [cit. 2022.02.03.] Dostupné na internete: <https://www.epi.sk/zz/2007-549/znenie-20090701>.

[2] TOMEŠ, M. 2004. Junkers Ju 87 Stuka. [online]. [cit. 2022.02.04.] Dostupné na internete: <https://www.valka.cz/10765-Junkers-Ju-87-Stuka>.

[3] Letecká informačná služba Slovenskej republiky. [online]. [cit. 2022.02.04.] Dostupné na internete: <https://aim.lps.sk/web/index.php?fn=204&lng=sk&doc=75771&vfrmsk=1&sess=53kvleBvnHZM SUM38chIe1zkAQ22rXeYAGAJAIBE>.

[4] LOTN. História a súčasnosť. [online]. [cit 2022.02.04.]Dostupnénainternete: <https://lotn.sk/sucastnost-historia-leteckych-opravovni-trencin/>.

[5] AIP. Letecká informačná príručka. ENR 1.4 Klasifikácia vzdušného priestoru ATS. [online].[cit. 2022.02.15.] Dostupné na internete: <https://aim.lps.sk/eAIP/eAIP_SR/AIP_SR_valid /html/LZ-ENR-1.4-sk-SK.html>.

[6] Lietanie v „G-čku" [online]. [cit. 2022.03.18.] Dostupné na internete: <http://letectvo.nsat.sk/wp-content/uploads/sites/2/2014/11/Lietanie-v-priestore-G.pdf>.

[7] EASA. EASA Certification Noise Levels. [online]. [cit. 2022.03.12.] Dostupné na internete: <https://www.easa.europa.eu/domains/environme nt/easa-certification-noise-levels>.

[8] KAMENICKÝ, M. Protokol č. SLE-2106007/AK, Skúšobné laboratórium – EUROAKUSTIK.

[9] Letisko Trenčín. [online].[cit. 2022.02.18.] Dostupné na internete: <https://www.google.com/maps/place/Letisko+Tren%C4 %8D%C3%ADn+(ZTN)/@48.8653073,1 7.982146,14z/data=!4m5!3m4!1s0x4714a143390 c95dd:0x6ff3027055cc4033!8m2!3d48.869137!4 d18.0024514>.

[10] KAZDA, A., CAVES, R.E. 2007. Airport Design and Operation. Bingley: Emerald Group Publishing Limited, 2007. 538 s. ISBN 978-0-08-045104-6.

[11] KAZDA, A. 1995. Letiská design a prevádzka. Žilina: Edičné stredisko VŠDS 1995. 377 s. ISBN 80-7100-240-2