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DEVELOPMENT OF FLIGHT INSTRUMENTS FOR GENERAL AVIATION AIRCRAFT

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Abstract

Given the constantly evolving offer proposed for aircraft equipment, the aim of my work is to describe the innovations, that have been implemented in aircraft instruments. The content of the work is divided from the very beginnings of aircraft instruments and their gradual use and expansion. Subsequently, I deal with the data that are displayed by the devices, but also their design and the comparison of the current state compared to the initial versions. Innovations of aircraft instruments are focused on both components and the display of flight data, which leads to simplification of their operation and individual assembly. One of the advantages of modern instruments is their ability to detect errors that may occur during the flight, which serves the pilots to ensure the flight. Furthermore, I focused on the system of collection, processing and evaluation of information, as well as their final production on board the aircraft. My work is mainly focused on the Dynon system, whose functions, display and implementation I described in detail, use and design in aircraft cockpits. The main goal of the thesis is additional processing of information for the subject Aircraft Instruments I and their processing from the student's point of view.

Keywords

Flight Instruments, Flight data, Displays, Inovation, System EFIS, Processing method, System setup, System errors

1. INTRODUCTION

With the growing demand for air travel, they have grown to design, display data, as well as versions that are displayed as accurately as possible and easy for the pilot to read during the flight. A characteristic feature of technical development is, in particular, the simplification of the implementation of aircraft instruments as well as their smaller construction dimensions.

The work describes the gradual improvement of aircraft instruments, their components and the use of new systems in the field of computer technology on board aircraft. The transition from classic, analog instruments to the use of LCD screens has made the components and display of flight data easier to read for the pilot, but they also represent advantages for their installation by relieving the maintenance requirements of aircraft instruments for designers. The components used in the beginnings of aircraft instruments have been replaced by those aircraft, and the structural elements have greatly reduced the weight of the aircraft, which is very sensitive to efficient mediation in air transport. More modern design elements bring many advantages, which are described in the work.

The work is focused on systems installed in the aircraft of the University of Žilina, which are included in the basic training of pilots. The aim of this work is a detailed description of the Dynon system. It contains a description of the SkyView SE system, as well as its settings and extensive data display. The main task is to provide information about the system, its settings and analysis of individual information that the system combines and then processes.

Advanced flight data processing systems include the introduction of Inertial Navigation Systems, an aerometric computer and the introduction of integrated modular avionics, which combines products from different manufacturers into one system. Ensuring fast data processing is beginning to use bus systems, displaying data on screens, which have gradually replaced the classic analog display.

2. MODERNIZATION OF INSTRUMENTATION

Modern technologies have made it possible to introduce electrical flight instrument display systems into the aviation. The information displayed on the screens works with the information from the sensors, while it is transmitted via buses to the on-board computers. which evaluate them. The basic task of the EFIS system is an efficient and reliable replacement of electromechanical instruments as well as gyroscopic instruments. Its great advantage is the relatively simple structural maintenance, as well as the elimination of the high degree of wear of the mechanical parts of analog devices. As regards the operation of instruments combined in the EFIS display, the crew must be sufficiently familiar with and trained in its operation.

2.1. Bus systems

Bus systems are used for data transmission, so-called serial transmission, which we divide into a one-way bus system or a two-way bus system.

The two-way serial system represents the principle of sending and receiving a message by each radio exchange unit - RVJ, based on the use of time multiplexing of messages, which means that at a given moment one RVJ is active and the rest listen.

Half-duplex transmission is a mode of two-way communication - alternately, but at the moment this transmission is only one-way. In half-duplex transmission, one bus circuit of transmitting and receiving RVJ is created. The control of such transmission can be centrally and distributed. Bus control is challenging.

The one-way serial system is a simpler design, as each RVJ uses one bus, a large amount of cabling is created - it reads and monitors all messages [1].

3. MODERN AERONAUTICAL DATA PROCESSING SYSTEMS

EFIS combines information on position, flight speeds as well as vertical speed, flight altitude, slope and more. It also allows you to view the terrain map, plot the terrain, or traffic in space. Further display of meteorological conditions, engine flight data, if the ECAM system is included in the design, while the information is displayed on one or two displays. These are PFD - primary flight display and MFD - multifunctional flight display.

The PFD display includes the basic instruments needed for the flight. In general, it displays altitude, flight speed, vertical speed, position, course, and slope [1,4,5]. The MFD display shows the real situation in the cockpit, it can also display a moving map, approach maps, terrain warnings. The transition from analog devices to LCD displays had several advantages, the most important of which are:

• weight and size reduction,

• prevention of wear of moving parts,

• more efficient and clear data display,

• increased safety due to better readability.

3.1. Displays used in aircraft

Innovations in data display technologies on board aircraft are gradually moving to the use of LCD displays. Although most manufacturers mainly use LCD displays for their equipment, we also encounter the use of CRT displays.

A CRT screen is basically an image rendering of millions of dots in the basic RGB color scale (red, green, blue), which, when in contact with an electron beam in the screen, lights up and renders the desired image [1,3].

At the back of the monitor is a light source, which is most often in the form of a CCR (cold cathode) cathode and is replaced by LEDs. Light passes through the layers and its task is a homogeneous distribution of the light layer on the display surface. The rays pass through a polarizing filter made of liquid crystals. The light is white, after passing through the RGB filter it passes to the polarizing filter. At the top of the display, three layers are introduced, the purpose of which is even light distribution and image quality [1,3]. The use of LCD displays in the cockpits of aircraft brings several benefits. Displays last longer and render images more reliably in a variety of low-cost flight conditions [10].

4. SYSTEMS INSTALLED IN THE AIRCRAFT OF THE UNIVERSITY OF ŽILINA

GARMIN and Dynon systems are installed in the aircraft of the University of Žilina for basic training. As the topic of GARMIN instrumentation has already been processed, the work is mainly devoted to the Dynon SkyView SE system. User manuals for the systems are issued by the companies in English as well as the menu of the instrument system on board the aircraft is displayed in English. For this reason, some terms in the following chapter are given in English, for a better understanding of the system and inefficient use of translations when operating the devices.

4.1. Zlin Z242 L

The Zlín Z 242 L aircraft model has the Garmin G500 TXi system installed, which is displayed on the PFD and MFD. Based on static and total pressure, the pitot-static system displays basic flight data on the primary display unit. This data is processed using ADC - air data computer. Position and direction tracking is provided by AHRS, which is combined into one ADAHRS unit. The basic task of the primary display is: to display altitude, true airspeed, vertical speed, reference position of the aircraft with respect to the horizon, direction and information for navigation in space. The display on the multifunction display is mainly on map information, information about the terrain around the aircraft and navigation information [13].

5. DYNON SYSTEM

Dynon produces devices in aircraft cockpits with lower display complexity and cost. The company's main goal was to effectively reduce the cost of their systems, making them significant. This is mainly a limitation of functions for IFR flights. The devices are intended for use in VFR flight conditions. SkyView SE displays operate in PFD mode - primary flight display or EMS - engine management system.

5.1. Viper SD-4 RTC - DYNON EFIS-D600/900

The Viper SD-4 RTC model is equipped with the Dynon EFIS D900 system using the SkyView SE display. These systems are suitable for VFR flights. Flight data can be configured on board the aircraft using the SkyView system according to your requirements.Dynon EFIS-D900 is an electronic, information system with a 10-inch display that combines several aircraft instruments such as a magnetic compass, variometer, transverse inclinometer, flight clock and more. It is designed especially for small aircraft of general aviation. The information is displayed differently, depending on the screen layout selected.

The displays are powered in series via five ports connected to the SkyView Display Harness (SV-HARNESS-D37). These displays use LED backlighting (described above), precisely because of their advantages, especially regarding uniform backlighting and also reduced energy consumption [7,9].

Table 1: Dynon displays configuration [7].

Parameters	100%	80%	50%	20%	OFF
PFD	✓	✓	✓		✓
EMS	✓		✓	✓	✓

5.2. USB ports

SkyView has three inputs to USB ports, two in the back and one in the cable harness, which is used for more accessible USB connection to the system. Two of these inputs are for firmware for system updates, backup and the ability to download data from the database. Only one USB key can be connected at a time [7].

5.3. System operations

Operation is via eight buttons located on the bottom edge of the display frame and two joysticks. They are used for various instructions, including the possibility of switching the system on and off, navigating the systems and also for adjusting values [7]. The display can be in display mode 1/1, which means display in full screen, or in mode 1/2 or 1/5. This is the data of the PFD display and information about the engine, when we select how much space the data should take up. Table 1 Percentage display of individual parameters on the Dynon display [7].

5.4. Display synchronization

If there are multiple displays on board the aircraft, SkyView SE will synchronize the information between these displays. When there are multiple displays on the aircraft, it is only necessary to make changes, set data and acknowledge alerts (if they appear) on one display. Certain data that can be set up with SkyView SE is intentionally not synchronized. For example, the layout of the data displayed on the screen is different for each display and is not synchronized. If Ethernet access is on board, it is possible to link airport frequency data from the radio database. If there is no Ethernet connection, airport frequency data cannot be synchronized between screens [7].

5.5. Skyview compatible applications programs

SkyView systems allow you to synchronize application programs from a tablet or mobile phone using a Wi-Fi adapter. These programs include the possibility of flight planning and preparation. Subsequently, by connecting to the SkyView system, this plan can be displayed on the flight display. These are applications from Seattle Avionics, FlyQ, ForeFlight Mobile, PocketFMS Easy VFR, iFlyGPS and SkyDemon [11].

5.6. Main features of SkyView SE

Leading features of this system include the ability to monitor engine parameters, display devices on the screen and in the format of analog devices, autopilot installation, angle of attack monitoring and compatibility with ADS-B Out [6,8].

<u>The main parts displayed by the PFD</u>

The primary flight display combines information:

• Air speed as well as its errors, trend indicator.

• Position indication together with warning of excessive approach angles.

• Altitude information, barometer settings and altitude.

• Vertical speed along with its error.

• Directional gyroscopes.

• Transverse inclinometer.

• Indication of the angle of attack.

• Wind information.

The information combined on the PFD display is generated from calibrated sensors that are part of the SV-AHARS-200/201 module. The devices have fixed parts. Measurements in all three directions are using accelerometers and thus sensors: rotational speeds (rotation around three axes), pressure transducer (air data) and magnetometers (measuring the magnetic course on all three axes). The sensors are the core for Dynon Air Data Attitude and ADAHARS [7].

5.7. ADAHARS

The Air Data and Attitude Heading Reference System is a system that groups position, course, and air information. It is a reference system using MEMS sensor sensing technology to measure magnetic, inertial and air data.

5.7.1. <u>How does ADAHRS works</u>

Alttitude calculation - the display of the artificial horizon SkyView SE is generated by an algorithm using sensor data. The system uses air speed to make the calculation as accurate as possible. If the pitot sensor input is blocked, GPS information will be used. If there is information in the GPS system, it notifies it with a GPS ASSIST message.

Magnetic compass - the accuracy of synthetic vision, map performance and autopilot are affected. Therefore, it is necessary that the Mk - magnetic course be as accurate as possible. The ADAHRS and magnetometer must also be installed and calibrated correctly to work in any position. As the system is sensitive to such magnetic interference, the SV-ADAHRS-200/201 and the installation of a remote gravity magnetometer outside the box are implemented so that its interference is minimal. SV-MAG-236 serves these requirements.

Engine data - this information is obtained from SV-EMS-220.

Engine Monitoring sensors - t measures various parameters such as rpm, line pressure, EGT exhaust gases, CHT cylinder head temperatures, oil, fuel and coolant pressure, fuel level, voltage, current. The system can display the temperatures of all cylinders on a display for easy comparison by the pilot.

GPS receivers - SV-GPS-250 and SV-GPS-2020 modules are used for this. These are 5Hz GPS receivers that receive WAAS-enabled information that is designed specifically for this system. The data is in NMEA format. The SV-GPS-2020 module is compatible with ADS-B Out 2020.

Uninterruptible power supply - SV-BAT-320 battery serves as an alternative power supply for operation at least 60 minutes from the moment of electrical system failure.

VHF radio - module SV-COM-25 integrated VHF radio has two modules SV-COM-425 and SV-COM-PANEL with a spacing of 25kHz.

Optional control panel - SV-KNOB-PANEL is an optional module that consists of three buttons and is recommended especially in systems with autopilot installed. Used to correct the most common errors in the system.

Autopilot function - using SV32, SV42 and SV52 and allow this system to operate in autopilot mode [7,8].

6. DATA COLLECTION METHOD

The entrance to the system is located on the left wing from the bottom, from where the total pressure is led to the ADAHRS and the barometric air velocity indicator. The approach angle is processed in the ADAHRS. In the upper part of the vertical stabilizer we find a static pressure sensor for measuring its value, from where it is transmitted to the ADAHRS system, which then evaluates the data for the analog speedometer and analog altimeter [7,12, 16].

Course information and barometric data are transmitted from the ADAHRS system to the EFIS system and EMS, which are collected in the Data Bus in digital form [7,12,18].

Engine information shows the engine intake manifold pressure as well as the speed on the EFIS page. To obtain the measured parameters, it is necessary to correctly install the pressure sensor and the tachometer drive, using an EMS-based configuration that is connected to the DSAB [7,17,19].

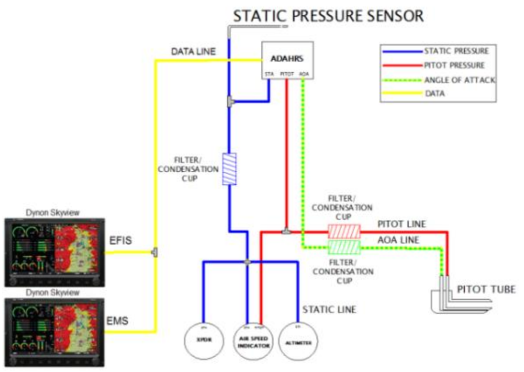

Figure 1: Dynon EFIS and EMS system. [7]

6.1. Message alerts, notifications and alerts

Button 8 is used for the notification area, where all system messages are accessible. This area is used to inform about messages and alerts. In SkyView, these alerts are categorized into 3 areas according to the severity and impact of the flight. These areas are divided into messages, alerts and warnings.

6.2. System check

SkyView SE obtains data from the ADAHRS system. This data is constantly cross-checked. In the event of a system failure, it switches to backup modules in the event that ADAHRS fails completely. A notification about parameters that are not identical in the system is displayed on the screen. The parameters are cross-checked and include: position, magnetic course, G meter, rotation coordinator, air speed and altitude.

6.2.1. Message alerts, notifications and alerts

Button 8 is used for the notification area, where all system messages are accessible. This area is used to inform about messages and alerts. In SkyView, these alerts are categorized into 3 areas according to the severity and impact of the flight. These areas are divided into messages, alerts and warnings.

Breakdown of messages by severity:

1. MESSAGE - Advisory report.

2. CAUTION - Abnormal condition, but not critical. There may be an increase in the pilot's workload.

3. WARNING - Critical condition. The need for an immediate solution affects flight safety.

In a situation where the system detects a message or a critical or abnormal condition, a visual indication is displayed in the notification area. This label appears and flashes until the user opens the notification area. If there are multiple alerts in the system at the same time, the system points to the alert with the highest severity.

CAUTION Warning - When the system detects a second severity error, a CAUTION message, it will display a flashing message in the display bar. The following events occur with this alert:

- If there is an audible warning for a given error, it will be played as soon as the error is detected by the system.

WARNING - A WARNING warning is displayed when the system evaluates a system fault with the highest severity. Whenever this error is evaluated, a red warning is triggered. The following events may occur:

- If an external alarm check is installed, it will flash. This represents errors that are due to EMS - Engine Malfunction / Engine Activity Report.

- If there is an audible warning for a given error, it will be played as soon as the error is detected by the system.

- If the origin of this error is an engine parameter on the ENGINE page, this parameter will be highlighted in red and will flash at the same time.

Motor status warnings are only displayed if the sensors are correctly activated and configured. If the sensor alarm is configured as off, the error will not appear on the display even if the sensor measurement is recorded as a third level alarm.

7. CONCLUSION

Instrument development is an essential part of general aviation. Aviation personnel need to be sufficiently qualified and familiar with the systems installed in the aircraft they operate. We have seen the greatest technological progress in aircraft instruments since the Second World War. Many changes have been implemented since then. Given the rapidly evolving technology in the field of aviation, we can consider this development to be a great step forward and a benefit for aviation personnel in terms of simplifying the acquisition of flight information.

The aim of the bachelor thesis was to approach the innovation in the display and design of aircraft instruments, which have been carried out since the beginning of instrumentation. In the bachelor's thesis, we also focused on the benefits for aviation personnel in terms of the effectiveness of the use of new technologies on board aircraft, as well as their effective impact on the design characteristics of aircraft. The main benefit of these innovations is the ability to display warning messages and self-detection of certain problems that we may encounter during the flight as well as during operation. When using displays on board aircraft, we relieve aircraft components from heavy mechanical parts of initially used analog instruments, but it also represents a great benefit for pilots in terms of the ability to configure the display of parameters as well as the implementation of flight data according to their preferences.

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REFERENCES

[1] GECEJOVÁ, N. Stendové zariadenie systému EFIS. Diplomová práca, 2021

[2] Instrument Flying Handbook: Chapter 5,6,7 [online]. Dostupné na internete: https://www.scribd.com/read/397274291/Instrument-Flying-Handbook-FAA-H-8083-15B# (2022-02-02)

[3] Čo je RGB LED: Obvod a jeho fungovanie: Štruktúra RGB LED [online]. Dostupné na internete: https://sk.jf-parede.pt/what-is-rgb-led-circuit (2022-02-21)

[4] GARMIN: Garmin G1000 [online]. Dostupné na internete: https://www.garmin.com/en-US/p/6420 (2022-01-31)

[5] GARMIN: Garmin G500 [online]. Dostupné na internete: https://www.garmin.com/en-US/p/63598 (2022-01-31)

[6] Viper SD-4: Prístrojové panely a farebné škály [online]. Dostupné na internete: https://sk.wikipedia.org/wiki/Viper_SD-4 (2022-01-31)

[7] DYNON SkyView SW: Pilot´s User Guide [online]. Dostupné na internete: https://dynonavionics.com/includes/guides/SkyView_SE_Pilots_User_Guide_Rev_D.pdf

[8] DYNON SkyView SYSTEM SOFTWARE FOR CLASSIC/TOUCH/SE [online]. Dostupné na internete: https://www.dynonavionics.com/skyview-software-updates.php (2022-02-07)

[9] DYNON SV-D900: SV-D900 10“ SkyView SE Display [online]. Dostupné na internete: https://www.chiefaircraft.com/avionics/dynon-avionics/skyview/dynon-sv-d900.html (2022-02-09)

[10] AVIONICS CRT DISPLAYS BEYOND 2020: THE RISING COST OF OBSOLESCENCE [online]. Dostupné na internete: https://www.aviationtoday .com/wp-content/uploads/2019/01/33520-avs-thomas-global-idustry-report.pdf (2022-02-21)

[11] Wi-Fi ADAPTER FOR SKYVIEW: SkyView Adds Wireless Connectivity to Mobile Devices [online]. Dostupné na internete: https://dynonavionics.com/ skyview-wifi-adapter.php (2022-03-07)

[12] Aircraft Flight Manual Viper SD-4 RTC: Kapitola 7.15 Pitot-static System str. 35 [online]. Dostupné na internete: https://static1.squarespace.com/static/5cbd9e82 65a707b68560908d/t/5ebfa682b9557a14273c3a2c/1589 618338973/Viper_SD4_RTC_Flight_Manual_HA-BEW-sn21737.pdf (2022-03-07)

[13] BRACINÍK, T. 2021, Materiálna časť ZLIN Z 242 L, Žilina: Žilinská Univerzita v Žiline, 2021, 46 str. ISBN 978-80-554-1783-7

[14] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A., JANOVEC, M. 2020. Komunikačné systémy v letectve. 1. vyd. - V Žiline : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 164 s. ISBN 978-80-554-1737-0.

[15] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

[16] NOVÁK, A. 2011. Komunikačné, navigačné a sledovacie zariadenia v letectve. Bratislava : DOLIS, 2015. - 212 s. ISBN 978-80-8181-014-5.

[17] NOVÁK, A., HAVEL, K., JANOVEC,M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

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

[19] NOVÁK, A., PITOR, J. 2011. Flight inspection of instrument landing system. IEEE Forum on Integrated and Sustainable Transportation Systems, pp. 329-332.

[20] NOVÁK, A., ŠKULTÉTY, F., KANDERA, B., ŁUSIAK, T. 2018. Measuring and testing area navigation procedures with GNSS. MATEC Web of Conferences 236, 01004

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PROPOSAL FOR MODIFICATION OF THE L-13 “BLANIK” SAILPLANE’S WING HINGE STRUCTURAL DESIGN

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Abstract

As a result of a tragic accident in Southern Austria, all L-13 “Blanik” sailplanes were grounded. During this accident, the factory structural design failed, even though the plane underwent all mandatory inspections and repairs. The intention of this article is to introduce the possibilities of structural modification of this aircraft, specifically its wing beam and hinge. Already existing modifications are described, as well as new ones with the aim to strengthen its critical parts. Structural modification of the wing hinge and beam, replacement of rivet joints with stronger Hi-Loks and use of different hole angles to ensure a firmer joint and better stress distribution around these holes are covered. Last two beforementioned modifications are described in more detail, a tensile test is carried out and its results are compared to the results of the control samples. In the end, viability and practicability of these modifications are discussed

Keywords

Strengthening, Wing hinge, Structural modification, Hi-Lok, Tensile test, Blanik, L-13

1. INTRODUCTION

The L-13 “Blanik” is a two-seater high wing sailplane which was produced in the former Eastern Bloc country – Czechoslovakia. The development of this aircraft began in 1954 at the National Center for Research, Development and Testing in Aerospace (VZLÚ) in Prague. First two prototypes were built and tested in 1956. After these successful tests, the production of L-13 was moved to Let Kunovice national company. 2616 planes were made until the end of production of the original model in 1978, from which many are still flying all over the world. Modernized versions of this sailplane are still produced in the Czech Republic by the company Blanik Aircraft, namely the L-13AC and L-13 SW equipped with Rotax 912 ULS engine [1][2].

Sadly, the success of this famous aircraft was stained by a tragic accident. On the 12th of June 2010, an aircraft with registration OE-0935, crashed near the airfield Ferlach-Glainach (ICAO code: LOKG), roughly 10 km south from the city of Klagenfurt am Wörthersee in Austria. While on final, after a routine aerobatic flight, the right wing broke from the plane, the plane then spun out of control and crashed into the ground killing both pilots on board. As a result of this accident, all L-13s around the world were grounded until a solution of this, at that time unknown, problem was provided. Today a handful of companies, including the manufacturer, provide structural modification of the wing hinge, which, according to the investigators, broke off because of fatigue cracks in riveted joints used to connect the wing hinge with the wing spar [3][4].

The factory wing hinge was never structurally modified, as there was no reason to do so. It was a proven structure which served its purpose for many years without any flaws. The wing hinge and spar are joint together using conventional steel rivets in three rows. In every row the are seven rivets, which comes up to 21 in total. By the wing root, two more rivets in rivets are installed to counter the longitudinal and transversal strengths [3][4].

2. EXISTING STRUCTURAL MODIFICATIONS

Individuals as well as companies came up with solutions to this issue. The most important ones are covered in this paper. The first man who came up with a proposal for modification is a Brazilian engineer Glavão. His proposal counted on the introduction of a few new components into the already existing structure of the plane. The most significant being the wing struts, which are usually used on general aviation aircraft, such as the Cessna 172. These should relieve the stress of the wings, mainly its spar and the joints joining them to the wing hinge and prevent another failure of this critical part of the plane’s structure. These would be connected to the wing spar and to a metal strip, which would be connected to the fuselage of the plane using rivets. These struts would reduce the bending moments inboards of the strut attachment point and reduce the tensile stress in the same area. For the possibility of these struts to be installed, additional reinforcement of the components connecting the struts to the plane is needed. This is solved by doubling the wing spar and the thickening of the wing cover in the affected areas [5].

These modifications were analyzed mathematically with promising results, but not a single “Blanik” was rebuilt using this proposal. The technological implementation is just too difficult and not viable [5].

Other modifications were presented by a private company named Aircraft Design and Certification (AD&C), based in Germany. This company specializes in aircraft modifications. Their proposal suggests the implementation of a L profile near the wing root, connecting both the wing hinge and spar to the fuselage. The lower wing spar is strengthened around the area of the original fatigue crack. The most stressed rivets are replaced for ones with bigger diameter, which makes them stronger and able to withstand greater tensile and shear stress. These modifications were tested with promising results. A plan of maintenance inspection before the rebuild was prepared. It consisted of the visual check of the fuselage and wing covers for cracks and tears. The wings are then detached, and the wing spar is examined and checked for fatigue damage using the eddy current testing method. This method is a non-destructive test, which determines whether any material defects are present inside the material. If the spar does not pass the test, the wing cannot be modified and the whole wing needs to be replaced. The same goes for the holes drilled in the wing hinge and spar. If the holes are too elliptical, either the wing hinge or the whole wing needs to be replaced for a new one [6].

EASA then issued a directive EASA AD 2011-0135, by which they approved the use of this modification. After a rebuild is done, the airplane gets its airworthiness back for 3750 flight hours with maximum 2 % aerobatic use. EASA later issued another directive further approving the modification and granting 5000 flight hours, but without aerobatic use. The operator of the plane must decide. Either he can use the plane longer without further structural modifications, or he can keep the aerobatic use, but sacrifice 1250 flight hours [6].

Structural modifications are also carried out by today's manufacturer – Blanik Aircraft. They do similar pre-rebuild inspections as the AD&C company. The difference being that Blanik dismantles the fuselage as well and they do inspect the insides of it, specifically the sixth partition. They also check the symmetry of the fuselage. Again, the spar is tested using the eddy current method, the roundness of the holes used for rivets is checked as well. The next step is to change the wing hinge for a longer one, factory holes for rivets are redrilled from 6 to 6.36 millimeters and the rivets are changed for stronger Hi-Loks. The number of these Hi-Loks grew from 23 original pieces to 33 [7][8].

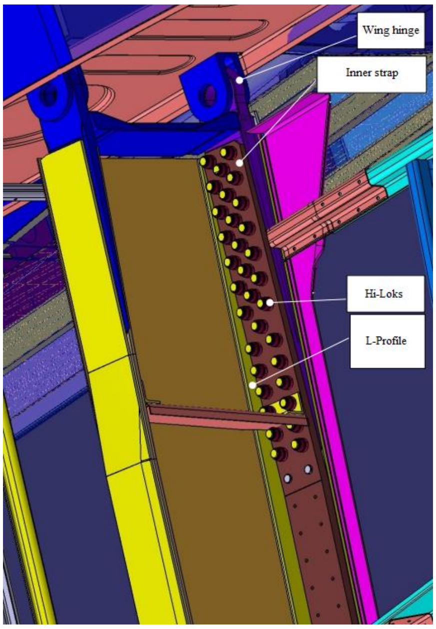

Figure 1: Modifications proposed and made by Blanik Aircraft. [7]

Using these modifications, the critical point of the wing spar gets shifted by 100 millimeters further away from the wing root and the resulting forces decrease by 60 %. Calculations confirmed that a wing hinge modified this way withstands twice as much force as the factory one. EASA approved this modification and the planes using it are airworthy for additional 6000 flight hours [7][8].

3. THEORETICAL WING HINGE MODIFICATIONS

While suggesting modifications, it is not needed to think overly complex. It is possible to draw inspiration from the aforementioned modifications. That goes both for the pre-rebuild inspection and the modifications themselves.

To determine whether the plane can be modified, its structure needs to be examined. The examination of the wing spar and the sixth partition is very important and would be carried out the same way, as described by Blanik Aircraft. The visual inspection and eddy current testing method would be used. The same goes for the hole roundness check. The results of the inspection would be then evaluated, and the following steps would be determined. If the wing spar, hinge assembly or sixth partition would not pass the previously mentioned tests, the corresponding part must be replaced for a new and reinforced one. The fuselage is checked as well for any surface damage on the cover, the symmetry is checked, and the structure of the fuselage is inspected as well. Any fatigue cracks or damage found must be repaired to prevent any further harm. The wing hinge itself does not need to be inspected, as it will be changed for a new and improved part [6][7][8].

3.1. Extension of the Wing Hinge

To strengthen the wing hinge assembly, the wing hinge itself needs to be reworked and changed. The easiest thing to do is to install a longer and stronger wing hinge. This would shift the critical point further away from the wing root, making it stronger and able to withstand greater stress. This adjustment has a countereffect. The implementation of an extended wing hinge will result in the creation of a longer lever according to (1), which expresses the equilibrium of the forces on a lever [7][8][9].

$$F_1 \times L_1 = F_2 \times L_2 \qquad (1)$$

Equation (1) says that the force F1 acting on the longer arm with length L1 must be equal to the force F2 acting on the shorter arm with length L2. This means that if the wing hinge is extended, but force acting on it does not change, the force being transferred to the shorter unchanged arm has to be greater. To counter this, the sixth partition must be reinforced to withstand such loads [9].

3.2. Reinforcing of the Wing Spar and Wing Cover

Another important structural modification is the strengthening of the wing spar in the most exposed areas. These are located near the wing root, as the biggest loads are being transferred through there. Inspiration can be drawn from the work of engineer Galvão. He mentioned the reinforcement of the wing spar by doubling it in the most stressed areas. This would help to achieve better stress distribution over the spar. To be sure, strengthening of the wing cover in the same areas is needed for the same reasons. The factory wing cover is made of duralumin.

For it to be stronger, higher thickness cover or a cover from stronger materials must be used. Both modifications would provide better tensile and shear stress distribution over these critical parts of the plane's structure [5].

3.3. Replacing Rivets with Hi-Loks

While using conventional steel rivets, it is important to pay close attention to the quality of the rivet joint. Not only for aesthetic purposes, but for premature fatigue reasons. With tensile tests, it was proven that displacement of a rivet by only one degree changes the stress distribution in and around it, which has a negative effect on fatigue of this joint. As it is hard to manually make a rivet with a one-degree accuracy, it is better to replace rivets with another type of joint [7][8][10].

For aeronautical use, rivets can be substituted by Hi-Loks. This joint was developed in 1943 in the United States by the Hi-Shear Corporation. They were used for the first time in the P51C Mustang fighter aircraft. The Hi-Loks are made from strong metals such as titanium or Inconel and can withstand greater forces and stress than conventional rivets. They are made of two parts – pin and collar. These get screwed together clamping the materials. These joints are then able to withstand high tension, high temperatures, friction, and vibrations. The substitution of rivets with Hi-Loks would ensure a stronger and reliable joint between the wing hinge and spar [11][12][13].

3.4. Extension of the Hi-Loks Service Life

Currently, while disassembling Hi-Lok joints, it is common practice to throw out both parts of the Hi-Lok. However, one of these components can be kept and used repeatedly. This could cut maintenance costs and lower the impact on the environment.

The Royal Military College of Canada did research on this topic. They carried out tensile tests to prove the possibility of this modification. The results proved that only the collar needs to be changed to preserve the limits prescribed by the manufacturer. The results even proved that the clamp force is higher than the limits with the collar change. Further research needs to be done, but the results are promising. If this modification is applied in practice, these joints could achieve higher static and shear strength values and this should result in a reliable and stronger joint, which will be cheaper to maintain and has a smaller impact on the environment [14].

3.5. Change of the Hole Angles for the Hi-Lok Joints

The most important change is to change the hole angles for the Hi-Lok joints. This means that the holes will not be drilled perpendicular to the material, but under an angle. This should provide better stress distribution around these holes and a greater contact surface for the joint to lean on. That should result in a stronger joint. The stress distribution was already discussed at the International Conference on Challenges and Opportunities in Mechanical Engineering (ICCOMIM) in 2012. There was an article published regarding this topic. Simulations and tensile tests were performed. Stress distribution around holes with different hole angles, namely 0°, 30° and 60°, is shown in figure one [15][16].

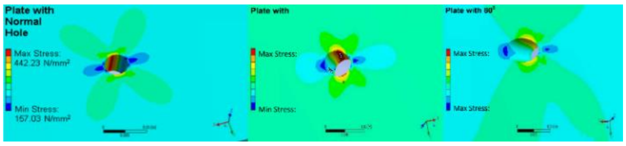

Figure 2: Stress distribution around holes with different hole angles. [15]

Better stress distribution is seen in the figure, as it is more distributed into the surrounding areas. But the tensile test results, which are shown in table one, proved that the tensile load decreased by 30°, but grew significantly by 60°. Maximum stress decreased with growing oblique angle [15][16].

Table 1: Tensile load and max. stress comparison. [15]

Oblique Angle (°)	Uniaxial Tensile Load (kN)	Maximum Stress (N/mm^2)
0	160.30	438.25
30	158.20	396.50
60	162.50	387.06

Inserting a joint into these holes ensures a bigger contact surface. If a material with 8-millimetre thickness is considered, hole drilled under an angle of 30° ensures a 15.5 % increase in contact surface. The same goes for the 45° tilt – contact surface is increased by 41.25 %. These numbers promise that stronger joint can be achieved using these structural modifications. But with relation to the material taken out while drilling holes under an angle, it cannot be said for certain. Further research needs to be done, combining both oblique hole angles and Hi-Lok joints. As no other paper describes such an experiment, it will be described in this article [15][16].

4. EXPERIMENTAL VERIFICATION

As stated, the results and hypothesis from the previous chapter need to be examined further using a tensile test. For a tensile test to be carried out, a sample of sort is needed. A sample proposal was done in the CAD software Autodesk Inventor 2021. It consisted of two metal strips, one from steel and the other from aluminium. These strips were then joined together using a Hi-Lok under various angles. After simulations were carried out, the angles of 0°, 30° and 45° were determined to be the most viable. 0° representing the control sample to compare the other results to. In this design, the implementation of Hi-Loks is not possible, as the pin and collar have no place to lean on. It just will not be able to clamp the materials together.

An improved design was introduced with two additional components for the Hi-Loks to clamp onto. This design was determined as best reflecting the real conditions on the wing hinge.

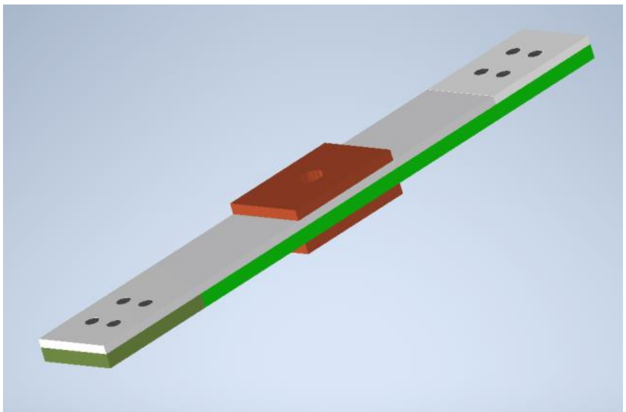

Figure 3: Control sample for tensile tests. [Authors]

Sadly, this design could not be built because of lack of material and time pressure. Workaround had to be made to successfully carry out the tensile tests. The design and materials had to be changed. Steel metal strip was changed for an aluminium one, as it is easier to drill into. Sadly, neither the Hi-Loks could be used, as no supplier was able to deliver them in time. The redesign consisted of two metal strips, one from conventional aluminium, the other one from 2044-T4 aluminium. That is a high strength aluminium with a tensile strength of 475 MPa, twice as strong as regular aluminium. These components will be joint together using a M10 bolt. Three types of samples were designed with varying oblique hole angles of 0°, 30° and 45°. Each type was produced three times, nine in total.

4.1. Simulated Tensile Tests

The tensile tests were simulated at first. They showed the same results as the beforementioned article from the ICCOMIM 2012 conference. With increasing hole angle, the strength of the material decreased, but the stress distribution changed, as it is more spread into the environment, viz. figure three [15].

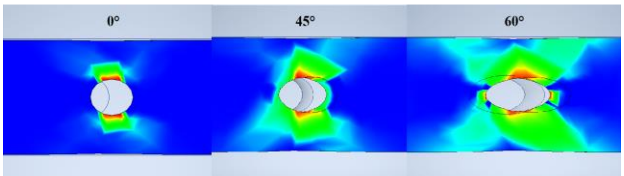

Figure 4: Stress distribution during simulated tensile tests. [Authors]

According to these simulations and to determine precise results, real tensile tests are needed to prove or disprove the hypothesis.

4.2. Tensile tests

The tensile tests were carried out on the before described samples, viz. figure four.

Figure 4: Control sample for tensile tests. [Authors]

The results of the tensile tests of the control sample are shown in table two. We can use these numbers to compare and evaluate the results of the other tensile tests. The table contains the number of the sample, original cross section, maximal strength, and tensile strength.

Table 2: Control sample tensile test results. [Authors]

Sample number	Original cross section (mm²)	Max. Strength (N)	Tensile Strength (MPa)
1	37.81	7748.30	204.93
2	38.00	8357.17	219.93
3	38.19	7998.84	209.45

The same goes for the results of the samples with 30°- and 45°-hole angles. The results are written in their respective tables numbered three and four.

Table 3: 30° sample tensile test results. [Authors]

Sample number	Original cross section (mm²)	Max. Strength (N)	Tensile Strength (MPa)
4	36.29	7245.03	199.64
5	35.72	7119.62	199.32
6	35.91	7016.44	195.39

Table 4: 45° sample tensile test results. [Authors]

Sample number	Original cross section (mm²)	Max. Strength (N)	Tensile Strength (MPa)
7	36.48	7133.73	195.55
8	36.29	7246.52	199.68
9	36.49	6618.01	181.41

As you can see, the tensile strength and maximal strength both decreased with increasing oblique angle. You can see the samples after the tensile test in the figure lower. To prove the accuracy of the results, tensile tests for aluminium metal strips with a hole were conducted as well.

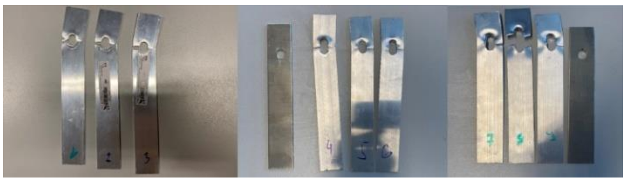

Figure 5: Samples after tensile tests. [Authors]

The results of the metal strip tensile test can be seen in table number five. They show promising numbers, as the increase from 30°- to 45°-hole angle did increase the tensile strength and maximal strength.

Table 5: Tensile test of the metal strip with an oblique hole. [Authors]

Oblique angle (°)	Sample No.	Cross section (mm^2)	Max. strength (N)	Tensile Strength (MPa)
0	10	37.05	7567.60	204.25
	11	37.62	7610.25	202.29
30	12	36.29	7314.07	201.54
	13	36.48	7270.06	199.29
45	14	36.67	7335.58	200.04
	15	36.29	7350.54	202.55

5. DISCUSSION

As the results from the previous chapter suggest, the strength of the joint probably cannot be increased by changing the hole angle. Sadly, due to a lack of time, the tensile test had to be carried out using a non-ideal sample design. By using the design seen in figure two and a Hi-Lok instead of regular bolt to join them together, the results should be more precise and could prove the hypothesis from chapter III.

If the results of the tensile tests were positive, by implementing this modification, the joint between wing hinge and spar could be further reinforced. This could result in decreasing the number of used Hi-Loks, ultimately cutting down costs.

The same can be said about the extension of the Hi-Lok joints' service life. If further research proves that the repeated collar change has no effect on the Hi-Lok clamp force and toughness, maintenance costs could be cut down as well as environmental impact.

REFERENCES

[1] HANÁCKÝ AEROKLUB OLOMOUC. 2015. L-13 Blaník: Popis kluzáku.

[2] Hanácký Aeroklub Olomouc [online]. Olomouc: [cit. 10-10-2021].

[3] Available at: https://hao.cz/letadla/klubova/blanik.html

[4] ZUSKA, Adam. L13 Blaník. Aeroweb [online]. Prague: [cit. 06-04-2021]. Available at: https://www.aeroweb.cz/letadla/kluzaky/l13-blanik. ISSN 1801-6847

[5] SICHERHEITSUNTERSUCHUNGSSTELLE DES BUNDES, BEREICH ZIVILLUFTFAHRT. 2017. Unfall mit dem Segelflugzeug Type L13 Blanik am 12.06.2010 im Gemeindegebiet Glainach, Kärnten. Vienna, 2017. GZ. BVIT-85.164/0002-IV/SUB/ZLF/2017.

[6] STŘÍHAVKA, L. 2013. Prohlášení ÚZPLN k letecké nehodě větroně L13 Blaník. Praha: Ústav pro odborné zjišťování příčin leteckých nehod, 2013.

[7] GALVÃO, F, L. 2011. A fail safe fatigue life extender proposal for the Blaník L – 13 [online]. São José dos Campos: 2011. Available at: http://soaringcafe.com/2011/07/a-fail-safe-fatigue-life-extender-proposal-for-the-blanik-l-%E2%80%93-13/

[8] AIRCRAFT DESIGN & CERTIFICATION LTD. 2011. 5000h approved for Blaník L-13 modification. Aircraft Design & Certification [online]. Neckargemünd: 2011 [cit. 17-11-2021]. Available at: https://www.aircraftdc.de/en/

[9] BLANIK AIRCRAFT CZ. 2015. Beranových 65, Letňany, 199 00 Praha 9. Závěr z pevnostní zprávy ZP001_9250_14_Modifikace spodního závěsu L-13 Blaník. 9 s. Závěr z pevnostní zprávy.

[10] DVOŘÁK, J. 2017. How do you rebuild Blaník L-13? Come see with us!. Flying revue [online]. Prague: [cit. 19-11-2021]. Available at: https://www.flying-revue.com/how-do-you-rebuild-blanik-l-13-come-see-with-us

[11] MACHÁČEK, M.1995. Encyklopedie fyziky. Prague: Mladá fronta, 1995. ISBN 80-204-0237-3.

[12] QINGXIAO, L. et al. 2021. Effect of Riveting Angle and Direction on Fatigue Performance of Riveted Lap Joints. [online]. Xi'an: Coatings, 2021. [cit. 2021-11-20]. Available at: https://www.mdpi.com/2079-6412/11/2/236

[13] TREMBLAY, S. – BANDOIM L. 2017. What Is a Hi-Shear Fastener?. Sciencing [online]. Santa Monica: 2017 [cit. 28-11-2021]. Available at: https://sciencing.com/info-10064484-hishear-fastener.html

[14] HOWMET AEROSPACE. Hi-Lok Fastening System. Howmet Aerospace [online]. Pittsburgh: [cit. 28-11-2021]. Available at: https://www.howmet.com/global/en/products/product.asp?bus_id=1&cg_id=88&cat_id=216&prod_id=537

[15] JET-TEK. Hi-Lok Fasteners. Jet-Tek [online]. St. Petersburg: [cit. 28-11-2021]. Available at: https://jet-tek.com/product-specialties/hi-lok-fasteners-hi-lok/

[16] HARDY, D. F. - DUQUESNAY D. L. 2019. Effect of Repetitive Collar Replacement on the Residual Strength and Fatigue Life of Retained Hi-Lok Fastener Pins. [online] Kingston: Metals, 2019 [cit. 12-12-2021]. Available at:

[17] https://www.mdpi.com/2075-4701/9/4/445

[18] MALLIKARJUN, B. – DINESH, P. – PARASHIVAMURTHY, K. I. 2012. Study of Elastic Stress Distribution around Holes in Infinite Plates Subjected to Uniaxial Loading. [online] Bengaluru: 2012. [cit. 15-01-2022]. Available at: https://www.researchgate.net/publication/263280563_Study_of_Elastic_Stress_Distribution_around_Holes_in_Infinite_Plates_Subjected_to_Uniaxial_Loading

[19] Available at: https://www.sciencedirect.com/science/article/pii/S1877705817326036

[20] MRŇÁK, L. – DRDLA, A. 1980. Mechanika pružnost a pevnost pro SPŠ strojnické.

[21] 3. opr. vyd. Prague: STNL, 1980. ISBN 04-005-80.

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

[23] 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.

[24] 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.

[25] LUSIAK, T., NOVÁK, A., JANOVEC, M., BUGAJ, M. 2021. Measuring and testing composite materials used in aircraft construction. Key Engineering Materials, 2021, 904 KEM, pp. 161–166. ISBN 10139826.

[26] JANOVEC, M., BUGAJ, M., SMETANA, M. 2019. Eddy Current Array Inspection of Riveted Joints. Transportation Research Procedia, 2019, 43, pp. 48–56. ISSN 23521457.

[27] 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.

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CHANGES IN AIRPORT INFRASTRUCTURE CAUSED BY THE HISTORICAL DEVELOPMENT OF AIRCRAFT

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Abstract

The airport infrastructure is constantly influenced by the development of aircraft. It has always been, that the aircraft was first designed, and based on its performance parameters and geometrical characteristics, a space for the airport were sought to serve the new aircraft. Even today, we can see the different development of aircraft in different aircraft manufacturers, which determine how the airport infrastructure will change in the future.
In the introductory chapters, we analyze several aircraft requirements for airports that have been affected by changes in ground infrastructure and the subsequent development of airports. The main objective of this bachelor thesis is to document the changes in the airport infrastructure caused by the historical development of aircraft. The discussed development of aircraft and reaches out from the beginning of aviation to the end of World War II through the era of jet aircraft to large-scale long-haul aircraft.
Based on the creation of a database of aircraft and a description of typical aircraft representatives of the period, an analysis of their parameters and the described impact on selected airports is performed. Three historical international airports were selected for a detailed analysis of airport development. There are two analyzed airports in Europe: Munich Riem together with Munich - Franz Josef Strauß and Amsterdam Schiphol. In the United States, John F Kennedy Airport is chosen near New York City in terms of the highest airline utilization.
Until 1951, selected airports were analyzed from historical footage and, after the publication of ICAO Annex 14 Aerodromes, also documented by changes in the regulation. Airports had to adapt to changes in environmental requirements and the introduction of new technologies in the form of more fuel-efficient and smaller commercial aircraft.
One of the benefits of the thesis is to emphasize the need to plan airport changes in relation to the needs of aircraft technology in the future. This area includes the planning and modernization of runways (RWY), terminals, aprons and stands. At present, RWY design pays attention to reducing noise in suburban areas, reducing turn-round time at stands by using jetways, the number of taxiways (TWY) connecting the RWY to the airport and operating aircraft with a smaller code letter.

Keywords

Airport, Aircraft, Runway (RWY), Taxiway (TWY), Infrastructure

1. INTRODUCTION

Air transport became known for the first flight of the Wright Brothers in 1903 and demonstrated new possibilities for using aircrafts as a means of comfortable and fast travelling. Each type of transport means needs its own infrastructure which has certain specifics. Air transport, which is one of the youngest transport sectors is no exception. At present even with the decline in air traffic it is necessary to increase the emphasis on the construction and modernization of airport infrastructure constantly.

From a historical point of view the aircraft was always first designed and the airport was built according to its parameters. This relationship between aircrafts and airports can be seen to this day in the history of aviation. Graphical analysis of aircraft key parameters can illustrate the changing aircraft infrastructure requirements of aircraft.

To document the impacts of changes in aircraft parameters on airports, an analysis was performed on the examples of some airports. In terms of airport history three international airports were selected. At individual airports, various designs and modernizations of airport areas are pointed out, which were caused by the historical development of aircraft.

The construction of new parts of airport terminals and runways is also analyzed at selected airports. At present the completion of existing airports is influenced by a number of factors, including: the geometric characteristics of F-code aircraft, the different types of boarding bridges and the environmental impact of aircraft operations.

2. RELATIONSHIP BETWEEN PERFORMANCE PARAMETERS, AIRCRAFT GEOMETRIC PARAMETERS AND AIRPORT CHARACTERISTICS

Different forces affect on the aircraft during takeoff and landing. Some have to cross the plane to take off and land. These forces include lift, gravity, thrust and drag. In addition to these forces, several other factors affect the take-off and landing performance.

2.1. Wing shapes

In aviation, different shapes of wings are used, each of which has its advantages and disadvantages. The shape of the wing is determined by the needs of the aircraft in service, for example, transport aircraft use swept wings and aircraft for supersonic operation use a delta wing. From the point of view of airports, the wingspan is especially important, the smaller the wingspan, the generally the smaller the size of the stands required. The wingspan also affects the width of the TWY and the width of the runway, alternatively runway side strips.

2.2. Different types of power units

Three types of power units are used in aviation. From a historical point of view, piston engines were the first, at the end of the Second World War aircraft with jet engines were designed, and the last of these was a hybrid of these two engines in the form of turboprop engines.

2.2.1. Differences between piston and turboprop engines

Piston and turboprop engines are quite similar in their flight modes. However, these two types of engines are different in different categories. These categories include the areas of safety, efficiency, cost and performance of individual engines. Reciprocating engines are usually cheaper and less maintenance than turboprop engines. The advantage of turboprop engines is their reliability, longer resources, higher efficiency at higher power and provide better performance at high altitudes [1].

The performance of reciprocating engines decreases with increasing height. This disadvantage can be partially compensated by using a compressor or turbocharger on the engine, which maintains power at higher altitudes. After exceeding the limit height, the power on the piston engine starts to decrease again. Turboprop engines are suitable for aircraft that have higher cruising speeds at higher altitudes, where the engine is able to achieve higher performance. The disadvantage of using higher power (turboprop engines) is the higher weight and higher fuel flow [2]. The advantage of turboprop aircraft is the possibility of reversing the propeller, which reduces the landing distance and thus improves the landing characteristics of the aircraft [1].

2.2.2. Differences between turboprop and jet engines

Turboprop and jet engines operate on the same principle in terms of thermodynamics. Both engines are equipped with a gas turbine. The main difference is in the use of engine exhaust gases. Turboprop engines use a turbine connected to a reducer to drive the propeller, and jet engines accelerate the exhaust gases, which in turn create thrust to the engine.

The power of turboprop engines decreases with increasing height. This is due to a reduction in air density. Jet engines still maintain their thrust if sufficient air and fuel are supplied to the engines. Examples of applications are the Aerospace-British Aerospace Corporation (BAC) Concorde and Tupolev Tu-144 transport aircraft, which also had afterburning and flew at Ma = 2. Jet engines can have a split airflow into primary and secondary. The secondary airflow has a great influence on the final thrust of the engine [3].

These factors indicate that both types of power units are safe to operate on commercial aircraft. Turboprop engines are more efficient for lower altitudes with flight speeds up to Ma = 0.6 [3]. Jet engines, on the other hand, are more suitable for operation at higher flight speeds and altitudes [4].

2.2.3. Impacts of various factors on take-off and landing length

The weight of the aircraft and the power of the propulsion unit, the range and the required take-off and landing length are closely related. A longer runway is required during takeoff at a higher aircraft weight, as is landing.

The length of take-off and landing is also affected by the air density, which depends on the altitude of the airport and the outside temperature. At airports located at higher altitudes, a longer runway is required for take-off and landing. Conversely, at airports located at sea level, a relatively shorter take-off run is required. In some cases, at high temperatures and sufficient take-off run, the engines may not be set to 100% power / thrust, but smaller ones will suffice, e.g. 85-90%. This not only reduces fuel consumption but also extends engine life. The prevailing higher temperatures of the airport resp. alternatively lower pressure (altitude), can significantly affect the runway length for take-off and landing [5].

Another factor that affects the length of takeoff and landing is the slope of the runway. If the runway slope is negative - descending, a shorter runway is required for take-off. Positive runway slope - ascending, prolongs the required runway length for take-off. A shorter runway is sufficient for a landing and a positive runway slope; for a negative runway slope, the aircraft needs a longer runway for safe braking [6].

3. DEVELOPMENTS FROM THE BEGINNING OF THE AVIATION TO THE END OF WORLD WAR II.

Aviation is one of the youngest industries in terms of transport history. Initially people used road transport for short distances and rail or water transport for longer distances. The first breakthrough in aviation occurred in 1903 by the flight of the Wright brothers [7]. That's when we started talking about the birth of planes. Later, spaces had to be created for these aircraft on which they could take off and land.

The greatest technological boom of aircraft came during the First World War, when the armies of the warring countries began to use aircraft for various actions, whether for the defense of their territory, reconnaissance or bombing. From the beginning, the aircraft had different types of fuselage, wings, power units, which changed over time. The aircraft manufacturers tried to ensure that the resulting design parameters were optimal for the aircraft (Maximum take-off mass (MTOM), range and performance). At this time, the construction of biplanes with a fixed spur landing gear prevailed. Aircraft on takeoff and landing had poor longitudinal and lateral stability, and the wing profiles themselves had a low lift coefficient, which produced quite high drag [8]. Rolling on the runway was relatively difficult due to the use of an uncontrolled spur type landing gear. With this type of landing gear, the pilot could not see directly in front of him and the plane could crash into an object. The airports were with unpaved runways. Because hard landings could not be ruled out, the landing gear was designed with a more robust construction.

The requirements of the above-mentioned aircraft at airports differed considerably from the first transport aircraft. The Junkers F-13 needed only 200 m to take off, with new aircraft from Douglas up to 1 200 m to take off and 600 m to land. The exception was the Junkers Ju 52, which had only 400 m to take off and land. Airports had to increase runway lengths because of these aircraft. The new aircraft already had better take-off and landing stability and maneuverability than their predecessors. Also their more robust design allowed aircraft to take off and land at higher crosswinds. These planes still had a spur-type landing gear and the pilots did not see in front of them when taxiing. The capacity of the airports gradually began to fill with new, larger aircraft, and the movement of passengers between the terminal and the stand was very dangerous. For this reason, the construction of the first terminals, which would provide greater safety and comfort to passengers, began to be considered. The first terminal was built in 1936 at London-Gatwick Airport [9]. It had a circular shape and rotating stands which allowed the aircraft to turn on the stand without the need to push them out [10]. The passengers got to the plane using a telescopic jetways.

During World War II several transport aircraft began to be used as transport aircraft. The construction of paved runways, which were needed for aircraft with higher weights, began. Two parameters were important for the bombers - range and weight of cargo (bombs), which they could carry on board [7]. The chassis type also began to change from a spur landing gear to a landing gear with a nose landing gear. The most famous bombers were the Boeing B-17, Heinkel He111 or Avro Lancaster [7]. These aircraft no longer had a fixed spur on the tail, but a spur wheel, which allowed better controllability and maneuverability of the aircraft when taxiing and to guide the aircraft to the stand.

4. THE BEGINNING OF THE JET ERA

Even after the end of World War II the Air Force still used piston-engined aircraft, either for short distances or on routes across the Atlantic Ocean. After the war it was possible to see the difference in airport infrastructure requirements. In Europe, for example, most airports were equipped with concrete runways, while the USSR still had many airports with unpaved runways or taxiways.

A big change occurred in the use of jet engines in commercial aircraft. The first jet was the de Havilland D.H. 106 Comet 1, which made its first flight in 1952 [7]. A few years later, he was followed by an aircraft manufacturer from the USSR Tupolev with a Tu-104 aircraft [7]. These aircraft belonged to the group of low wing with a nose landing gear. Such an arrangement gave the pilots a better view from the cockpit during taxiing and take-off, and compared to the spur landing gear, the controllability of the aircraft during taxiing and take-off was significantly improved. During takeoff and landing, the aircraft with the nose landing gear were more stable and maneuverability was improved by allowing pilots to adjust the balance of the aircraft before takeoff or landing. The export of the aircraft appeared in the Air Force at the end of World War II on North American P-51 Mustang aircraft [11].

Airports also had to adapt to the new aircraft. The runways began to lengthen and their width also increased. During taxiing pilots were not allowed to use increased engine power so that engine exhaust gases would not damage airport facilities or airport facilities in their vicinity. Airport stands have been enlarged to prevent airport equipment from being sucked into the jet engine.

5. USE OF LARGE-SCALE AIRCRAFT FOR LONG-HAUL FLIGHTS

In the late 1960s several well-known and successful aircraft from various aircraft manufacturers were built. One of the basic changes concerning the construction of aircraft was the more frequent use of the swept-shaped wing. The advantage is less drag at higher speeds [12]. Disadvantages include the complex mechanization of the wing, such as the use of flaps on the trailing edge and slots on the leading edge. This ensures sufficient lift even at lower speeds. All aircraft are already equipped with a retractable landing gear.

Between 1960 and 1970 the idea arose to design supersonic transport aircraft. The first supersonic aircraft was created in the USSR by the aircraft manufacturer Tupolev. Tupolev Tu-144 managed to make the first takeoff and landing before its competitor from Europe Aérospatiale-BAC Concorde. The wingspan, MTOM, seat capacity and take-off distance are similar. From aircraft requirements to airports, Aérospatiale-BAC Concorde needed a longer takeoff length. In contrast, the Tupolev Tu-144 had several technical shortcomings and sometimes when taking off from some runways due to the high speed of exhaust gases, tore pieces of concrete on the runway. Aérospatiale-BAC Concorde with its neo-Gothic wing shape had good flight characteristics at both low and high flight speeds and was the first aircraft to be equipped with an electro-impulse control system "Fly By Wire" [13].

In the field of subsonic aircraft a novelty came in 1969 in the form of large-capacity aircraft [14]. These aircraft belonged to the group of wide-body aircraft. This meant that there were two aisles in the passenger cabin. The first wide-body aircraft was the Boeing 747, also called the "Jumbo Jet", and in the following years the McDonnell Douglas DC-10 and Lockheed L-1011 Tristar were designed [14]. These aircraft were deployed over long or medium distances, where their high seating capacity was used the most. With a higher number of passengers the airline's operating costs are also lower. The Boeing 747-200 and McDonnell Douglas DC-10 aircraft had a larger wingspan compared to the aircraft manufactured before 1969, and the MTOM value increased up to threefold compared to the first jet Boeing used on long routes. The passenger seating capacity has doubled, for example the Boeing 707 could carry 179 passengers and the Boeing 747-200 up to 366 passengers. The McDonnell Douglas DC-10 had a capacity almost 100 passengers greater than the Douglas DC-8. The airports had to increase the runway length again to 3 000 m. The taxiways were also modified for wide-body aircraft, as the wheelbase was significantly larger than previous aircraft. The maneuverability of the aircraft and its weight were also taken into account. According to these data, restrictions have arisen for TWY airports. Airports have begun to modernize boarding bridges for faster boarding and disembarking of passengers.

6. AIRCRAFT REQUIREMENTS AT AIRPORTS IN ICAO ANNEX 14

Until 1951 there was no standardization at the international level in the field of airports. The creation of Annex 14 for airports was first discussed during the Chicago Conference in 1944. Annex 14 - Aerodromes was adopted on 29 May 1951 under Article 37 of the 1944 Convention on International Civil Aviation and entered into force on 11 November 1951 [15].

In the first editions terms such as runway strips, clearways, taxiways or aprons were defined. From the beginning, the forecourt was located just behind the end of the runway, today it is moved 60 m further from the end of the runway. The various requirements for runway parameters were gradually supplemented until 1958 [15].

With the advent of larger large-capacity aircraft a new letter was introduced in 1999 in the Aerodrome reference code-F [15]. Airbus A380-800 aircraft or their competitors Boeing 747-8 later fell into this category.

During the take-off of large-capacity wide-body aircraft, there was damage to the unpaved area in front of the runway threshold behind the runway and dangerous runway edge detection due to strong exhaust gases. This problem was solved by adding a paved area in front of the runway - Blast pad [15].

7. DOCUMENTING THE IMPACTS OF AIRCRAFT PARAMETER CHANGES ON AIRPORTS ON THE EXAMPLES OF SOME AIRPORTS

Documenting the historical development of airports is described on the examples of 3 historic international airports.

7.1. Munich Riem Airport

At present there are several modern airports in operation in Germany in terms of airport infrastructure, which rank among the most modern airports whether in Europe or in the world. Most of the airports were destroyed or damaged in World War II and the Germans were able to rebuild them and gradually adapt them to the needs of more modern aircraft.

Figure 1: Munich Riem Airport – 1950. [Source: https://www.mil-airfields.de/de1/muenchen-flughafen-riem/1950-02-flughafen-muenchen-riem.jpg]

In Figure 1 we can see the restored airport from 1950. During World War II the airport was bombed several times by Allied aircrafts and the entire airport infrastructure was damaged. In 194, the construction of a new paved runway was completed, which was 1 907 m long and 60 m wide [16]. The load capacity of this runway was 140 t [16]. The length of the runway suited aircraft flying in the following years, such as Sud-Aviation SE 210, Ilyushin IL-18 or Lockheed L-188. In terms of load capacity, it can be determined that the Boeing 707 could move on the runway, as its MTOM is below the load capacity limit of the runway. However, the runway length required to make a safe take-off would not be suitable for this type of aircraft. Even after the completion of the airport, it retained its elliptical shape, as shown in Figure 1. After the period after the World War II, the TWYs have changed - they are reinforced and have a unique shape. From the runway they are located around the perimeter to the apron, where there is a restored terminal with an airport control tower and hangars. On the western side of the airport a new paved apron for aircraft in the shape of a semicircle has been added. In 1958 the Sud-Aviation SE 210 jet landed at the airport for the first time [16]. This indicated the gradual replacement of propeller aircraft by more modern jet engines.

The last flight from Munich Riem Airport took place on 16 May 1992 by a Boeing 737-500 of Lufthansa [16]. The next day a new airport began to be used - Franz Josef Strauß.

7.2. Amsterdam Schiphol Airport

Amsterdam Schiphol Airport is one of the largest airports in Europe. It is the only airport near Amsterdam. For comparison the English city of London serves five airports. It ranks among the oldest international airports in the world. During its 106 years of operation the airport has undergone several expansions and modernizations.

The area where today's airport is located was a large lake before 1852. The Netherlands decided in the second half of the 19th century to dry the lake and use it for agricultural purposes. In 1916 the plan was changed and the area was bought from a local farmer for the construction of the first airport buildings. At the beginning it was considered that the airport would serve as a military air base. The first landing was made on September 19, 1916 by a military aircraft. Later the airport began to focus on commercial aircraft and as early as 1917 it was one of the largest airports in Europe [17] [18].

Figure 2: New Pier C at Amsterdam Schiphol Airport – 1971. [Source j: https://www.airporthistory.org/photos-klm747-schiphol.html]

In 1971 a new Pier C was built at Schiphol Airport, which was primarily designed for wide-body aircraft and was equipped with a new type of jetway [19]. Figure 2 shows 3 types of jetways and KLM aircraft.

The oldest type of jetway is at the Douglas DC-9. From a technical and operational point of view it had several disadvantages, such as limited movement, because it could only move in a circle. Because it was a rotating stand, the jetway had to be moved a long distance from the aircraft after the aircraft was checked in, so that the aircraft could safely roll out of the stand. On the contrary the advantage of this type of stand and jetway was the unrolling of the aircraft without the need for pushback.

The McDonnell Douglas DC-10 shows the type of jetway used to date. Compared to the previous type, it has several advantages, the most significant being the free movement of the jetway on the stand. It is limited only by its length.

The last type of jetway is a novelty that the Dutch themselves came up with in 1971 [19]. It consists of two separate jetways, one is designed for the front aircraft door and the other is used to operate the rear door. We can distinguish this type according to its robust steel construction, as it must be located at a higher height so as not to damage the wings. It has no grip or manoeuvrable wheels from below. Such an arrangement of jetways allowed two or more categories of passengers to board at the same time, for example: business and economy class passengers. Figure 2 shows this type on a Boeing 747-200 aircraft, which is between two McDonnell Douglas DC-10s.

7.3. New York John F Kennedy Airport

New York City before the Wright Brothers' first flight was a gateway for Europeans who came to the United States by boat for better working conditions. Currently the New York metropolitan area is served by several airports, New York John F Kennedy, LaGuardia and Newark, which are different distances from the center of New York - Manhattan. The most distant airport is New York John F Kennedy. When designing it, the airlines had the opportunity to design their own terminal according to their ideas. The best known example is the Trans World Airlines (TWA) terminal [20].

Figure 3: New York JFK Airport Terminal 4. [Source: https://www.autoprio.com/wp-content/uploads/5122732_geonameid_New_York_JFK_Airport.jpg]

At the end of the 20th century flying with wide-body aircraft to JFK spread in air transport. These aircraft include the Boeing 767/777, Airbus A330 / 340 and newer versions of the Boeing 747-400. The airport infrastructure of both runways and terminals and aprons had to be adapted to this type of aircraft.

At present JFK Airport has 4 runways, the shortest of which is RWY 04R / 22L, has a length of 2,560 m and is used mainly for landings. All runways are 61 m wide, which also allows the operation of aircraft with the code letter F, such as the Airbus A380-800 [21].

Figure 3 shows Terminal 4, in the middle of which is the newest airport control tower. It divides the terminal into two parts.

To the right is a terminal for aircraft of code letter F. There are two Airbus A380-800s from Etihad Airways and Singapore Airlines on the stands, the third is located on the apron and belongs to Emirates.

Looking at the left side of Terminal 4, on the stands closer to the center of the terminal, there are wide-body aircraft, such as the Boeing 747-400 from Virgin Atlantic or the Airbus A330-300 Swiss. Towards the bottom of the picture, there are Delta large-capacity aircraft on the stands. At the end of the terminal are the smallest aircraft of this company such as the Bombardier CRJ900 or Airbus A319.

8. CONSTRUCTION OF A NEW AIRPORT INFRASTRUCTURE

In 2019 Munich Airport announced the construction of a new part of the satellite Terminal 2 [22]. The new terminal is designed for narrow-body aircraft on one side and for wide-body aircraft on the other side. The reason for the further construction of stands for large-capacity aircraft is the purchase of new Boeing 787-9 by Lufthansa. Compared to Frankfurt, Munich Airport is more focused on short and medium-haul routes, as a result of which it is not necessary to count on a higher runway capacity in the future.

The construction of a third, parallel runway on the northern edge of the airport is also planned at Munich Airport. It should be primarily intended for aircraft of code letter C, such as: Boeing 737 MAX 8 or Airbus A320neo. These aircraft have a shorter take-off length as well as MTOM. The new runway will be limited to aircraft MTOM and will not be able to be used by large-capacity aircraft.

9. CONCLUSION

Due to the change in various geometric parameters and performance characteristics of aircraft during their development, trends in the field of airport infrastructure design changed rapidly.

Several historical factors have influenced the development of aircraft. The aircraft manufacturers tried to achieve the use of the latest power units as well as wing shapes for the aircraft at the time. The overview of aircraft history is completed by 21st century aircraft, which are important for today's airports.

In the future even greater emphasis will be placed on the environmental impacts of aircraft operations. The main factor will be the correct choice of location with the design of new runways. Airports near large cities will have a problem. Some airports have introduced a slot system to ensure optimal use of the busiest airports. However, this solution was not sufficient. After the completion of the new runways, the airports must reckon with the fact that their operation will not be possible throughout the day, but only at designated hours, e.g. the airport will be closed from 06:00 until 22:00 and at night.

The construction of new runways will also take into account the construction of TWY connecting the runways with the airport. From an operational point of view, it is efficient to have two TWY, in which aircraft can move independently in both directions. The disadvantage of this arrangement is the double price and higher maintenance costs of these areas. The advantage of building new runways is to increase the airport capacity, which allows more aircraft to turn around and reduce the number of aircraft waiting to take off. The disadvantage is the consumption of a larger amount of fuel, which is needed to reach a remote runway.

Since the 1960s new terminals at international airports have started using boarding bridges instead of airport stairs. This has had the effect of increasing the comfort and safety of passengers, but in some cases it has resulted in an increase in the time required to turn - round aircraft on the stand.

The use of airports and aircraft was affected by the pandemic situation of Covid-19. This caused the postponement of the construction of some terminals or their modernization. This situation has forced a reassessment of the operation of individual types of aircraft, which has also caused a change in the view of the airport infrastructure. Air traffic is expected to resume to pre-pandemic levels in the coming years, as well as the need to plan airport infrastructure development in the future.

REFERENCES

[1] AirplaneAcademy, „AirplaneAcademy," 12 Marec 2022. [Online]. Available: https://airplaneacademy.com/piston-vs-turboprop-performance-efficiency-and-safety/?fbclid=IwAR0vKjb8bejaUDUW3WW95vjMehJnainoXDWthf5VYhXz39ct180g1PY4EQU.

[2] J. Kríž, Lietadlové pohonné jednotky, 1. ed., Žilina: Žilinská univerzita v Žiline, 2008, p. 285.

[3] AirplaneAcademy, „AirplaneAcademy," 12 Marec 2019. [Online]. Available: https://airplaneacademy.com/turboprop-vs-turbofan-safety-efficiency-and-performance/.

[4] M. H. Jozef Čerňan, Turbínový motor I. Teória a konštrukcia, Žilina: EDIS-vydavateľské centrum ŽU, Univerzitná HB, Žilina, 2020, p. 335.

[5] The Conversation, „The Conversation," 13 Marec 2019. [Online]. Available: https://theconversation.com/how-hot-weather-and-climate-change-affect-airline-flights-80795.

[6] M. Swayne, „boldmethod," 13 Marec 2020. [Online]. Available: https://www.boldmethod.com/learn-to-fly/performance/runway-surface-and-slope/.

[7] M. Jurica, Obrazová história letectva, Bratislava: Lindeni, 2019, p. 320.

[8] A. Dwayne, „U.S. Centennial of Flight Comission," 12 Marec 2015. [Online]. Available: https://www.centennialofflight.net/essay/Evolution_of_Technology/Monoplane/Tech13.htm.

[9] Control Towers, „Control Towers," 26 Február 2018. [Online]. Available: https://www.controltowers.co.uk/G/Gatwick.htm.

[10] Big, Bigger, Biggest, „Big Bigger Biggest-Airport," 2015. [Online]. Available: https://www.youtube.com/watch?v=uTolfGjFDLQ&t=65s

[11] R. Mola, „Smithsonian magazine," 28 Február 2013. [Online]. Available: https://www.smithsonianmag.com/air-space-magazine/how-things-work-trim-tabs-129376547/.

[12] Stadsarchief Amsterdam, „Amsterdam Airport Schiphol 1916-2016," 14 September 2016. [Online]. Available: https://www.youtube.com/watch?v=6Xvj_5JG1Oc.

[13] J. Krist, Encyklopedie moderních letadel, Praha: NAŠE VOJSKO, 2011, p. 442.

[14] D. J. Š. Eva Malá, Encyklopedie letadel, Ivanka pri Dunaji: SLOVO, 1993, p. 432.

[15] Airbus, „Airbus," 7 Apríl 2019. [Online]. Available: https://www.airbus.com/en/newsroom/press-releases/2019-01-easa-certifies-a330neo-for-beyond-180-minutes-etops.

[16] ICAO-International Civil Aviation Organization, „Annex 14, Aerodromes, Volume I," 2 Apríl 2018. [Online]. Available: https://www.iacm.gov.mz/app/uploads/2018/12/an_14_v1_Aerodromes_8ed._2018_rev.14_01.07.18.pdf.

[17] Flughafen münchen, „flughafen münchen," 26 Marec 2015. [Online]. Available: https://flughafen-muenchen-riem.de/.

[18] Schiphol, „Schiphol," 29 Marec 2019. [Online]. Available: https://www.schiphol.nl/en/you-and-schiphol/page/airport-history/.

[19] AirportHistory, „AirportHistory.org," 31 Marec 2020. [Online]. Available: https://www.airporthistory.org/photos-klm747-schiphol.html.

[20] AirportHistory, „AirportHistory," 2 Apríl 2022. [Online]. Available: https://www.airporthistory.org/.

[21] AirNav, „AirNav," 2 Apríl 2022. [Online]. Available: https://www.airnav.com/airport/kjfk.

[22] Flughafen München, „Flughafen München," 26 Marec 2022. [Online]. Available: https://www.munich-airport.de/.

[23] KAZDA, A., CAVES, R.E. 2007. Airport Design and Operation. Bingley: Emerald Group Publishing Limited, 2007. 538 s. ISBN 978-0-08-045104-6.

[24] KAZDA, A. 1995. Letiská design a prevádzka. Žilina: Edičné stredisko VŠDS 1995. 377 s. ISBN 80-7100-240-2

[25] 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.

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MONITORING OF TECHNICAL STATE OF UNMANNED AERIAL VEHICLES

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Abstract

The aim of this work is to study current possibilities of monitoring the technical state of the unmanned aircraft from the most basic activities to the more advanced aircraft systems. Partial goal is to create a simple general maintenance checklist for cases when the manufacturer does not publish any maintenance procedures, or the manufacturer is the owner and pilot of the aircraft, in case of DIY aircraft. Theoretical part is devoted to description of most common components of current UAVs and their possible failures and stating current possibilities for maintaining awareness of the technical state of the aircraft prior to, during and after the execution of a flight. Second part will state how to extract the flightlogs and what tools can be used to analyze them. The result of this work is creating general maintenance checklists as well as stating the information about the process of modifying this checklist for the UAV in question. Mentioned checklists will be created for pre-flight, post-flight and regular maintenance check.

Keywords

UAV, DIY, maintenance, checklist, flightlog

1. ÚVOD

V dnešnej dobe zažíva civilný sektor UAV masívny rozmach. Toto je spôsobené hlavne nízkymi nákladmi v porovnaní s lietadlami klasickými, ktoré majú pilota na palube. Ďalšími faktormi sú nízky dopad na životné prostredie, nižšia miera škody v prípade nehody atď. Dôležitým faktom je, že v dnešnej dobe pilot diaľkovo riadeného lietadla vďaka pokročilým systémom pomoci pri nemusí mať také technické vedomosti ako piloti týchto prostriedkov v minulosti. Toto môže viesť k pilotovu neschopnosť rozoznať základné technické nedostatky daného stroja, čo často vedie k zbytočným nehodám ktorým by sa dalo jednoducho predísť. Túto skutočnosť ešte zhoršuje fakt, že sa výrobcom z ekonomického hľadiska neoplatí publikovať manuály pre monitorovanie a udržiavanie technického stavu daných lietadiel. Napríklad ak sa jedná o finančne nákladnejšie UAV, tak výrobca publikuje pomerne rozsiahle postupy technických kontrol jednotlivých komponentov daného UAV. Takto je to napríklad v prípade UAV od firmy DJI konkrétne model Matrice 300 RTK. V tomto prípade sa jedná o model značne finančne nákladný na obstaranie, ale tu už firma DJI publikuje striktné postupy a intervaly jednotlivých prehliadok na monitorovanie technického stavu a zníženie rizika nehody.

2. SÚČASNÝ STAV

V Úvode článku si najskôr ujasníme pojmy nakoľko veľa ľudí dnes používa nesprávne termíny a neskôr popíšeme jednotlivé časti daných lietadiel a zdokumentujeme metódy monitorovania technického stavu lietadiel pomocou rôznych aplikácii. Budeme sa snažiť písať o UAV všeobecne, ale niektoré časti budú orientované priamo lietadlám od firmy DJI, nakoľko flotila Katedry leteckej dopravy spočíva hlavne z týchto modelov.

2.1. Terminológia

V tejto časti uvádzame naše dôvody, prečo by sa mal používať výlučne pojem UAV, prípadne diaľkovo riadený model lietadla. Zjednodušenie pojmu UAV ako bezpilotný prostriedok nám príde zavádzajúce, pretože narozdiel od pojmu Unmanned Aerial Vehicle vynecháva pilota ako hlavný prvok riadenia lietadla. Problémom tohto je, že dané liatadlá pilota majú, len sa nenachádza na palube ale na zemi.

2.2. Komponenty UAV

Monitorovanie technického stavu nie je možné bez toho aby sme poznali jednotlivé časti, z ktorých sa dané lietadlo skladá a ktorých technický stav chceme monitorovať, či už za účelom predĺženia ich životnosti alebo za účelom zvýšenia bezpečnosti vykonania letu. V tejto časti sa budeme venovať jednotlivým komponentom a prípadným závadám na nich. Medzi hlavné systémy RC lietadiel patria: batérie, motory a ich regulátory otáčok, vrtule, servomotory ovládacích plôch, prijímače rádiového signálu, kamera a jej stabilizátor, osvetlenie lietadla prípadne letový počítač alebo stabilizácia modelu a v neposlednom rade netreba zabúdať na kontrolu kabeláže a pristávacieho zariadenia. Starostlivosť o niektoré je jednoduchá a spočíva hlavne v počiatočnom nastavení, kalibrácií a kontrole ich funkcie. Starostlivosť o iné však priamo ovplyvňuje ich životnosť či dokonca ich vplyv na životnosť iných komponentov [1].

2.3. Sledovanie letových dát zo zapisovačov

V tejto kapitole sa budeme venovať sťahovaniu a sledovaniu letových dát z našich modelov lietadiel. Budeme sa venovať hlavne systému od firmy DJI pretože v dobe písania tejto práce sú všetky lietadlá vo flotile katedry leteckej dopravy s funkciou zaznamenávania letových dát od tejto firmy. Na začiatok je potrebné vedieť aké typy súborov naše lietadlá generujú a kam ich ukladajú. Úložiská sú dve a to interné úložisko na palube daného lietadla a úložisko aplikácie pomocou ktorej zobrazujeme aktuálne video a konfiguráciu lietadla, zvyčajne na našom smartfóne, ktorý používame na lietanie, alebo v ovládači modelu [1],[2].

3. MONITOROVANIE TECHNICKÉHO STAVU

V dnešnej dobe môžeme monitorovanie technického stavu v leteckom modelárstve rozdeliť na pár hlavných častí a to sledovanie za letu a postupy a kontroly na zemi. Monitorovanie stavu lietadla za letu je dosiahnuté buď telemetrickými údajmi alebo najjednoduchšie len sledovaním pohybov a počúvaním zvukov ktoré náš model vydáva, na tento účel je dobré mať pilota s precíznym okom a uchom. Toto je najrýchlejší spôsob spozorovanie nežiadúcich vibrácií a chýb. Jedným z úplne najjednoduchších systémov je klasický „strážnik“ batérii. Je to zariadenie ktoré sleduje napätie na jednotlivých článkoch batérie a pri dosiahnutí prednastavenej hodnoty vysiela hlasný akustický signál, ktorý dá znamenie pilotovi, že je čas ukončiť let. Medzi zložitejšie systémy patria rôzne typy telemetrických systémov. Poznáme dva hlavné typy. Prvým je telemetria zabudovaná do systému ovládania pomocou rádiového spojenia kedy sa jedná o systém ktorý sleduje nejaký dôležitý parameter a vysiela ho pomocou rádiového spojenia do vysielača. Vysielač potom buď zobrazí danú hodnotu na obrazovke alebo v lepšom prípade spustí zvukový signál v prípade, že je táto hodnota kritická. Zvukový signál je lepší nakoľko nevyžaduje spustiť zrak z nášho modelu čo by mohlo ľahko prispieť ku strate orientácie. Druhým je externý telemetrický systém, ktorý pozostáva z vysielača napojeného na letový počítač, ktorý zhromažďuje parametre a posúva ich vysielaču ktorý ich pomocou samostatného rádiového spojenia posiela do pozemnej jednotky, ktorá dáta prijme a zobrazí. Špičkové systémy dokážu vysielať všetky zaznamenávané údaje a zobrazujú ich na obrazovke počítačov technikov ktorý ich vedia analyzovať v reálnom čase, podobné systémy sa používajú vo vesmírnych misiách a tiež napríklad v pretekárskych autách atď [3].

Táto časť je venovaná činnostiam spojeným s monitorovaním a udržiavaním technického stavu UAV. Keď chceme monitorovať technický stav, tak musíme určiť metódy a postupy pre nasledovné činnosti: sledovanie letovej doby, predletová prehliadka, sledovanie technického stavu za letu, poletová kontrola a prípadne pravidelné prehliadky. Niektoré z nich môžu pozostávať z celkom jednoduchých krokov a iné bývajú celkom dôkladné. Postupy kontrol na zemi v prípade drahších modelov publikuje výrobca pre každý príslušný model. Býva tu definovaný postup ako predletovej prehliadky tak poletovej prehliadky a interval a postup pravidelných prehliadok. Problém tu nastáva v tom, že toto nerobí každý výrobca pre každý svoj model. V prípade, že výrobca nevydáva danú príručku pre náš model, bývajú niektoré základné informácie ohľadne údržby v prevádzkovej príručke. V prípade, že ide o model navrhovaný a stavaný samotným modelárom je dôležité aby sa daný človek zamyslel nad spôsobom vykonávania prehliadok pred letom po lete a prípadne aj pravidelných prehliadok. Samostatná pozornosť bude venovaná batériám, nakoľko sú najkritickejším prvkom ohľadne údržby a bezpečnosti vykonania letu. V závere budú dané prehliadky zhrnuté do tabuliek [4].

3.1. Sledovanie letovej doby

V tejto časti sa venujeme dôležitosti sledovania letovej doby ako aj rôznym spôsobom akými sme v dnešnej dobe schopný túto úlohu splniť. Dôležitosť sledovania letovej doby rastie hlavne v prípade, že nám výrobca modelu zadá postupy pravidelných prehliadok prípadne sa prevádzkovateľ modelu rozhodne si dané postupy vytvoriť. Potreba tohto rastie s množstvom prevádzky daného modelu. Ak sa pozrieme ako sa daná problematika rieši u klasického letectva, tak môžeme vidieť, že každé lietadlo a každý pilot má svoj zápisník letovej doby pomocou ktorých sledujeme letovú dobu a ďalšie dôležité skutočnosti ako sú napríklad udalosti ktoré sa stali počas letu. Nie je nutné aby sme u modelov lietadiel alebo letúnov riešili danú problematiku až tak obsiahlo ako v klasickom letectve. Parametre ktoré je dôležité sledovať u modelov sú: množstvo letov, letová doba, použitá batéria, meno zodpovedného pilota a miesto na zaznamenávanie zvláštnych udalostí. V prípade že daný let prebehol bez tzv. bez závad môžeme letovú dobu zlučovať do jedného celku v daný deň. V špeciálnom prípade že máme zapisovač letových dát a stala sa nejaká dôležitá letová udalosť treba daný let poznačiť aj časom letu aby sme neskôr vedeli prezrieť zaznamenané údaje a diagnostikovať problém. Letové udalosti môžu byť rôzne od nehôd až po časté výpadky signálu alebo akýkoľvek zvláštny pohyb alebo zvuk z lietadla. Spôsoby sledovania letovej doby môžu byť rôzne a závisia od rozhodnutia prevádzkovateľa daného modelu napríklad akýkoľvek zošit v kufríku daného modelu, súbor online ktorý je zdieľaný medzi pilotmi a osobami ktoré sú zodpovedné za údržbu alebo môžeme používať aplikácie ako je Airdata a ďalšie, ktoré nám budú zaznamenávať dané skutočnosti. Je dôležité spomenúť, že za niektoré spôsoby od nás budú vyžadovať viac práce ako iné ale na druhej strane za iné viac automatizované si bude musieť prevádzkovateľ platiť [4],[5].

3.2. Predletová prehliadka a činnosť za letu

V tejto časti sa venujeme kontrolným úkonom pred letom a činnosti pilota za letu. Podobne ako u klasického letectva je aj pri UAV potrebné sa pred vykonaním letu uistiť, že je naše lietadlo pripravené na let. Správna prehliadka pred letom spočíva z pár jednoduchých krokov. Postupy záležia od rozhodnutia prevádzkovateľa modelu a hlavne od konfigurácie lietadla, čiže faktu či je to model s pevným krídlom tzv. letún alebo model s rotačnými nosnými plochami tzv. multikoptéra alebo helikoptéra. Dôležité kroky sú: vizuálna kontrola poškodenia modelu, kontrola upevnenia vrtúľ na motory, kontrola výchyliek, kontrola ťahu u modelov letúnov, kontrola polohy ťažiska u modelov letúnov, kontrola nabitia pripojenej batérie lietadla ako aj vysielača, prípadne na začiatku letu krátke vznášanie na mieste v prípade, že sa jedná o model s rotačnými nosnými plochami. Pre komplexnejšie modely pribúdajú ďalšie kroky ako: kalibrácia senzorov, nastavenie maximálnej výšky letu poprípade maximálnej vzdialenosti od miesta vzletu, nastavenie polohy pre funkciu návrat na miesto vzletu a kontrola aktualizácií firmwaru modelu [6],[7],[8].

3.3. Prehliadka po lete a uskladnenie

Táto časť je venovaná činnostiam potrebným na správne uskladnenie lietadla a úkonom po vykonaní letu. Po pristátí modelu nastáva čas na po letovú prehliadku. Aj v tomto prípade si skontrolujeme manuál kvôli výrobcom odporúčaným krokom pre po letovú kontrolu. Jedným z prvých krokov po pristátí modelu je odpojenie batérie, ktorú následne necháme vychladnúť a skontrolujeme stav napätia jednotlivých článkov batérie, jednotlivé články by mali mať rovnaké napätie bez veľkých odchýlok, čiže by mali byť vyvážené. Ak by odchýlka po vychladnutí nadobúdala viac ako 0,1 V opakovane, mohlo by to indikovať starnutie jednotlivých článkov a treba dbať zvýšenú pozornosť pri nabíjaní a používaní danej batérie. Počas chladnutia batérie sa môžeme venovať vypnutiu vysielača a kontrole teploty motorov a ich regulátorov, samozrejme v prípade, že nám konštrukcia dovoľuje tieto komponenty kontrolovať. Následne budeme pokračovať vizuálnou kontrolou poškodenia konštrukcie modelu a zápisom údajov o lete do zápisníka, údaje niektoré modely zapisujú automaticky a v tomto prípade môžeme tento krok vynechať alebo vykonať ho až „doma". Poslednými krokmi na mieste letu je vyčistenie modelu samotného a zabezpečenie modelu na cestu „domov". Je dôležité nechať model pred uskladnením vyschnúť ak sme po lete zistili, že je jeho povrch mokrý. Po príchode ale prehliadka pokračuje nabitím batérií a sťahovaním a analýzou dát v prípade, že sa stala nejaká neočakávaná udalosť počas letu. Batérie nabíjame podľa toho či v blízkej dobe plánujeme prevádzku alebo nie. Ak áno tak nabíjame batérie hneď do plného stavu nabitia. Ak najbližšia prevádzka plánovaná o viac ako 3 dni nabijeme batérie len na cca 3,8 V na článok, čo je napätie na uskladnenie batérií [9],[10].

3.4. Pravideľná prehliadka

Táto časť je venovaná pravideľnej prehliadke. Poslednou z technických kontrol je pravidelná kontrola. Jej účelom je objaviť a opraviť závady, ktoré by klasická prehliadka nedokázala spozorovať alebo závady, ktoré vyžadujú špeciálne nástroje k ich oprave. Pravidelnú kontrolu treba vykonávať podľa postupov postupov publikovaných výrobcom nášho modelu. V prípade, že výrobca dané postupy nepublikuje, mal by sa prevádzkovateľ zamyslieť nad krokmi po vykonaní ktorých vieme oddialiť najbežnejšie problémy. Samozrejme ďalej zmienená prehliadka je všeobecná a nemá vymeniť výrobcom odporúčanú kontrolu ale ju prípadne len doplniť. Pri tejto prehliadke je dôležité riešiť postup ale aj interval, ktorý určuje ako často budeme danú prehliadku vykonávať. Interval ktorý sme zvolili je 200 letov 50 letových hodín alebo 6 mesiacov [11].

3.5. Starostlivosť o batérie

Ďalšou veľmi dôležitou časťou sú samotné batérie. Ako už bolo v tejto práci zmienené, na pohon UAV sa najčastejšie používajú Lítium-polymérové batérie, ktoré majú svoje výhody ale aj nevýhody. Pri práci s nimi postupujeme podľa istých postupov. To ale neznamená, že môžeme vynechať čítanie postupov publikovaných výrobcom danej batérie. Tento krok je dôležitý pretože niektorý výrobcovia udávajú, že ich batérie je napríklad nutné vybíjať a nabíjať počas doby dlhšieho skladovania napríklad každé 3 mesiace. Toto je špeciálne prípad batérií od formy DJI. Ak sa jedná o inteligentné batérie je nutné skontrolovať príručku kvôli ďalším postupom ako napríklad aktualizácia firmvéru. Ak naše lietadlo používa konfiguráciu s dvoma batériami je dôležité vytvoriť dvojicu a používať danú dvojicu ako by to bola jedna batéria aby sa zabránilo použitiu jednej novej a druhej starej batérie, čo by mohlo spôsobiť katastrofu. V prípade že je treba batérie transportovať, napríklad dopravným lietadlom, je dôležité ich prepravovať vybité, pretože tak znížime riziko spontánneho požiaru. Ďalej je potrebné ich prepravovať v špeciálnom vrecku na li-po batérie a v príručnej batožine, nakoľko v prípade požiaru je nutné sa k nim dostať a tento požiar ideálne v počiatočnej fáze zneškodniť [12].

4. ZÁVER

Monitorovanie a udržiavanie technického stavu je celkom komplexný súbor činností. Vo viacerých aspektoch sa ukazuje aplikácia AirdataUAV ako vhodný pomocník a preto ju odporúčame používať hlavne v prípade, ak sa jedná o model podporovaný danou aplikáciou.

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REFERENCIE

[1] https://dictionary.cambridge.org/dictionary/english/drone. [Cit. 7 apríl 2022].

[2] ICAO, „ICAO Cir 328, Unmanned Aircraft Systems (UAS)," 2011.[Online].Available: https://www.icao.int/meetings/uas/documents/circular%20328_en.pdf. [Cit. apríl 2022].

[3] KiwiKvads, „LiPo Battery C-Ratings – What do they actually mean?," KIWIKVADS, 2. Február 2020. [Online]. Available:

[4] https://www.kiwiquads.co.nz/lipo-battery-c-ratings-what-do-they-actuallymean/. [Cit. 7. apríl 2022].

[5] Dongguan Large Electronics, „Large.net," Dongguan Large Electronics, [Online]. Available: https://www.large.net/news/8ju43nv.html. [Cit. 7 apríl 2022].

[6] J. Farrar, „The Drone Girl," 15 jún 2021. [Online]. Available: https://www.thedronegirl.com/2015/02/07/lipo-battery/. [Cit. 7 apríl 2022].

[7] ArduPilot Dev Team, „ardupilot.org," ARDUPILOT, [Online]. Available: https://ardupilot.org/plane/docs/automatic-landing.html. [Cit. 7 apríl 2022].

[8] DJI, „dji.com," DJI, [Online]. Available: https://www.dji.com/sk/service/djicare-refresh/info. [Cit. 7 apríl 2022].

[9] D. Joyce, „youtube," [Online]. Available: https://www.youtube.com/watch?v=AfS7gXmEDno. [Cit. 7 apríl 2022].

[10] „datfile.net," [Online]. Available: https://datfile.net/. [Cit. 7 apríl 2022].

[11] Airdata UAV, „airdata.com," [Online]. Available: https://airdata.com/features#tab-panel-0. [Cit. 7 apríl 2022].

[12] Process Street, „process.st," [Online]. Available: https://www.process.st/checklist/drone-pre-flight-checklist/. [Cit. 7 apríl 2022].

[13] DJI, „dji.com," 28 Február 2015. [Online]. Available: https://dl.djicdn.com/downloads/inspire_1/en/Inspire_1_Maintenance_Manual V1.0_en.pdf. [Cit. 7 apríl 2022].

[14] 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.

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

[16] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A., JANOVEC, M. 2020. Komunikačné systémy v letectve. 1. vyd. - V Žiline : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020.

[17] 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.

[18] 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.

[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.

[20] 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.

[21] 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.

[22] 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.

[23] Škultéty, F., Cernan, J., Sisák, T. 2020. VTOL design for fixed wing UAVs. Transport Means - Proceedings of the International Conference, 2020, 2020-September, pp. 985–990. ISSN 1822296X.

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INNOVATION OPTIONS FOR SELECTED SYSTEMS OF M60 ENGINE: EXHAUST SYSTEM AND ENGINE COOLING

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Abstract

Our article deals with the design and construction of a resonant exhaust system and cooling system for the M60 engine. In introductory part, the article provides the reader with a final overview of two-stroke. In the next chapter, the focus is only on the resonant exhaust system. The article of the reader informs about the basic principles of resonant exhaust systems and points out their fundamental effect on power, torque and fuel consumption. Subsequently, the article gets to the calculation of the resonant exhaust system and its execution. The final chapter deals with the cooling system and solves the design optimization of the shape of deflectors. Both in the previous chapter and in this chapter, it first deals with theoretical knowledge, design and subseguent production of deflectors.

Keywords

Two-stroke engine, Resonant exhaust system, Cooling system, Heat transfer, Optimization

1. INTRODUCTION

Today's progress has brought a new heart to the eyes of simple two-stroke engines, e.g. in the form of a control unit which controls the individual fuel and oil injection. This has significantly reduced the usability of these engines. Among other things, the engine gained a wider range of usable speeds with this system. However, our experimental M60 engine is a source of increased emissions not only due to grease lubrication, but also due to the leakage of fresh mixture into the exhaust system. This leakage was primarily solved by a resonant exhaust system, the pressure waves of which were to return the fresh mixture back to the combustion chamber.

In two-stroke engines, the exhaust system thus contributes significantly to the power, engine torque and consumption. Since the resonant exhaust system thus fundamentally affects important engine parameters, we decided to design our own exhaust system on the experimental two-stroke M60 engine. Our goal was to design a suitable exhaust system that will be used in travel mode, ie. that we focused on a wider range of speeds used.

The next step was to design the cooling system of our air-cooled engine. By optimizing the design of the deflectors, we should improve the heat transfer from the engine heads to the surrounding atmosphere.

2. TWO-STROKE ENGINE

A two-stroke engine is a heat engine that is used to drive vehicles such as aircraft, cars, motorcycles, ships, etc., but also to drive various equipment and devices in construction, gardening, etc. It is a reciprocating internal combustion engine with non-stationary flow, which works in two such ways. The entire operating cycle takes place during one revolution of the crankshaft in two ways. The first bar is intake and compression, the second bar is expansion and exhaust.

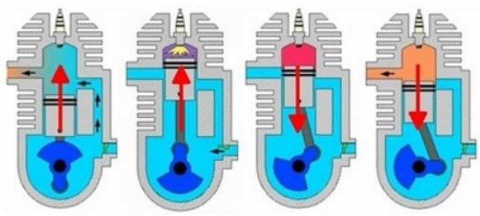


Figure 1: Engine operation. [15]

It is unique in its design simplicity, which is its great advantage. This makes it lighter and smaller and its production but also maintenance is easier. There are no valve lines in it, which are replaced in the two-stroke engine by individual channels, which are opened and closed by the moving piston itself.

The cooling of two-stroke engines is mostly air, as is the case with the M60 engine. The air-cooled engine is characterized by its ribbing, which aims to increase the area of heat transfer to the surrounding atmosphere.

3. EXHAUST SYSTEM

The exhaust system of two-stroke engines fundamentally affects the power, torque and consumption of the engine. The main requirements include: flue gas discharge into the surrounding atmosphere, ensure the required course of pressure waves and partial noise attenuation. Up to 1/3 of the engine power is involved.

The disadvantage of these exhausts is that they are not able to provide sufficient power over the entire engine speed range.

These are often tuned exhausts, with a narrow speed range at which we want to achieve the maximum possible performance. However, we can also focus on a wider range of speeds, then we choose this band at the expense of the maximum achieved power. The expansion chamber consists of different parts, each of which affects the power curve as well as the torque curve in its own way. It can consist of, for example from the elbow, the widening diffuser, the straight middle part, the tapering cone and from the outlet pipe.

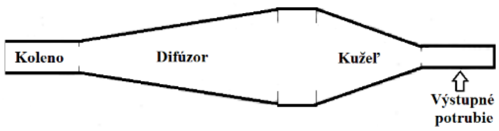


Figure 2: Parts of the exhaust system. [Source: Authors]

3.1. Principle of resonant exhaust systém

Initially, the engine burns, producing exhaust gases. The pressure in the combustion chamber is currently high and low in the exhaust pipe. As a result, the molecules will move extremely fast at the speed of sound through the resulting slit, creating a positive shock wave. The speed inside the exhaust pipe is much higher than the speed of sound in the open atmosphere [1].

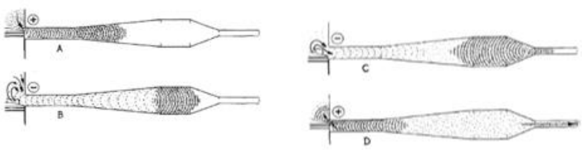


Figure 3: The course of pressure waves. [1]

The pressure wave moves in front of the gases. At first, the gases have a high velocity, but as the piston goes to the bottom dead center, the pressure drops and the gases slow down. The velocity of the gases is proportional to the pressure. However, the pressure wave continues to move at its speed of sound until it passes into the diffuse part. A positive shock wave is followed by a negative oscillation. This has a role in the resonant exhaust, slowing down the exhaust and thus reducing the amount of fresh mixture in the exhaust pipe. Also, this vacuum will reduce the pressure in the combustion chamber, which will allow a better supply of fresh mixture through the bypass channel. This wave does not push the exhaust gases back, it only takes away their energy. The negative wave helps to eliminate the positive wave [1].

The positive shock wave continues through the exhaust to the cone, where the pressure wave is partially reflected back into the engine cylinder. The wave bounces off and begins to travel back to where it must arrive before the piston closes the exhaust duct. By timing the reflected pressure wave correctly, we bring back the mixture that has left the combustion chamber together with the exhaust gases. A positive reflected pressure wave pushes the leaked mixture back. Proper timing must ensure that the bypass channel is already closed [1].

3.2. Calculation of the expansion chamber

For the correct function of the exhaust system, it is necessary to correctly dimension the individual parts. For the correct design of the exhaust system, it was necessary to find out the following data:

- The exhaust duct is open for 165 degrees
- Suction ducts are open for 152 degrees
- Exhaust elbow diameter D1 - 40mm

3.2.1. Tuned length

As the first dimension, the so-called tuned exhaust length. This length is from the inner edge of the exhaust duct (where it is covered by the piston) to the middle of the length of the tapering cone. Tuned exhaust length, calculated according to the authors [1]:

$$L_t = \frac{E_0 * V_s * 83{,}34}{N} \quad (1)$$

Where:

L_t – tuned exhaust length (mm)

E_0 - exhaust duct opening angle (°)

V_s – pressure wave speed (m/s) (1700 ft/sec (518m/s). [1])

N – engine speed

$$L_t = \frac{165 * 1700 * 83{,}34}{6000}$$

$$L_t = 46{,}75\ in = 1187{,}4\ mm$$

The calculated length of the tuned exhaust is 1187.4 mm. If we construct a rounded resonant exhaust system, this dimension will speak of the length of the center section axis.

3.2.2. Diffuser

The author proposes an optimal diffuser angle A_1 - 8 °. The choice of the diffuser angle will already significantly affect the performance curve of the motor and in this choice we must already focus on the desired result [1].

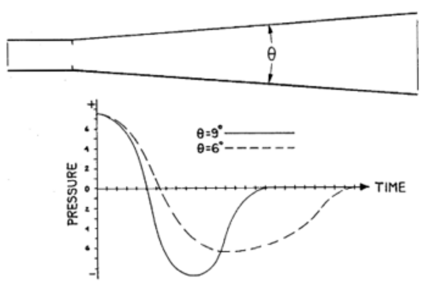


Figure 4: Diffuser. [1]

To meet our requirements, we decided to use a 6 ° diffuser angle. The engine has a high power, kt. we will not use. And so, at the expense of peak power, we will expand the power band.

We calculate the mean exhaust diameter according to the author [1]:

$$D_2 = \sqrt{6{,}25 \cdot D_1^2} \tag{2}$$

Where:

D_2 – mean exhaust diameter (mm)

D_1 – exhaust knee diameter (mm)

D_2= 100 mm

$$D_2 = \sqrt{6{,}25 \cdot 40^2}$$

We choose the diffuser angle of 6 ° and the average exhaust diameter is 100 mm.

We calculate the diffuser length as follows:

$$L_4 = \left(\frac{D_2 - D_1}{2}\right) \cdot cot(A_1/2) \tag{3}$$

Where:

L_4 – diffuser length (mm)

D_2 – mean exhaust diameter (mm)

D_1 – exhaust knee diameter (mm)

A_1 – diffuser extension angle (°)

$$L_4 = \left(\frac{100-40}{2}\right) \cdot cot(4) = 429\,mm$$

$$L_4 = 429\,mm$$

After fitting, the length of the diffuser is 429 mm.

3.2.3. Tapered cone

This part of the exhaust system tends to gradually narrow. A short cone with a large angle will increase maximum power, but the engine will lose power in the medium range. The standard exhausts of two-stroke engines do not cover the entire speed. A longer and slightly tapered cone expands the power range, and a sharper tapered cone is often a trade-off between range and maximum power [1] [2].

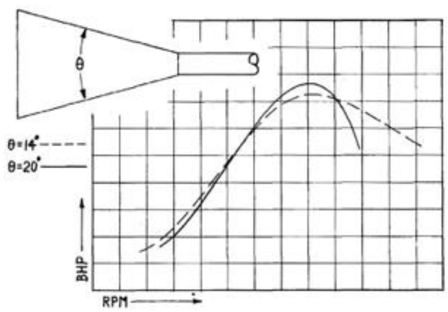


Figure 5: Tapered cone. [1]

According to the author, the angle A_2 from 14 ° to max. 20 °. When we design a guide cone with an angle of 20 °, the motor will give us high performance. However, if we exceed a given speed with this maximum power, the power will fail completely and the engine will appear as if it were in emergency mode, or as if the engine required us to shift to a higher gear. If we choose an angle, for example 15 °, we will achieve a slightly lower maximum power, but after exceeding the given speed, the engine power will not drop so extremely and will maintain a certain power [1].

The constriction is in most cases twice the diffuser used in the expansion chamber. There we chose the angle A_1 8 °,, so in the part of the guide cone we will use the narrowingA_2 16 ° [1].

Based on the selected angle, we can calculate the length of the tapering cone:

$$L_2 = \left(\frac{D^2}{2}\right) \cdot cot(A_2/2) \tag{4}$$

Where:

L_2 – cone length (mm)

D_2 – mean exhaust diameter (mm)

A_2 – taper angle (°)

$$L_2 = \left(\frac{100}{2}\right) \cdot cotg(8)$$

$$L_2 = 355{,}76\,mm$$

The length of the tapered cone is 355.76 mm.

3.2.4. Theoretical cone length

We calculate the theoretical cone length as:

$$L_6 = \left(\frac{D_2 - D_3}{2}\right) \cdot cot(A_2/2) \tag{5}$$

Where:

L_6 – theoretical cone length (mm)

D_2 – mean exhaust diameter (mm)

D_3 - outlet pipe diameter (mm)

A_2 – taper angle (°)

$$L_6 = \left(\frac{100 - 24{,}8}{2}\right).cot\ (8)$$

$$L_6 = 267{,}53\,mm$$

The length of the outlet pipe is 267.53 mm.

3.2.5. Exhaust elbow

The longer the exhaust elbow, the smoother the onset of power. It is recommended to choose a coefficient for calculating the length from 6 to 11. [1] Since we want to achieve a refined running of the engine in travel mode, but at the same time we do not want to lose a lot of power, we choose the value 8.

We calculate the knee length as follows:

$$L_3 = D_1 \cdot k_k \quad (6)$$

Where:

L_3 – exhaust elbow length (mm)

D_1 - exhaust knee diameter (mm)

k_k – coefficient for calculating the knee length (-)

$$L_3 = 40 \cdot 8$$

$$L_3 = 320\ mm$$

The length of the knee after fitting into the formula is 320 mm.

3.2.6. Exhaust length from the exhaust duct to the cone

Another dimension for the design of the engine is the length from the beginning of the exhaust duct, ie from the edge of the piston, to the beginning of the cone. We calculate it as follows:

$$L_1 = L_t - \left(\frac{L_2}{2}\right) \quad (7)$$

Where:

L_1 – exhaust length from piston edge to cone (mm)

L_t – tuned exhaust length (mm)

L_2 – cone length (mm)

$$L_1 = 1187{,}4 - \left(\frac{355{,}76}{2}\right)$$

$$L_1 = 1009{,}52\ mm$$

The length of the exhaust from the edge of the piston to the cone is 1009.52 mm.

3.2.7. Length of the middle part of the exhaust

We calculate the length of the middle part of the exhaust:

$$L_5 = L_1 - (L_3 + L_4) \quad (8)$$

Where:

L_5 – length of the middle part of the exhaust (mm)

L_1- exhaust length from piston edge to cone (mm)

L_3 - exhaust elbow length (mm)

L_4 - diffuser length (mm)

$$L_5 = 1009{,}52 - (320 + 429)$$

$$L_5 = 260{,}52\ mm$$

The length of the average exhaust length after installation is 260.52 mm.

3.2.8. Outlet piping

According to the author, the outlet pipe has a diameter between 0.58 and 0.62 times the diameter of the supply pipe and its length is equal to 12 times its own diameter. [1] This part of the exhaust is more sensitive to changes in diameter than to changes in length. This calculation only brings us closer to the optimal solution, it is necessary to adjust it in our own measurements so that we achieve the best possible result.

We calculate the diameter of the outlet pipe as:

$$D_3 = D_1 \,.\, k_v \quad (9)$$

Where:

k_v – coefficient for calculating the outlet pipe diameter (0,58÷ 0,62)

D_3 – outlet pipe diameter (mm)

D_1 – exhaust knee diameter (mm)

$$D_3 = D_1 \,.\, 0{,}62$$

$$D_3 = 24{,}8\ mm$$

The straight pipe outlet after installation is 24.8 mm.

We calculate the length of the outlet pipe as:

$$L_7 = D_3 \,.\, 12 \quad (10)$$

Where:

L_7 – outlet pipe length (mm)

D_3 – outlet pipe diameter (mm)

$$L_7 = 24{,}8 \,.\, 12$$

$$L_7 = 297{,}6\ mm$$

The length of the outlet pipe is 297.6 mm.

When designing, it must be borne in mind that if the diameter is too long or the pipe is too long, both cases excessively limit the output of the resonant exhaust system. The temperature rise can be so sudden that the engine can overheat [1].

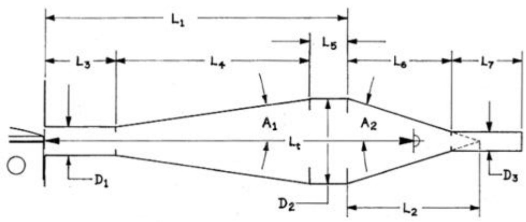


Figure 6:: Dimensions of the resonant exhaust system. [1]

3.3. Exhaust production and testing

The production took place in the following steps. Based on the calculation, we cut out individual parts of the exhaust from steel sheets, where we could not forget to subtract the length of the exhaust duct from the calculated tuned length of the exhaust. We continued by turning the individual parts. The exhaust elbow and outlet pipe had dimensions that could be purchased. We subsequently welded the individual parts (welding - joining metal parts by heat).

We continued with the surface treatment, especially by grinding it, so that we had a perfect base for the surface heat-resistant paint, which is intended for the exhaust system. Usually, resonant exhaust systems are not surface-treated, but due to the fact that the experimental engine is not used as often and can also serve as a teaching aid and students will be able to touch it, we decided to surface-treat it.

Figure 7: Exhaust system production. [Source: Authors]

We also had to solve the exhaust mount, which cannot be fixed. The exhausts are attached to the engine with flanges and springs. In the next part, the exhausts are attached using silent blocks and other springs. Flexible mounting prevents fatigue of individual materials, whether the expansion chamber itself, the motor, but in our case also the stand.

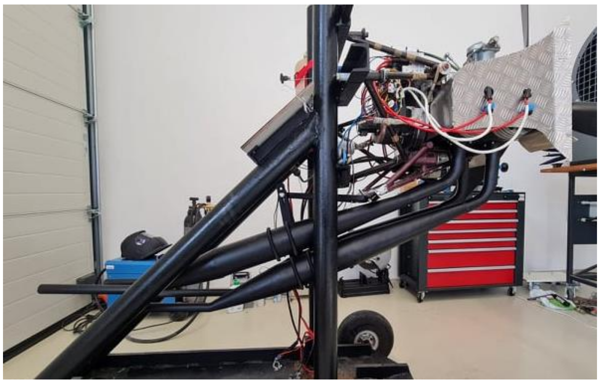


Figure 8: Exhaust system installation. [Source: Authors]

4. COOLING SYSTEM

An internal combustion engine is a heat engine in which physico-chemical processes take place, during which energy is released from the fuel and high pressures and temperatures are created. Reciprocating engines use potential energy and thus hot flue gas pressure energy. Approximately 30% of the heat supplied is converted into useful work and up to 25% of the heat is removed in the cooling itself. The heat dissipated by cooling is loss-making, we do not get any work from it. However, it has an important role to play in ensuring sufficient heat dissipation from the thermally stressed parts of the combustion chamber to maintain proper operating temperatures. Much of the heat is removed from the walls of the cylinders and heads, and only a small part passes into the oil. In aviation, air-cooled engines are used to a greater extent. Their advantage is lower weight, very good reliability and less vulnerability. An air-cooled engine has statistically 20% fewer failures than a liquid-cooled engine [11].

4.1. Cooling design

With in-line reciprocating engines, we often encounter the problem of insufficient cooling of the rear rows of cylinders and heads. Our goal was to direct a sufficient amount of air flow to this area. We physically measured part of the engine and it was modeled in SolidWorks. In Inventor, we continued to design and shape the deflectors. We created several designs on an ongoing basis, which we simulated in the Autodesk CFD program, and gradually we got to the final version of the deflectors, which will solve the mentioned problem of rear cylinder overheating.

4.1.1. <u>Object measurement and modeling</u>

The first step in our work was to thoroughly measure the parts in which the cooling itself takes place. We decided to use only two engine cylinders for the simulation. Since the original deflectors were also designed, each pair of cylinders had its own deflector. Deflectors are a reflection of the mirror.

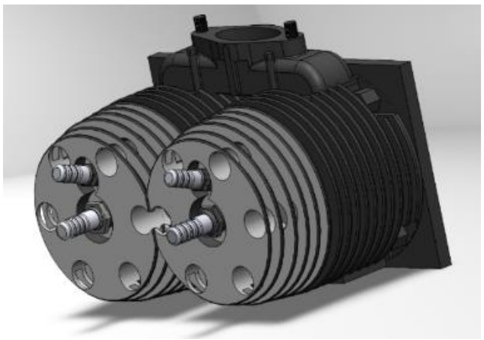


Figure 9: M60 engine heads. [Source: Authors]

4.1.2. <u>The simulation</u>

The simulation took place in three parts. And in the simulation of the engine itself, followed by the simulation of the deflector, kt. created by the previous engine owner and finally a simulation of the proposed deflector. The input data to the simulation were air velocity 50 m / s and temperature 21 ° C. In the shape of a deflector, we were limited by the space before entering the deflector, where the propeller is actually located.

a) Simulation of the original deflector

In this simulation, we created a deflector model created by the previous engine owner. The motor is currently used only on stands, to which the shape of the deflector itself tried to adapt. We see that although the author tried to keep the air supply to the engine as large as possible, the air did not have enough space around the engine and especially the deflector shapes were not smooth enough to ensure the necessary flow. In the critical part, behind the second cylinder, the flowing medium moved too slowly. As a result, very little heat was removed from this area, which caused the rear cylinder of the engine to overheat.

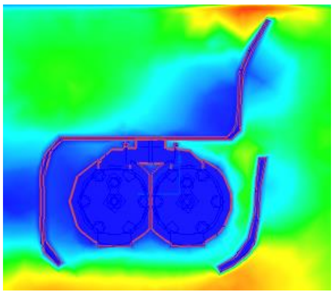


Figure 10: Simulation of the original deflector. [Source: Authors]

b) Simulation of the proposed deflector

Countless simulations preceded the final deflector. When designing it, we worked with various shapes, which we gradually adapted with small modifications. In the first stage, we had proposals, kt. they also consisted of several deflectors, which were to use the principle of the Bernoulli equation. However, this did not prove to be the right way to optimize the shape, so we returned to the two-part deflector. In order to ensure a sufficient amount of air and its sufficient speed in the headspace, we had to expand the input device. This proved to be the case with the first designs, and we continued to work only on optimizing the shape in order to direct the air to the problems of the part behind the second cylinder as much as possible. Continuous shape optimization eliminates the emerging air vortices shown in the figure. The proposed deflector is widened at the inlet, which should ensure a sufficient supply of flowing air. The shape tapers smoothly and directs more air into the space behind the second cylinder. By achieving smoother deflector shapes, the emerging air vortices were also alleviated.

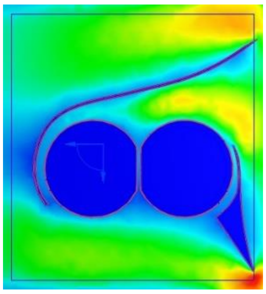
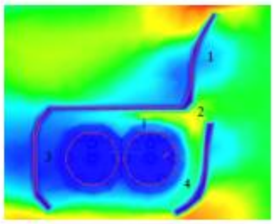


Figure 11: Proposed deflector.[Source: Authors]

In the resulting deflector, the shapes were optimized to such an extent that the velocity of the medium behind the second cylinder increased almost threefold compared to the original deflector. With the original deflector, we reached an average speed of about 10 m / s behind the second cylinder (area 3). With the new deflector, we reached a speed of 30 m / s.

Area	Flow rate (m / s)
1	1
2	50
3	10
4	20



Area	Flow rate (m / s)
1	20
2	65
3	30
4	30

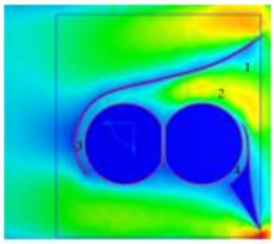


Figure 12: Original and new deflector. [Source: Authors]

Furthermore, it was possible to increase the speed at the entrance to the deflector (area 2), where the speed of the original deflector reached 50 m / s, the proposed deflector is 65 m / s.

4.2. Deflector design

After optimizing the deflector, we decided to test the correct dimensions by creating a paper template. The production of the designed deflector subsequently continued by firing the individual parts, creating technical holes for the spark plugs themselves and also for the carburetors.

We first placed the deflectors in place and then we spot welded them to verify their correctness, or to reveal some other shortcomings. After testing them, we went on to the welding itself. The deflectors are made of aluminum embossed alloy sheet, which we chose mainly due to its low density and low weight. The same steel sheet would be much heavier. And so we save fuel by reducing weight. With the right surface treatment, this aluminum sheet is corrosion-resistant and shows no signs of aging.

Figure 13: Installation of the proposed deflector. [Source: Author]

5. CONCLUSION

The article demonstrates the design and implementation of an exhaust and cooling system for the required power, consumption and torque of a two-stroke engine. We believe that the harmonization of all systems, whether the exhaust, cooling, injection and oil systems, but also the ignition system, will return the favor of two-stroke engines to their users and will thus be used to a greater extent. The simplicity of these engines is also due to their design simplicity, which makes the engine lighter and smaller and its production but also maintenance easier.

The article explains the resonant waves and their influence on the motor parameters. The reader will learn how to design your own exhaust system, the individual parts and their dimensions affect the power and engine speed. It also documents the resonant exhaust calculation for the M60 experimental engine to be used in cruising mode. Another goal of the article was to optimize the shape of the deflectors, which in the original design caused overheating of the rear cylinders. The article compares the original deflector of the experimental engine M60 with the new designed deflector and acquaints the reader with the design optimization and simulations of the new deflector. The chapter ends with the production of deflectors and also shows the final deflector.

The result of the article are four resonant exhausts and two cooling system deflectors designed for the travel mode of the M60 engine, which contribute significantly to the proper functioning of the engine and keep its operating values and temperatures within the correct ranges.

ACKNOWLEDGMENT

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REFERENCES

[1] JENNINGS, G. Two-stroke tuner's handbook, Tuscon: HP Books, 1975. ISBN 09-126-5641-7

[2] BELL, A. Two-stroke performance tuning, Haynes Publishing. ISBN 1-85960-619-3

[3] HUSÁK. P. Upravujeme motocykl pro závod, Praha: Nakladatelství technické literatury, 1972. ISBN 04-214-72

[4] Počítáme výfuk, Motorkari.cz, [Online]. Available at: https://www.motorkari.cz/profil/?uid=312667&act=clanky&cid=1821.

[5] CAMERON, K. Unique Solutions in Motorcycling [Online]. Available at: https://www.cycleworld.com/story/blogs/ask-kevin/unique-solutions-in-motorcycling/

[6] SEDLÁŘ, J. Úprava motoru Jawa 23 pro zvýšení výkonu, Bakalárska práca, Praha, 2019.

[7] Walter Kaaden. 1963, [Online]. Dostupné na internete: https://ajsstormer.wordpress.com/chapter-6/

[8] DANIEL – SZABO J. - HAJKO V., Základy fyziky, Bratislava: vydavateľstvo slovenskej akadémie vied, 1980. ISBN: 71-46-80

[9] VÝZKUMNÝ ÚSTAV BEZPEČNOSTI PRÁCE, Vývoj a validace požárních modelu pre předpověď vývinu/šíření tepla, kouře, toxických plynu, tlakové vlny výbuch k interpretaci scénářu požáru/výbuchu a jejich ničivých účinku,[Online]. Available at: https://www.bozpinfo.cz/vyvoj-validace-pozarnich-modelu-pro-predpoved-vyvinusireni-tepla-koure-toxickych-plynu-tlakove-vlny

[10] Rázová vlny, [Online]. Available at: https://www.wikiskripta.eu/w/R%C3%A1zov%C3%A1_vlna

[11] MACKERLE, J. Vzduchem chlazené vozidlové motory, Praha: Státní nakladatelství technické literatúry, 1960. ISBN: 621.43-712

[12] D. R. PYE, The Internal Combustion Engine, Oxford and the Clarendon Press, 1934. ISBN:1649517076

[13] ELLERBROCK, - HERMAN, H. jr. a spol, Surface heat-transfer coefficients of finned cylinders, biermann, Arnold E, 1939, Document ID: 19930091751

[14] MATTHEWS, A., Surface and coatings technology, 1993, Editors: B.D. Sartwell, ISBN: 0257-8972

[15] VEDA NA DOSAH, Ako pracuje motor? Odhaľme jeho tajomstvá, [Online]. Available at: https://vedanadosah.cvtisr.sk/technika/ako-pracuje-motor-odhalme-jeho-tajomstva/

[16] 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.

[17] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

[18] LUSIAK, T., NOVÁK, A., JANOVEC, M., BUGAJ, M. 2021. Measuring and testing composite materials used in aircraft construction. Key Engineering Materials, 2021, 904 KEM, pp. 161–166. ISBN 10139826.

[19] PECHO, P. et al. 2017. Modification in Structural Design of L-13 “Blanik” Aircraft's Wing to Obtain Airworthiness. In: Procedia Engineering. [online] 2017, vol. 192, s. 330-335. [cit. 15-01-2022] ISSN 1877-7058.

[20] HRÚZ, M., PECHO, P., MARIÁŠOVÁ, T., BUGAJ, M. 2020. Innovative changes in maintenance strategies of ATO's aircraft. Transportation Research Procedia, 2020, 51, pp. 261–270. ISSN 23521457.

[21] 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.

[22] 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.

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INNOVATION OPTIONS FOR SELECTED M60 ENGINE SYSTEMS: IGNITION SYSTEM AND ENGINE PARAMETER MONITORING

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Abstract

The topic of this paper is the possibility of innovating the ignition system of the M60 engine. The main part is the practical solution of the assignment. It shows the condition of the original ignition system, which was innovated in this work. It was a contact ignition system with a fixed advance, using a system of hammers. This solution was replaced by a new type of ignition, specifically an electronic ignition system that allows to change the ignition advance depending on the engine speed and load. The main parts of the new system consist of a control unit and a Hall sensor. It is these two components that make the main difference compared to the original ignition system. We deal with a more detailed description of design, construction and installation in the practical part. We paid attention to the design, the wiring diagram and its installation. At this stage, we addressed the possibilities of fastening a Hall sensor. The use of old components for assembly was not possible, so we proceeded to the design and production of new ones. The innovative ignition system will allow the engine to achieve higher power, lower consumption and the proportion of pollutants in the exhaust gases

Keywords

Ignition advance, Ignition system, Ignition, Ignition optimization, Hall sensor

1. ÚVOD

Zrod prvého lietadla, ktoré bolo možné následne použiť na komerčné účely naša civilizácia rýchlo prijala a začala s jeho využívaním na rôzne druhy činností. Lietadlá našli uplatnenie nielen v osobnej doprave, a to v súkromných spoločnostiach alebo u jednotlivcov, ktorí ich využívajú na rýchle a komfortné presuny, ale aj v záchranných zložkách, u vojska a v nemalej miere aj v nákladnej doprave. S prudkým rozvojom a narastajúcim dopytom po leteckej doprave bol neodmysliteľnou súčasťou vývoj technológií používaných v lietadlách. Bolo nutné prispôsobiť konštrukčné časti lietadiel, ako aj ich pohonné jednotky a všetky ostatné zariadenia potrebné pre zabezpečenie bezpečnej prevádzky. V súčasnosti sa vynakladá značné úsilie aby boli súčasné pohonné jednotky šetrnejšie k životnému prostrediu, preto je dôležité venovať pozornosť systémom, ktoré dokážu znížiť ekologické dopady na požadovanú úroveň.

Najdôležitejšou časťou motorových lietadiel sú pohonné jednotky, ktoré zabezpečujú uskutočnenie samotného letu. Nežiadúcim javom ich prevádzky je produkcia škodlivých látok (pri spaľovacích pohonných jednotkách). Pri veľkom množstve lietadiel, ktoré sú dnes používané, bolo preto nutné začať intenzívne pracovať na ich úpravách. Vyžaduje sa, aby prevádzka pohonných jednotiek bola čo najefektívnejšia a zároveň aby spĺňala kritéria stanovené celosvetovými požiadavkami na nižšie emisie. Tie stanovujú povolené množstvo škodlivých emisií vo výfukových plynoch najmä v rámci krajín EÚ. Navrhnutím a neustálym vývojom moderných elektronických zariadení je dnes už možné v pohonných jednotkách kontrolovať a riadiť komplexnú prevádzku jednotlivých sústav, napríklad spaľovacieho systému, výfukového systému a všetkých ostatných systémov potrebných pre činnosť motora.

V minulosti bol už samotný štart pohonných jednotiek náročný a dochádzalo pri ňom k uvoľňovaniu obrovského množstva spalín. Tento nežiadúci jav bolo nutné vyriešiť, preto sa začalo aj s vývojom a úpravou systému zapaľovania. Prvé zapaľovacie sústavy nedokázali presným spôsobom zapáliť zmes a často dochádzalo k ich poruchám. Preto sa hľadali a vyvíjali sofistikovanejšie, presnejšie, výkonnejšie a bezpečnejšie typy.

Jedným z kvalitných a moderných druhov zapaľovacích sústav je riadenie pomocou elektronickej riadiacej jednotky a bezkontaktového snímania polohy kľukového hriadeľa.

Nahradením pôvodného kontaktového zapaľovania motora M60 elektronickým zapaľovaním sa zefektívni proces spaľovania, čím sa zníži spotreba paliva, uľahčí sa štart a zvýši výkon motora a zníži obsah škodlivých látok vo výfukových plynoch. V porovnaní s pôvodným systémom obsahuje menej komponentov, čím sa minimalizujú prevádzkové náklady na údržbu, opravu a chod motora.

Sústavným vývojom technológií a materiálov je možné modernizovať aj staršie typy použitých zariadení. Ich úpravou dosiahneme vyššiu efektívnosť motora a naplnenie požiadaviek pre použite v súčasnosti. Zámerom je tiež predĺženie životných cyklov motora.

2. OPTIMALIZÁZIA ZAPAĽOVACEJ SÚSTAVY MOTORA M60

M60 je dvojtaktný štvorvalcový motor typu boxer, ktorý nebol sériovo vyrábaný. Z tohto dôvodu neexistuje dohľadateľná dokumentácia zapaľovacej sústavy inštalovanej v tomto motore. Jedná sa však o jednoduchý systém, v ktorom sa pomocou vačky umiestnenej na kľukovej hriadeli ovládajú kontakty prerušovačov pod uhlom 180°. Každý z nich riadi jednu cievku s dvoma vývodmi z jedného sekundárneho vinutia. Tento systém je zdvojený a pod dvojicou kontaktov prerušovača je uložená ešte druhá dvojica znázornená na obrázku 1. Predstih zapaľovania je nastavený pevne na 22° kľukového hriadeľa pred dosiahnutím hornej úvrate s napájacím napätím 12 voltov.

Obrázok 1: Druhá dvojica prerušovacích kontaktov motora M60. [Zdroj: autori]

K zapáleniu zmesi v dvojtaktnom motore typu boxer dochádza každým pootočením kľukového hriadeľa o 180°. Zmes sa v jednotlivých valcoch zapaľuje v poradí, kde 1 a 2 valec súčasne a následne 3 a 4 valec súčasne. Pri pohľade na motor spredu môžeme vidieť, že k tomuto procesu dochádza najprv prednej strane motora a až potom na zadnej. Obrázok 2 ilustruje poradie zapálenia zmesi v jednotlivých valcoch. [1]

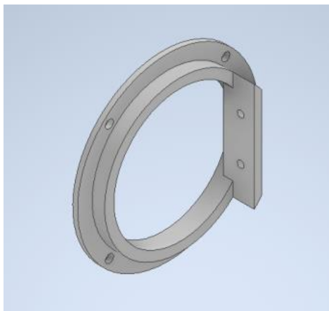
Obrázok 2: Znázornenie poradia zapálenia zmesi v motore typu boxer. [Zdroj: https://www.autoforum.cz/technika/jak-funguje-motor-typu-boxer-funkcni-model-z-3d-tiskarny-vam-to-ukaze-zevnitr/]

2.1. Uchytenie Hallovho snímača

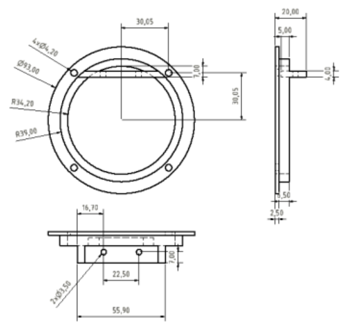
Pôvodný systém zapaľovania sme nahradili úplným elektronickým zapaľovaním. Snímanie polohy kľukového hriadeľa je zabezpečené pomocou Hallovho snímača. Niekdajšie riešenie však pre jeho inštaláciu nebolo prispôsobené, z toho dôvodu bolo potrebné navrhnúť a vyrobiť špeciálnu konzolu pre jeho uchytenie. Dôležitým parametrom pri navrhovaní a zameriavaní konzoly snímača bol existujúci otvor v bloku motora, ktorým prechádzali elektrické vodiče k pôvodne nainštalovanému kladivkovému zapaľovaniu. Tento otvor sme sa rozhodli použiť aj pri našom elektrickom pripojení Hallovho snímača, nakoľko ďalšie navŕtavanie by znižovalo jeho pevnosť a zvyšovalo možnosť prenikania cudzích látok do vnútorných častí motora. Po zohľadnení pôvodného stavu, sme preto nameranie umiestnenia polohy snímača situovali priamo nad otvor bloku motora. To určilo aj miesto jeho montáže. Pre nameranie rozmerov základnej konzoly a ďalších komponentov nami navrhovaného zapaľovania bolo nevyhnutné najskôr demontovať všetky časti pôvodného kladivkového zapaľovania. Venovať pozornosť bolo potrebné hlavne na zameranie prstenca konzoly, ktorý sa vsúva do bloku motora pri ústí kľukového hriadeľa. V našom prípade sme museli zohľadniť a opakovanými meraniami určiť polohu, smer a vzdialenosť ukotvovacieho bodu Hallovho snímača, aby jeho poloha bola v presnej vzdialenosti od osi kľukového hriadeľa a nedochádzalo tak k nárazom a treniu oceľového kotúča do snímača. Pre dokonalé usadenie ukotvovacieho Týmto krokom sme chceli predísť nežiadúcemu vibrovaniu a pohybu snímača. Samozrejmosťou bolo tiež presné nameranie otvorov na zaisťovacie skrutky umiestnené na hornej stene prstenca. V ďalšej fáze sme zamerali medzikus kľukového hriadeľa. Jeho valcovitý priemer musel byť rozmerovo identický s priemerom odnímateľnej vačky a jeho výška, po odpočítaní hrúbky oceľového kotúča, musela zodpovedať výške stredového otvoru snímača po uchytení na konzolu. Nameraním stredu medzikusu sme tak určili miesto na otvor pre skrutku, ktorá bude spájať medzikus s kľukovým hriadeľom. Pri meraní sme zohľadňovali aj následné dočisťovanie, obrusovanie a doleštovanie styčných plôch tak, aby po zrealizovaní týchto úkonov, všetky merané parametre zodpovedali skutočným rozmerom nami navrhovaných komponentov.

Vizualizácie návrhov požadovaných súčiastok sme vyhotovili v programe Autodesk Inventor (obrázky 3 a 5). Z návrhov sme následne vychádzali pri tvorbe výslednej výkresovej dokumentácie (obrázky 4 a 6).

Na výrobu konzoly sme museli zvoliť a zabezpečiť vhodný typ materiálu. Prvý kus bol zhotovený z bežnej ocele. Pri jeho výrobe však došlo k deformácii, až lomu prstenca konzoly. Z tohto dôvodu bolo nutné použiť materiál typu HARDOX 600. Jedná sa o vysoko pevnostnú oceľ. Opracovanie do požadovaných tvarov a rozmerov zaistilo špecializované zariadenie CNC, vďaka ktorému výroba dosiahla presnosť 0,05 mm. Drážku pre upevňovací bod snímača sme vytvorili zafrézovaním do konzoly a pomocou bodových zvarov zaistili proti pohybu v konzole. Dodatočne sme zabrúsili dotykové plochy [2].

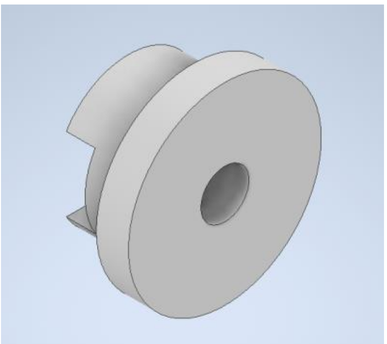


Obrázok 3: Konzola pre Hallov snímač. [Zdroj: autori]

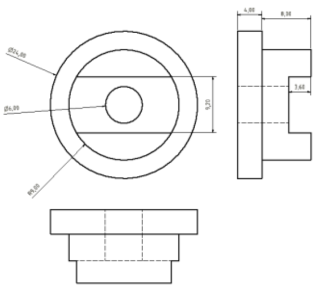


Obrázok 4: Výkres návrhu konzoly. [Zdroj: autori]

Hallov snímač pre svoju činnosť potrebuje oceľový kotúč uchytený na kľukový hriadeľ. Vačku je možné, vďaka jej odnímateľnosti, nahradiť špeciálnym medzikusom, na ktorý sa kotúč upevní pomocou skrutky. Voľba materiálu a proces výroby uplatnené pri špeciálnom medzikuse boli rovnaké ako pri konzole snímača.

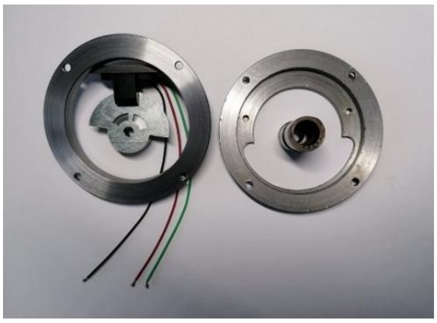


Obrázok 5: Medzikus kľukového hriadeľa. [Zdroj: autori]



Obrázok 6: Výkres návrhu medzikusu kľukového hriadeľa. [Zdroj: autori]

Po výrobe navrhnutých komponentov nasledovala montáž. Do bloku motora sme vsunuli špeciálnu konzolu, ktorú sme upevnili skrutkami a následne sme na ňu upevnili Hallov snímač zaistený skrutkami. Špeciálny medzikus kľukového hriadeľa sme spolu s oceľovým kotúčom tiež uchytili do kľukového hriadeľa skrutkou. Na obrázku 7 môžeme vidieť porovnanie novej a starej konzoly.

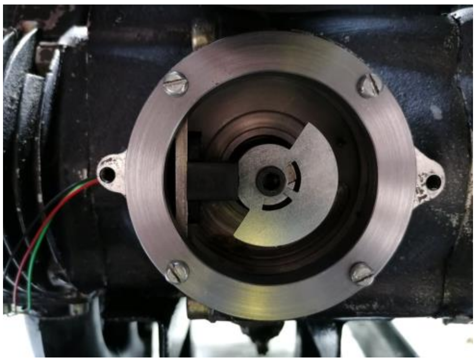


Obrázok 7: Porovnanie novej konzoly (ľavá strana) so starou. [Zdroj: autori]

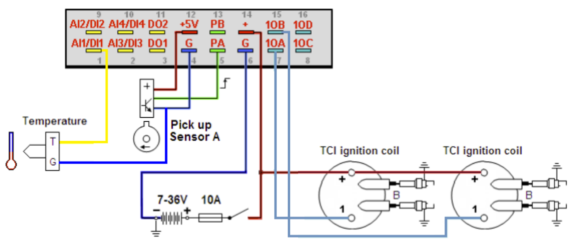
2.2. Zapojenie elektronického zapaľovania

Srdce novej zapaľovacej sústavy je tvorené riadiacou jednotkou ECU MASTER – MAP senzor od spoločnosti IMFsoft, s.r.o.. Aplikáciou takejto riadiacej jednotky dokážeme zabezpečiť nie len riadenie a optimalizáciu zapaľovania, ale aj vstrekovacej sústavy. Zefektívnenie zapaľovania a vstrekovania prebieha na základe vstupných údajov, získaných zo snímačov upevnených na motore. V našom zapojení sú získavanými údajmi dáta o polohe kľukového hriadeľa a teploty hlavy valca. Snímanie polohy kľukového hriadeľa je zabezpečené pomocou Hallovho snímača (obrázok 8), ktorý sme si vybrali pre jeho lepšie vlastnosti v porovnaní s inými typmi snímačov. Ide o konštrukčne jednoduchý systém, ale zároveň veľmi presný a spoľahlivý, pretože nie je závislý od okolitého prostredia. Okrem už spomenutých výhod má oproti kontaktovému zapaľovaniu vyššiu životnosť, pretože nedochádza k priamemu prechodu prúdu k zapaľovacím sviečkam. Hallov snímač vysiela signál len do riadiacej jednotky. Z nej sú v požadovaný moment napájané zapaľovacie cievky a zapaľovacie sviečky. Vodiče vyvedené z Hallovho snímača bolo potrebné predĺžiť, aby bolo možné ich pripojenie ku vstupnému konektoru riadiacej jednotky, pomocou špeciálnych konektorov zasúvaných do vstupného konektora [3].

Ich umiestnenie na konektore je dané schémou zapojenia, ktorú sme si museli upraviť pre naše potreby (obrázok 9). Je dôležité, aby boli vodiče zapojené v správnom usporiadaní, preto sú farebne rozlíšené. V opačnom prípade by zapaľovanie nepracovalo správne. Nemôžu byť tiež vedené súbežne s vodičmi zapaľovacích cievok pripojených na vstup 10A a 10B alebo s inými vysokonapäťovými vodičmi. Červený vodič sme pripojili na vstup „12“, ktorým je napájaný snímač kladným napätím 5 voltov. Vstup „4“ slúži na uzemnenie obvodu a pripájame naň vodič s modrou farbou. Ich zapojením sa tak uzatvorí obvod a môže ním pretekať prúd. Signál pre riadenie zapaľovania sa do riadiacej jednotky privádza zeleným vodičom pripojeným na vstup „5“ [3].



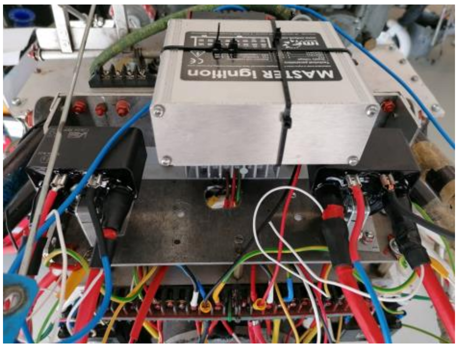
Obrázok 8: Nová upevnená konzola s Hallovým snímačom, medzikusom a oceľovým kotúčom. [Zdroj: autori]



Obrázok 9: Schéma zapojenia nového elektronického zapaľovania. [Zdroj: https://imfsoft.com/files/master/documentation/MasterSchemeV8_43_EN.pdf, upravili autori]

Zdrojom energie pre riadiacu jednotku a ostatných častí zapaľovacej sústavy je akumulátor s napätím 12 voltov. Pri pripájaní akumulátora ako zdroja energie je tiež dôležité dodržať polaritu zapojenia. Napájanie a všetky zapaľovacie vstupy sú chránené proti prepätiu a prepólovaniu, aby nemohlo dôjsť k poškodeniu riadiacej jednotky a pridružených častí. Kladný pól akumulátora je označený symbolom „+“ a vodič od neho vedúci má červenú farbu. Záporný pól akumulátora je uzemnený a označený symbolom „-“. V tomto prípade má vodič čiernu farbu. Na pripojenie vodičov k akumulátoru sme použili svorkovnice, ktoré zabezpečujú dokonalé spojenie vodiča a výstupu, čím nedochádza ku skratom a prehrievaniu vodičov a celej elektrickej sústavy. Kladný pól akumulátora pripájame na vstup „14“ a záporný na vstup „6“. Samotné napájanie musí byť vedené cez 10 ampérovú poistku, ktorá ochráni zapaľovaciu sústavu v prípade prepólovania, prepätia alebo iných porúch [3].

Ďalšou dôležitou časťou sú zapaľovacie cievky. Tie transformujú nízke napätie z akumulátora na vysoké napätie privádzané na zapaľovacie sviečky. V našom elektrickom obvode sa nachádzajú dve rovnaké zapaľovacie cievky, z ktorých každá má dvojicu výstupov zo sekundárneho vinutia. Vstup kladného pólu pre pripojenie zapaľovacích cievok do riadiacej jednotky je rovnaký ako pre kladný pól akumulátora, a teda vstup „14“. Do vstupného konektoru sa však pripája len po jednom vodiči pre jednotlivé vstupy. Riadiacu jednotku ku akumulátoru sme pripojili nasledovným spôsobom. Vodič od kladného pólu akumulátora sme priviedli do svorkovnice, od ktorej vedú vodiče do pripájacieho konektora riadiacej jednotky a zároveň aj na kladný pól zapaľovacích cievok. Záporné póly zapaľovacích cievok sú pripojené na vstupy „7“ a „15“ pripájacieho konektora riadiacej jednotky. Výstupy pre zapaľovanie nie sú chránené proti skratu, z toho dôvodu sa výstupy 10A až 10D nesmú pripájať na kladný pól zdroja, resp. k jeho vstupu na riadiacej jednotke. K zopnutiu elektrického obvodu na zapaľovacích cievkach dôjde na základe signálu z riadiacej jednotky, v dôsledku čoho sa v sekundárnom vinutí indukuje vysoké napätie (obrázok 10) [3].

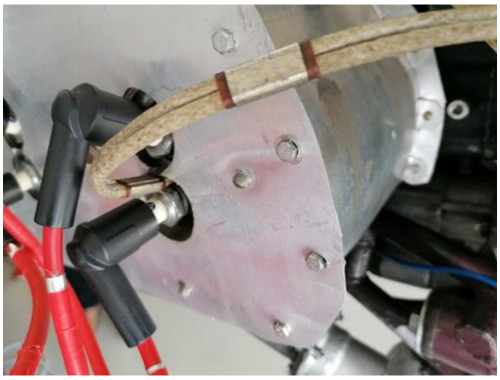


Obrázok 10: Riadiaca jednotka a zapaľovacie cievky. [Zdroj: autori]

Zo zapaľovacích cievok vedú vysoko napäťové zapaľovacie vodiče, ktoré majú nízky odpor a sú odolné voči okolitému rušeniu a zároveň aj voči mechanickému poškodeniu vznikajúcemu pri ich zohrievaní vplyvom prechádzajúceho prúdu. Sú pripojené k zapaľovacím sviečkam pomocou koncovky zapaľovacej sviečky. Napätím, ktoré na zapaľovacie sviečky privádzame, dochádza k zapáleniu pracovnej zmesi. Zapaľovacie sviečky, hlava valca a blok motora musia byť pripojené na záporný pól zdroja, aby bol zabezpečený tok prúdu zo sekundárnych vinutí zapaľovacích cievok [3] [4].

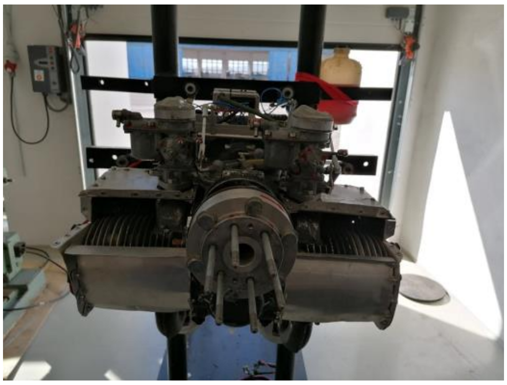
Zapaľovacia sústava musí byť inštalovaná tak, aby nebola priamo vystavená vode, chemikáliám, veľmi vysokým teplotám alebo vibráciám, pretože by to mohlo viesť k poškodeniu alebo až zničeniu funkčnosti zapaľovania [3].

Súčasťou novej zapaľovacej sústavy je aj termoelektrický snímač teploty hlavy valca umiestnený pod zapaľovacou sviečkou (obrázok 11). Údaj o teplote sa získavajú pomocou termoelektrického napätia, ktorého veľkosť sa odvíja od úrovne teploty pôsobiacej na snímač. Riadiaca jednotka obsahuje vstupy AI1 až AI4. Pripájame k ním snímače teploty v závislosti od druhu signálu, ktorý vytvárajú. Ak sa jedná o napäťový signál, vodiče od snímača pripájame na vstupy AI1 a AI2. V prípade odporového signálu sa vodiče pripájajú na vstupy AI3 a AI4. V našom zapojení sme použili jeden termoelektrický snímač, z ktorého získavame napäťový signál, preto sme od neho vedúci vodič pripojili na napäťový vstup 1 (AI1) [3] [5].



Obrázok 11: Zapojenie termoelektrického snímača. [Zdroj: autori]

Nová elektronická zapaľovacia sústava a jej navrhnuté súčasti sú kompatibilné s pôvodnými tak, ako je znázornené na obrázku 12.



Obrázok 12: Motor M60 s riadiacou jednotkou a založeným krytom kľukového hriadeľa. [Zdroj: autori]

Aby sme zvýšili bezpečnosť a znížili riziko vysadenia motora počas letu v dôsledku poruchy zapaľovacej sústavy, použili sme už inštalovaný zapaľovací systém VAPE ako záložný. Jedná sa o bezkontaktové zapaľovanie, ktoré má pevne nastavený predstih zapaľovania. Motor M60 má na každom valci inštalovanú dvojicu sviečok. To nám umožnilo použiť na každom valci jednu sviečku pre nové elektronické zapaľovanie a druhú pre záložné zapaľovanie systému VAPE.

Po inštalácií novej elektronickej zapaľovacej sústavy bude potrebné nastaviť predstih zapaľovania. Na to slúži software dodaný výrobcom, prostredníctvom ktorého vieme zobraziť parametre motora a následne upravovať predstih zapaľovania.

Uvedený proces prebieha tak, že pripojíme dátový kábel z jednej strany k riadiacej jednotke a z druhej pomocou USB vstupu k zariadeniu slúžiacemu na zobrazenie vstupných údajov a vykonanie potrebných zmien pre optimalizáciu zapaľovania [3].

2.3. Hybridný letecký pohon

Motor M60 môžeme upraviť a následne využiť v kombinácií s technológiami pohonu, ktoré v letectve stále nie sú bežné. Mnohé z nich sa už využívajú vo veľkom počte napríklad na pohon automobilov. Medzi takéto riešenia patrí aj elektrický hybridný systém [6].

„Do oblasti alternatívnych technológií pohonu možno zaradiť hybridné elektrické pohonné systémy. Alternatívne technológie pohonu zahŕňajú aj iné spôsoby pohonu lietadiel, ktoré sa líšia od konvenčného pohonu. Do tejto kategórie môžeme zaradiť pohonné systémy využívajúce alternatívne palivá alebo využívajúce solárnu energiu.“ [6]

„Elektrický hybridný pohonný systém teda môžeme nazvať pohonným systémom, ktorý využíva na pohon klasický spaľovací motor a elektromotor. V hybridno-elektrickom pohonnom systéme sa ako zdroj energie používa letecké palivo alebo batérie. Najčastejšie používané hybridné pohonné systémy sú paralelné a sériové systémy.“ [6]

„Paralelný hybridný systém využíva spaľovací motor pracujúci paralelne s elektromotorom, zatiaľ čo sériový hybridný systém pozostáva zo spolupracujúceho spaľovacieho motora a elektromotora zaradených do série.“ [6]

3. ZÁVER

Cieľom článku bolo navrhnúť možnú optimalizáciu zapaľovacej sústavy motora M60. Pôvodná zapaľovacia sústava mala predstih zapaľovania nastavený pevne na uhol 22° kľukového hriadeľa pred dosiahnutím horného úvratu. Nebola tak možná zmena predstihu zapaľovania s meniacimi sa otáčkami a zaťažením, preto táto zapaľovacia sústava neumožnila vyvinutie maximálneho možného tlaku v správnej polohe piesta. Tento problém sme sa rozhodli odstrániť náhradou pôvodnej zapaľovacej sústavy za novú, ktorá by predstih zapaľovania dokázala meniť v závislosti od otáčok a zaťaženia motora.

Inováciu sme zrealizovali inštalovaním elektronickej zapaľovacej sústavy. Jej hlavnou časťou je riadiaca jednotka ECU MASTER – MAP senzor od spoločnosti IMFsoft s.r.o.. Na upevnenie Hallovho snímača bolo potrebné navrhnúť a vyrobiť špeciálnu konzolu a rovnako aj medzikus pre upevnenie oceľového kotúča. Pomocou neho získavame pri otáčaní kľukového hriadeľa údaje o jeho polohe. Výsledkom presného zosnímania polohy kľukového hriadeľa je optimalizované nastavenie predzápalu ako aj výkonu motora pri jeho chode. Riadiaca jednotka umožňuje tiež snímanie teploty hlavy valca a zaťaženia motora na základe tlaku za škrtiacou klapkou v sacom potrubí pomocou integrovaného snímača tlaku. Okrem toho je možné pomocou tejto riadiacej jednotky nastaviť aj vstrekovanie paliva do spaľovacieho priestoru valca. Jedná sa tak o zariadenie, ktoré vo veľkej miere dokáže zo získaných údajov zvýšiť hospodárnosť motora.

Motor M60 na ktorom boli vykonané úpravy obsahoval aj zapaľovací systém VAPE. Ten sme ponechali inštalovaný, slúži ako záložný zapaľovací systém v prípade poruchy elektronickej zapaľovacej sústavy. Výrazným spôsobom sa tak zvýši spoľahlivosť zapaľovacej sústavy ako celku rovnako, ako aj bezpečnosť letu lietadiel s takýmto riešením zapaľovania.

V súčasnosti sa kladie čoraz väčší dôraz na množstvo škodlivých látok vo výfukových plynoch, vylučovaných pri prevádzke spaľovacích motorov. Kým staršie motory produkovali veľké a neregulovateľné množstvo týchto látok, nové motory svojou činnosťou už na životné prostredie vplývajú menej negatívne. Zníženie škodlivých emisii je do značnej miery dosiahnuté optimalizáciou procesu spaľovania prostredníctvom elektronickej zapaľovacej sústavy.

Z tohto dôvodu je využitie elektronického zapaľovania výhodné aj pri leteckých motoroch. Emisné požiadavky sú stále prísnejšie a množstvo starších typov spaľovacích motorov im nebude schopné vyhovieť. Pre zabezpečenie ich najdlhšej možnej prevádzky musíme docieliť, aby výsledná hodnota škodlivých látok vo výfukových plynoch bola čo najnižšia. Aj v tomto prípade môže byť riešením inovácia zapaľovacej sústavy, ktorá dokáže znížiť spotrebu paliva aj množstvo škodlivých exhalátov.

Ďalším dôvodom pre zmenu je vysoká nákladovosť prevádzky lietadiel. Výraznou položkou v nej je práve palivo. Preto sa hľadajú alternatívy na jej zníženie. Jednou z nich je optimalizácia procesu spaľovania, napríklad inštaláciou elektronickej zapaľovacej sústavy. Nová zapaľovacia sústava je teda prínosom nie len pre prevádzkovateľov lietadiel, ale aj pre celú civilizáciu v súčasnosti a rovnako tiež pre budúce generácie.

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REFERENCIE

[1] Autoforum.cz. Jak funguje motor typu Boxer?. Dostupné na internete: https://www.autoforum.cz/technika/jak-funguje-motor-typu-boxer-funkcni-model-z-3d-tiskarny-vam-to-ukaze-zevnitr/ (citované: 11-04-2022)

[2] Lomyatezba.cz. Deset věcí, které byste o Hardoxu chtěli vědět, ale zapomněli jse se zeptat. Dostupné na internete: https://www.lomyatezba.cz/2019/2019-1/item/927-deset-veci-ktere-byste-o-hardoxu-chteli-vedet-ale-zapomneli-jste-se-zeptat (citované: 27-02-2022)

[3] Imfsoft.com. ECU MASTER CDI – TCI scheme & configuration. Dostupné na internete: https://imfsoft.com/files/master/documentation/MasterSchemeV8_43_EN.pdf (citované: 02-03-2022)

[4] Mototechnika.cz. Kabel zapalovací. Dostupné na internete: https://www.mototechnika.cz/prislusenstvi-doplnky/ni50347830.html (citované: 03-03-2022)

[5] Youtube.com. The Thermoelectric Effect – Seebeck & Peltier Effects. Dostupné na internete:

https://www.youtube.com/watch?v=cZodo_BxBIo (citované: 03-03-2022)

[6] JANOVEC, M. et al. 2021. Design of Batteries for a Hybrid Propulsion System of a Training Aircraft. In *Energies*. ISSN 1996-1073, 2022, vol. 15, no. 1, p. 1-18.

[7] 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.

[8] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

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

[10] HRÚZ, M., PECHO, P., MARIÁŠOVÁ, T., BUGAJ, M. 2020. Innovative changes in maintenance strategies of ATO's aircraft. Transportation Research Procedia, 2020, 51, pp. 261–270. ISSN 23521457.

[11] 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.

[12] 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.

[13] NOVÁK, A., HAVEL, K., JANOVEC,M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126 .

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OWNERSHIP STRUCTURES OF REGIONAL AIRPORTS

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Abstract

This paper is focused on regional airports and their ownership structures. The first part defines the basic terms such as airport and regional airport from a legal point of view. It describes airport ownership models in general, focusing on the traditional organizational ownership model, and then it describes processes such as decentralization, corporatization, commercialization and privatization. This part also contains the advantages and disadvantages of privatization. In the second part, it is focused on the current state of the issue, when there are described selected scientific studies that address the issue of ownership models. Attention is also focused on the Covid-19 pandemic, which had a strong impact on the regional airport. The main goal of the paper is to analyse the ownership structures of selected regional airports, which are located in Austria and the Czech Republic. In connection with ownership structures, it also monitors the achieved economic result of regional airports.

Keywords

Ownership structures, Regional airport, Privatization, Decentralization, Austria, Czech Republic

1. INTRODUCTION

Air transport is one of the most important transport sectors. Airports in this sector are indispensable entities that connect even the most remote regions and towns. Today, we would find a lot of airports on the world map, which mainly provide passenger and cargo transport. Regional airports are also part of the global transport system, so it is important that they be mentioned. Regional airports can provide the necessary transport, but unfortunately the benefits in terms of profit are often insufficient. Demands for airports in the form of various innovations and modernization are constantly increasing, so it is very difficult for these airports to keep up with large and advanced airports. Every business requires money, as well as in the case of airport operations. In this case, regional airports have a withdrawn position, as the operation requires considerable funds, but also responsible management. For this reason, it is difficult for these airports to remain in the air transport market at all. When evaluating the business models of these airports, it is difficult to define them, because each airport is unique and has its own business model. Unfortunately, the model is not always successful. One of several aspects of the business model is the ownership structure.

Airport ownership structures have changed over the years. Of course, the changes also affected regional airports. Many of them generated losses, and for the purpose of maximizing profits, a change in ownership structure seemed to be one of the solutions. Some regional airports have started to prosper and the change in ownership structures has brought positive results. At the same time, regional airports began to modernize gradually, and some of them began to prosper.

This article is focused on the ownership structures of regional airports and their development. In the first part, there are described important terms such as airport and regional airport. There is added their importance, and then something about ownership models of the airports.

In the next part, it is described the current condition of this problem. Several scientific studies were selected that focus on the ownership, efficiency, and profitability of regional airports. Covid-19 pandemic was also a topic, which was described.

The aim of the article is to analyse the ownership structures of selected regional airports in two countries, namely the Czech Republic and Austria. In connection with the ownership structure, there are monitored the economic results, and the number of transported passengers at selected regional airports.

In the last part, there are presented the results and evaluated the ownership structures of selected regional airports. This part contains an analysis of the economic results of selected regional airports in connection with their ownership structure. In addition, there is evaluated the development of transported passengers during the reviewed period.

2. AIRPORT OWNERSHIP MODELS

Thanks to the development of air transport, people and cargo can be transported much more efficiently. Air transport has also developed thanks to airports.

2.1. Airports

To better understand the topic, it is necessary to provide a definition of what the term airport means. According to the Civil Aviation Act No. 49/1997 an airport is "a territorially demarcated and appropriately landscaped area, including a set of aeronautical structures and airport facilities, permanently designated for take-offs and landings of aircraft and related aircraft movements" [1]. Airports can also be classified, for example, according to their traffic density, size, function or type of ownership.

The airports can also be classified by density traffic:

- Major Airport - Carries more than 25 million passengers per year.
- National Airport - carries from 10 to 25 million
- passengers per year.
- Large regional airports - carry from 5 to 10 million passengers per year.
- Small regional airports - carry from 1 to 5 million passengers per year.
- Small airports - carry more than 200,000 passengers per year [2].

2.2. Regional airports

We can often find in various publications that a regional airport is defined based on the number of passengers carried per year. In this case, regional airports and small airports are defined by a smaller volume of passenger traffic. When examining the concept of regional airport, it is important to proceed from the current legislation. According to Regulation (EU) 2017/1084 amending the regulation (EU) 651/2014, as regards airport infrastructure, we can define a regional airport as "an airport with average annual traffic of up to three million passengers" [1].

2.3. Meaning of regional airports

According to ACI Europe, regional airports around the world are key, especially in terms of ensuring the accessibility of remote regions that are far from major transport hubs. Regional airports make a significant contribution to economic development, and they are also creating jobs within the regions in which they are located. From another point of view, they provide impulse for the overall development of the landscape within a framework that helps to meet policy objectives in economic and social terms. They are also an extremely important element of the critical infrastructure that is necessary to secure transport in the country and for the citizens in this area. They play a key role in the air rescue service, in fire monitoring and firefighting flights, but also in emergencies (natural and other disasters). Their operation is not easy and they most often focus on charter flights. Some regional airports operate sports and leisure flights. Compared to larger airports, regional airports do not provide passengers with the same standard of service as large international airports, but many passengers choose them for a variety of reasons. Regional airports are popular with passengers mainly due to lower ticket prices and fewer passengers, so they do not have to wait so long for security checks and are checked in faster. Of course, they also provide benefits for airlines. Overall, there are significant benefits due to lower prices for landing fees and other services. Another advantage of these airports is their geographical location, as they are often located in interesting destinations. This way they are closer to passengers. Disadvantages would include a smaller volume of passenger traffic compared to large airports. On the one hand, regional airports try to provide interesting destinations, but the volume of transported passengers or cargo does not bring them a high profit. The biggest problems are caused by high fixed operating costs, which revenues cannot cover. That is why regional airports operate in the traditional airport concept, where they do not have the latest technological conveniences. Financing of the operation is a very complex issue in this case.

If we focus on the disadvantages from the view of passengers, regional airports may not provide the same comfort as at larger airports. The disadvantage for airlines is the small number of paying passengers. Destinations offered by the regional airports may not be attractive. In this case, passengers prefer to depart from a better-connected airport with more attractive destinations. Another disadvantage may be the poor condition and equipment of the airport, because the operator does not have enough funds to constantly modernize the airport. The availability of public transport can also be poor [3].

2.4. Airport ownership structures

In history, airports have often been in public ownership. It was the traditional organizational model, where the main priority was to provide services in the public interest. In this case, the airports were owned by the state government. It was financed from the state budget and all the profits went to the state treasury. Over time, this model began to change for several reasons, mainly due to the rapid development of air transport. New commercial models thus began to emerge thanks to the following processes:

- decentralization of public ownership of the airport, which represents the transfer of central public ownership of the airport to several entities according to the landscape structure;
- corporatization, where the airport has become a company or corporation;
- commercialization, which is the application of airport management style and principles, as is typical of private sector companies;
- privatization, where a private entity became the owner and management of the airport.

3. AIRPORT OWNERSHIP MODELS

Thanks to the development of air transport, people and cargo can be transported much more efficiently. Air transport has also developed thanks to airports.

3.1. Scientific studies dealing with ownership structure

The issue of ownership of regional airports is extensive and also complex. That is why several experts are focused on it. Gillen (2010) solved the overall evolution of airport ownership, the change from a traditional airport to a corporate model, and also if airports should be regulated. According to this author, opinions on regulation can be considered mixed. The results of this study have shown that airport regulation is necessary in Europe, it is necessary precisely for airports to maintain market power [4]. Ison (2011) dealt with the commercialization and privatization of regional airports in the United Kingdom. The first airport was fully privatized here, it was East Midlands Airport. Over the years, successful privatization has taken place here, and many airports have been transferred from state-owned to private. In the UK, they wanted to improve airport business and efficiency. The results have shown that it is important that aviation matters are not predominantly subsidized by taxpayers

[5]. The Graham study (2011) also dealt with the privatization of airports. He takes the situation in the United Kingdom in 1987, when the first airport was 100% privatized, as the beginning of airport privatization. At this time, the privatization of airports was a controversial topic, but it was intended to improve the overall efficiency and management of airports. Research has shown that the structure of the airport industry is increasingly complex and very diverse [6]. Mantin's work (2012) examined whether private ownership of an airport or public ownership of an airport is better. The results showed that if the airport is owned by the state, there may be lower air fares, of course, it also depends on its location. If the airport is owned by a private entity, it will try to for the highest possible profits and set service prices in such a way as to maximize profits [7]. Saldiraner (2013) dealt with regional airport ownership and management in the European Union. According to the author, there are publicly owned airports in almost every state of the European Union, in some of which airports are owned by private entities. Every ownership structure has its pros and cons. There are often mixed ownership structures, where several entities take care of the management of the airport. In conclusion, the author mentioned that in most European countries, private airport management is becoming a more preferred choice [8]. Aulich and Hughes (2013) discussed the privatization of three major airports in Australia and the subsequent owners' arrangement. Until 1996, the major airports in Australia were owned and operated mainly by the government. Then the Minister of Government wanted to improve their financial performance through privatization. The prime minister also said it would be better if the government regulated safety and air traffic control at the airport. In the end, there is a combined model where the state is managed together with a private entity [9]. Kutlu and McCarthy (2016) looked at ownership structures in the United States and the overall efficiency of airports. According to the study, all commercial airports in the United States are public, but they differ in their ownership structure. The authors discuss about the economic efficiency of airports in public ownership and in private ownership. In conclusion, it cannot be said unequivocally that all commercial airports, either public or private, will be equally efficient, or which ownership will have a better impact on the airport's economy. It depends on many aspects that affect the economic situation of the airport [10]. Budd and Ison (2020) solved the evolution of airport ownership over 35 years in the UK. During these 35 years, many airports have been privatized. Since 1986, a total of 22 airports have shifted from public ownership to private or mixed ownership. The authors recommend that changing the ownership structure requires the involvement of the private sector, new practices, innovations and experience from other airports [11]. Lapcin (2021) described the state of airports after privatization in Turkey. It was observed that after privatization and regulation, the airports and their management began to change. The airports began to compete with each other, trying to improve and increase the services they can provide to passengers and airlines as much as possible. Each type of airport has its rivals in its type, so regional airports cannot compete with large international airports. In conclusion, each airport is something specific [12].

3.2. Scientific studies on the efficiency of regional airports

Many studies have looked at the efficiency of regional airports and their profitability depending on ownership structures. Oum discussed the overall efficiency and possible profits of regional airports depending on the ownership structure. (2006). The authors argued that airports, which have a majority-owned private entity in their ownership structure, have higher revenues from non-aviation services [13]. Huderek-Glapska and Nowak (2016) published a study describing the relationship between the airport and low-cost airlines. The work is focused on Poland, where most airports are run under public ownership and are therefore controlled by the state. The authors concluded that the cooperation between low-cost airlines and airports is very important and can be very beneficial not only for large primary airports, but even more so for regional airports [14]. The efficiency of Italian regional airports depending on the ownership structure was examined by Storto (2018). A total of 45 Italian airports were surveyed and compared on the basis of different ownership structures. Efficiency was examined on three perspectives, which were technical efficiency, cost-effectiveness and revenue efficiency. Heterogeneity of ownership has manifested itself as a factor that affects the overall efficiency of the airport. The results showed that publicly owned airports are more efficient [15]. Červinka (2019) dealt with whether regional airports are profitable. The regional airports try to increase profits through various non-aviation activities, such as renting space for various airlines, which may include an aviation school or cargo terminal, or various passenger services. Some regional airports may not be in profit precisely because of the lower number of passengers [16].

3.3. Development of ownership structures of regional airports in the Czech Republic

In this article, we were also interested in the development of ownership structures of regional airports in the Czech Republic. These are the regional airports, which transport up to 3 million passengers a year: airport Brno, airport Ostrava, airport Pardubice and airport Karlovy Vary.

Over time, there have been changes in ownership in the case of Czech regional airports. The original ownership of airports in the Czech Republic was public, where the owner was the state or the ministry. But in 2004, there was a change. It was decentralization at these airports, where it was the transfer of competencies and responsibilities from one state unit to a lower level, which means that ownership of these airports was transferred to self-governing regions or cities. This change was made by Act No. 166/2004 and the airports in Brno, Ostrava, and in Karlovy Vary were transferred to the ownership of self-governing regions. The airport in Pardubice is also owned by the city.

Brno-Tuřany Airport started to operate in 1954, at that time it was a state airport and there was a military operation. Since its decentralization in 2004, the airport is owned by the South Moravian Region. However, from the year 2017, its full operation has been provided by the Accolade investment group, which leases the airport [17] [18]. Ostrava Airport was also owned by the state, and after change in 2004, the Moravian-Silesian Region became the owner. [19].

The history of Pardubice Airport dates back to the beginning of the twentieth century. Until 1994, the airport was exclusively military and state-owned. The airport currently has two shareholders, namely the City of Pardubice, which owns 66% of the shares, and the Pardubice Region, which owns 34% of the shares. However, the airport still serves as a military backup airport [20].

The airport in Karlovy Vary was state-owned and after a change in 2004. Karlovy Vary region became the owner. [21].

Ownership structures in the Czech Republic have not changed in the last period, but there have not been significant changes anywhere in the world, because the air transport has been facing a crisis for the last 3 years caused by the Covid-19 pandemic. Changes in ownership structures went into the background, and the current situation was focused on the saving air transport. This was the priority for the EU [22].

3.4. Impacts of the Covid-19 pandemic on air transport

The outbreak of the Covid-19 pandemic has become an unprecedented event, not only in air transport. Travel began to be restricted in some way, which had the direct effect of reducing air transport. The pandemic began to spread around the world also thanks to air transport. Governments have begun recommending, that it is not safe to travel to countries affected by the virus. They began to emerge "Lockdowns" and people came abroad, they had to meet various requirements in order to enter a foreign country. All this had an effect on the stagnation of a number of passengers. According to ACI Europe, 73% fewer passengers were handled in Europe by 2020. The aviation industry began to lose profits, especially when it came to passenger transport. The other side of the aviation sector, which was not affected by the restrictions, was growing, and that was transport of freight. Airlines began to increase transport prices as the amount of cargo transported began to rise [23].

According to the statistics, in Africa, passenger numbers fell by 46.5%. In Asia, the decline was 47.9%. In Europe, the decline was lower than in the previous ones, at 40.5%. However, it was 67.2% in North America and 57% in Latin and the Caribbean. In the Middle East, the decline was 34.2%. When we transfer these values to the whole world, the decrease in checked-in passengers was almost half [24].

3.5. Situation in the Czech Republic

If we evaluate the situation in the Czech Republic, the number of transported passengers decreased sharply. If we compare the situation at the regional airports in Ostrava, Brno, Karlovy Vary, and Pardubice from the years 2018 to 2021 we can say, that in 2018, the number of passengers at these airports was 1,070,730 passengers. In the following year, the values decreased to 1,031,593. However, in the year 2020, it was already 170,270 passengers. In the year 2021, the situation began to stabilize, and the number of transported passengers increase to 405,359 [25] [26] [27].

4. METHODOLOGY

The main goal of this article was to analyse the ownership structures of selected regional airports in two countries, in Austria and in the Czech Republic. The ownership structure of the regional airport was chosen as priority data, and at the same time, additional data was selected for this analysis, which was the economic result for the last period and the number of transported passengers. Thanks to the economic result, it is possible to find out whether the regional airport generates a profit or generates a loss. The numbers of transported passengers were added for better information about the regional airport.

The first phase consisted in finding important theoretical data about the ownership structures of airports. It was also important to define the basic terms and analyse scientific studies so that we could better understand the issue. After processing the first phase or theoretical part, we were focused on the analysis of ownership structures of regional airports in Austria, where it was chosen regional airports: Innsbruck Airport, Graz Airport, Linz Airport and Salzburg Airport. In the Czech Republic were selected 4 regional airports: Brno Airport, Ostrava Airport, Pardubice Airport, and Karlovy Vary Airport.

As a limiting element of this analysis, we consider the availability of data. We tried to find the data about ownership structures in the annual reports, but in some cases, it was not available. That's why we decided to contact the management of the individual regional airports directly and requested this information.

5. RESULTS OF WORK

5.1. Regional Airport Innsbruck

The airport is located in Tyrol in the Alps, which are very attractive for lovers of winter sports. According to the table 1, we can see that the airport is publicly owned. It is public because the airport is owned by public shareholders, by the city or region. 51% shares belong to Municipal Services of the city Innsbruck, Tyrol region owns 24.5% shares, and 24.5% shares belongs to city of Innsbruck.

If we focus on the economic result, we can see that the airport is in profit throughout the period. The highest profit of the airport was achieved in 2017, when it was 8,447,000 € and the lowest profit was in 2020, only 638,053 €. It should be noted that this year there were significant restrictions caused by the Covid-19 pandemic. If we are focused on the number of transported passengers, the airport transported the most passengers in 2019, when it handled 1,144,471 passengers, and the following year it was the least, only 487,437 passengers [28] [29] [30] [31].

Table 1: Innsbruck Airport. [28], [29], [30], [31]

Year	Number of passengers	Economic results (in €)	Ownership structure
2016	1 006 738	5 290 141	51 % municipal services of the city Innsbruck 24,5 % Tyrol 24,5 % Innsbruck
2017	1 092 547	8 447 000	
2018	1 119 347	5 678 000	
2019	1 144 471	6 454 274	
2020	487 437	638 053	

5.2. Regional Airport Graz

The airport is located in the southeastern part of Austria. The airport has several shareholders. 93.9% of the shares belong to Holding Graz, 6% of shares belong to MCG Graz and 0.1% of shares belong to the company for strategic investments. MCG Gratz represents private shareholder. Other shareholders are from public side. This regional airport has a combined ownership structure. According to Table 2, we can see that the best economic result of the airport was reached in 2016, it was 8,571,740 €. The lowest economic result of the airport was achieved in 2020, when the airport generated a loss -4,429,000 €. If we are focused on the number of passengers, the best result was in 2019, when they transported a total of 1,036,929 passengers, and the following year 2020, the airport transported only 199,510 passengers [32] [33] [34].

Table 2: Graz Airport. [32], [33], [34]

Year	Number of passengers	Economic results (in €)	Ownership structure
2016	981 884	8 571 740	93,9 % Holding Graz 6 % MCG Graz 0,1 % Strategic investments
2017	959 098	6 566 264	
2018	1 030 929	6 028 199	
2019	1 036 929	6 082 035	
2020	199 510	-4 429 000	

5.3. Regional Airport Salzburg

The airport is located a few kilometers from the German border in the northeastern part of Austria. According to Table 3, we can see that the ownership structure is relatively simple, the largest part is owned by the Salzburg region (75 %), the other 25% shares is owned by the city of Salzburg [35] [36]. In terms of economic results, the most successful year for this airport was 2018, when they generated a profit 6,330,670 € and 2020 was the least successful, when they generated a loss -4,909,905 €. If we are focused on the number of passengers, the best year was 2017, it was 1,890,164 transported passengers. The lowest number of passengers, as usual, was in 2020, only 669,790 transported passengers [37] [38] [39].

Table 3: Salzburg Airport. [35], [36], [37], [38], [39]

Year	Number of passengers	Economic results (in €)	Ownership structure
2016	1 739 288	5 912 029	75 % Salzburg Region 25 % City of Salzburg
2017	1 890 164	5 901 459	
2018	1 844 362	6 330 670	
2019	1 717 991	2 854 125	
2020	669 790	-4 909 905	

5.4. Regional Airport Linz

In the case of this airport were not available annual reports, that is why we present only 3 years. According to Table 4, we can see that the airport has only 2 shareholders, 50% of shares belong to holding city of Linz and 50% of shares belong to the Upper Austrian Transport Company. The most successful year for airport was 2018, when they generated profit 1 551 000 €. The lowest economic result of the airport was in 2016, when their profit was 1 476 000 €. The best year for the airport was 2018, because they transported 465 798 passengers and the worst year was 2016 when they transported 1 476 000 passengers [40].

Table 4: Linz Airport. [40]

Year	Number of passengers	Economic results (in €)	Ownership structure
2016	435 468	1 476 000	50 % Linz city holding 50 % Upper Austrian transport company
2017	402 007	1 530 000	
2018	465 798	1 551 000	

5.5. Regional Airport Brno

The airport is located in the southeastern part of the Czech Republic. Table 5 shows that 100% of the shares are owned by the South Moravian Region, but the airport has been leased from the region to the holding Accolade since 2017, so the airport is in public ownership. The highest profit of the airport was recorded in 2017, when the economic result amounted 168,854,000 CZK. The lowest economic result of the airport was in 2016, when they generated a loss of -72,855,000 CZK. Unfortunately, we did not find or obtain any financial statements or annual report for the year 2020. However, we have complete passenger numbers. The best year was 2019, because they transported 543 633 passengers. In 2020, it was only 86,089 transported passengers [26] [41] [42].

Table 5: Brno Airport. [26], [41], [42]

Year	Number of passengers	Economic result (in CZK)	Ownership structure
2016	417 725	-72 855 000	100 % South Moravian Region lease Accolade holding
2017	470 285	168 854 000	
2018	500 727	49 580 000	
2019	543 633	-5 082 000	
2020	86 089	Nepodloženo	

5.6. Regional Airport Ostrava

The regional Airport Ostrava is located in the northeast of the Czech Republic, which is very industrial. As we can see in Table 6, the airport is owned by Moravian-Silesian region (100%). The airport did not show a positive economic result in any of the years examined. The lowest loss of the airport was in 2019, it was -4,943,000 CZK. The highest loss of the airport was in 2016, when it was -88,739,000 CZK. In terms of the number transported passengers, the airport transported the most passengers in 2018, it was 377,936 passengers. The lowest number of transported passengers was in 2020, only 37,709 passengers [43] [44] [45].

Table 6: Ostrava Airport. [43], [44], [45]

Year	Number of passengers	Economic result (in CZK)	Ownership structure
2016	258 223	-88 739 000	100 % Moravian-Silesian region
2017	324 116	-15 235 000	

2018	377 936	-8 202 000	
2019	323 320	-4 943 000	
2020	37 709	-58 930 000	

5.7. Regional Airport Pardubice

The airport is located in the western part of the Czech Republic. This airport is owned by two shareholders. The city of Pardubice owns 66% of the shares and the remaining 34% of the shares belong to the Pardubice Region. As for the economic result, the airport do not show a positive economic result for even one year as is visible in table 7. In 2017, the airport generated a loss -5,220,000 CZK and the highest loss was generated in 2020, it was -41,064,000 CZK. The airport transported the most passengers in 2018, it was 147,064 passengers and the least in 2016, only 31,174 passengers [24] [46] [47].

Table 7: Pardubice Airport. [24], [46], [47]

Year	Number of passengers	Economic result (in CZK)	Ownership structure
2016	31 174	-10 668 000	66 % City of Pardubice 34 % Pardubice region
2017	88 490	-5 220 000	
2018	147 064	-15 912 000	
2019	102 206	-34 343 000	
2020	32 238	-41 064 000	

5.8. Regional Airport Karlovy Vary

The airport is located in the northwest of the Czech Republic. The owner of the airport is the Karlovy Vary region (100%). Even in this case, a negative economic result is visible throughout the period. It is visible in table 8, the lowest loss was recorded in 2018, when it was 9,131,000 CZK. The worst year for the airport was in 2020, when it was 19,368,000 CZK. The highest number of transported passengers was in 2019, when they transported 62 234 passengers. The lowest number of passengers was in 2020, with only 17,234 passengers [48].

Table 8: Karlovy Vary Airport. [48]

Year	Number of passengers	Economic result (in CZK)	Ownership structure
2016	25 235	-14 935 000	100 % Karlovy Vary region
2017	21 404	-15 368 000	
2018	45 003	-9 131 000	
2019	62 234	-17 857 000	
2020	17 234	-19 368 000	

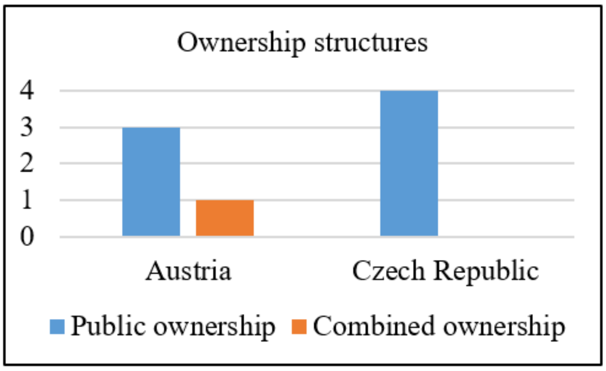
6. ASSESSMENT

Analysis of selected regional airports is focused on Austria and Czech Republic. This section compares their ownership structures and their economic results. The comparison, will determine how many selected regional airports were profitable and how many were loss-making.

6.1. Comparison of ownership structures

In the previous section are analysed the ownership structures of regional airports, and it is possible to compare Austria with the Czech Republic. A report from ACI Europe shows that more than 40% of European airports have at least one private shareholder [49].

According to Graph 1, in both countries are publicly owned airports and airports with combined ownership. In Austria are 3 regional airports in public ownership and one airport in combined ownership. Regional airports with public ownership are Innsbruck Airport, Salzburg Airport and Linz Airport. Graz airport is in combined ownership. In case of the Czech Republic, are all selected regional airports in public ownership. The airports were decentralized, and now they are owned by regions or cities. Brno Airport is taken as a publicly owned airport. This is a specific example of an airport being leased by a private company.

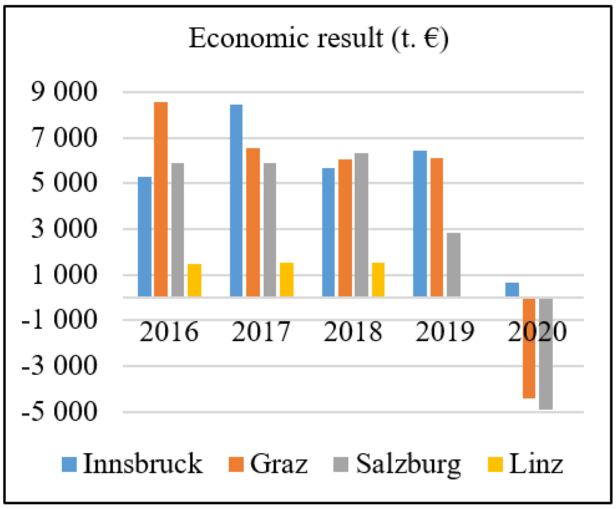


Graph 1: Ownership structures.

6.2. Comparison of economic results

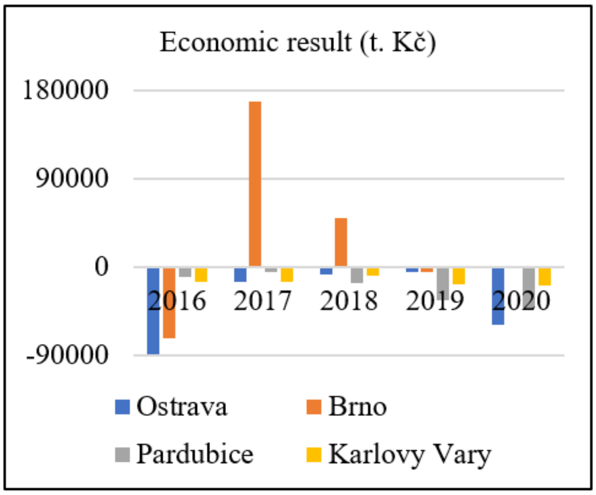
With the obtained data, it is possible to find out which selected regional airports were loss-making or profitable. According to ACI Europe, 42% of European airports are loss-making. As many as 72% of European airports carry less than one million passengers [49].

Only the available and verified data are compared. All economic results from selected regional airports in Austria are compared in Graph 2. In 2016 the highest economic result was achieved by the airport in Graz, followed by the airport in Salzburg. However, the airport in Innsbruck had the best economic results in 2017, but also in 2019 and even in 2020. It is important to mention that Linz Airport had the lowest economic result during 2016 until 2018, but since 2019 their economic results are not publicly available. In 2018 are similar economic results at the airports in Innsbruck, Salzburg and Graz, but the best economic result had Salzburg Airport. Innsbruck Airport has the best economic result in 2019 and the lowest economic result was in Salzburg Airport. However, 2020 was critical year for all selected regional airports, but the only Innsbruck Airport was profitable. Graz and Salzburg airports had a loss of almost 5,000,000 €.



Graph 2: Economic results Austria.

In the Czech Republic are also compared 4 regional airports. In this country are more often loss-making economic results than profitable ones. Graph 3 compares regional airports in Ostrava, Brno, Pardubice and Karlovy Vary. In 2016, the most loss-making airport was Ostrava airport, followed by Brno Airport. However, Brno Airport has the best economic result in 2017. This year, Brno Airport was the only one in profit. The airports in Ostrava, Pardubice and Karlovy Vary had a loss. Even in 2018, only Brno Airport made a profit and the rest of airports had a loss. The year 2019 was unsuccessful for the all selected regional airports. The critical year 2020 was the worst for Ostrava Airport, when they had the second-largest loss after 2016, followed by Pardubice airport. Unfortunately, we do not have the official data from Brno Airport for 2020.



Graph 3: Economic result in Czech Republic.

After comparing our selected regional airports in Table 9, it can be seen that the regional airports in Austria achieved a better economic result. In the Czech Republic, most airports had a negative economic result. For example, regional airports in Ostrava, Pardubice and Karlovy Vary are constantly at a loss. The critical year for both countries was 2020, when only Innsbruck airport was in profit. The most profitable year for the airports was 2017 and 2018, when only three of eight airports were at a loss.

Table 9: Economic Results.

Airport	2016	2017	2018	2019	2020
Innsbruck	Profit	Profit	Profit	Profit	Profit
Salzburg	Profit	Profit	Profit	Profit	Loss
Graz	Profit	Profit	Profit	Profit	Loss
Linz	Profit	Profit	Profit	-	-
Ostrava	Loss	Loss	Loss	Loss	Loss
Brno	Loss	Profit	Profit	Loss	-
Pardubice	Loss	Loss	Loss	Loss	Loss
Karlovy Vary	Loss	Loss	Loss	Loss	Loss

7. CONCLUSION

The aim of the article was to analyse the ownership structures of regional airports in Austria and the Czech Republic with regard to their achieved economic results. There were 4 regional airports in Austria: Innsbruck Airport, Salzburg Airport, Graz Airport and Linz Airport. It dominates public ownership. The regional airports in Innsbruck, Salzburg and Linz are in public ownership, as all entities that own these regional airports ultimately have the city or region as their shareholders. Graz Airport has a combined ownership structure due to the percentage participation of the private shareholder of MCG Graz. According to the information available before the Covid-19 pandemic, none of these regional airports were loss-making, and it was not until 2020 that the regional airports in Graz and Salzburg were loss-making. The only regional airport that was not among the loss-making in 2020 was the airport in Innsbruck, but it still had a lower profit of less than € 6,000,000.

In the Czech Republic, the ownership structures of 4 regional airports were analysed. These were Brno Airport, Ostrava Airport, Pardubice Airport and Karlovy Vary Airport. In this case, all regional airports are in public ownership. The airports are owned by regions or cities. A specific exception is Brno Airport, which is leased by Accolade. According to the results, it can be concluded that the lease of this airport has brought positives, mainly in improving economic results. Here, the specific participation of a private entity helped. Unfortunately, the pandemic affected the economic performance of these regional airports. In the case of the Czech Republic, we can say that the entry of a private sector to ownership structures could help other regional airports, improve their situation.

If we compare the ownership structures in these two countries, we can evaluate that it is different. In Austria there are in ownership structures different companies and corporations that own the airport. The shareholders of these companies and corporations are in fact a city or a region. In the case of ownership structures in the Czech Republic, it is very simple, because the direct owners of regional airports are regions or cities. Austrian regional airports achieved better, and especially positive economic results than Czech regional airports.

We can say that there is a significant difference between the regional airports in Austria and the Czech Republic. It can be said that the Austrian government supports air transport sector much more than the government of Czech Republic supports its air transport. In the Czech Republic, they are trying to help the region, but unfortunately this help is not enough. Of course, this difference in economic results may also depend on the management and control of the airports concerned, and on the operator. In conclusion, we can say that a clearly defined ownership structure is very important in the case of regional airports. It also depends on the approach of individual owners and the help of the government of the country.

REFERENCES

[1] EUR-Lex, 2017. EUR-Lex [online]. 2017. [cit. 2021-11-21]. Available on the internet: https://eur-lex.europa.eu/legal-content/SK/TXT/?uri=CELEX: 32017R1084

[2] TOMOVÁ, A. a kol. 2016. Ekonomika letísk. Žilina: Žilinská univerzita v Žiline EDIS-vydavatelské centrum ŽU. 2016. 219 stran. ISBN 978-80-554-1257-3.

[3] Corporate travel community, 2017. Corporate travel community [online]. 2017. [cit. 2021-11-21]. Available on the internet: https://corporatetravelcommunity.com/analysis/regional-airports-continue-to-be-vital-part-of-any-regions-strategy-as-they-help-to-keep-europe-conn-582841

[4] GILLEN, D. 2011. The evolution of airport ownership and governance. Journal of Air Transport Management. [online]. 2011, 3-13 [cit. 2021-12-10]. Available on the internet: https://linkinghub.elsevier.com/retrieve/pii/S096969971000089X

[5] ISON, S., FRANCIS, G., HUMPHREYS, I., PAGE, R. 2011. UK regional airport commercialisation and privatisation: 25years on. Journal of Transport Geography. [online]. 2011. [cit. 2021-12-13]. Available on the internet: https://linkinghub.elsevier.com/retrieve/pii/S0966692311000986

[6] GRAHAM, A. The objectives and outcomes of airport privatisation. [online]. 2011. [cit. 2022-12-13]. Available on the internet: https://www.sciencedirect.com/science/article/pii/S2210539511000058

[7] MANTIN, B. 2012. Airport complementarity: Private vs. government ownership and welfare gravitation. [online]. 2012. [cit. 2021-12-13]. Available on the internet:https://www.sciencedirect.com/science/article/abs/pii/S0191261511001391

[8] SALDIRANER, Y. 2013. Airport Ownership and Management in European Union countries, BOT Applications in Turkey, and Suggestions for Turkey. International Journal of Economics, Finance and Management Sciences. [online]. 2013. [cit. 2021-12-13]. Available on the internet: https://www.researchgate.net/publication/270707551_Airport_Ownership_and_Management_in_European_Union_countries_BOT_Applications_in_Turkey_and_Suggestions_for_Turkey

[9] AULICH, Ch., HUGHES M. 2013. Privatizing Australian Airports: Ownership, Divestment and Financial Performance. Public Organization Review. [online]. 2013. [cit. 2021-12-13]. Available on the internet: http://link.springer.com/10.1007/s11115-013-0226-y

[10] KUTLU, L., MCCARTHY P. 2016. US airport ownership, efficiency, and heterogeneity. Transportation Research Part E: Logistics and Transportation Review. [online]. 2016. [cit. 2022-12-14. Available on the internet: https://linkinghub.elsevier.com/retrieve/pii/S1366554516000314

[11] BUDD, L., ISON S. 2021. Public utility or private asset? The evolution of UK airport ownership. Case Studies on Transport Policy. [online]. 2021. [cit. 2021-12-14]. Available on the internet: https://linkinghub.elsevier.com/retrieve/pii/S2213624X20301553

[12] LAPCIN, H. 2021. Airport Competitive Strengths in Turkey: Primary, Secondary, and Regional Airports. Transportation Research Procedia. [online]. 2021. [cit. 2021-12-14] Available on the internet: https://linkinghub.elsevier.com/retrieve/pii/S235214652100884X

[13] OUM, T., ADLER N. a YU Ch. 2010. Privatization, Corporatization, Ownership Forms and their Effects on the Performance of the World's Major Airports. [online]. 2010. [cit. 2021-11-17]. Available on the internet: https://ageconsearch.umn.edu/record/208026/

[14] HUDEREK-GLAPSKA, S., NOWAK, H. 2016. Airport and low-cost carrier business relationship management as a key factor for airport continuity: The evidence from Poland. [online]. 2016. [cit. 2021-12-18]. Available on the internet: https://linkinghub.elsevier.com/retrieve/pii/S2210539516300724

[15] LO STORTO, C. 2018. Ownership structure and the technical, cost, and revenue efficiency of Italian airports. Utilities Policy. [online]. 2018. [cit. 2021-12-19]. Available on the internet: https://linkinghub.elsevier.com/retrieve/pii/S0957178717300619

[16] ČERVINKA, M. 2019. Is a regional airports business a way to make a profit?. Transportation Research Procedia. [online]. 2019. [cit. 2021-12-19]. Available on the internet:https://linkinghub.elsevier.com/retrieve/pii/S2352146519305897

[17] Brno Airport, 2012. Brno Airport about airport [online]. 2012. [cit. 2022-1-2]. Available on the internet:http://www.brno-airport.cz/letiste/o-letisti/

[18] Brno Airport, 2017. Brno Airport: Accolade [online]. 2017. [cit. 2022-1-2]. Available on the internet:http://www.brno-airport.cz/letiste/tiskove-zpravy/letiste-brno-meni-majitele-nove-je-soucasti-skupiny-accolade/

[19] PATRIOT, 2019. Magazín Patriot airport Mošnov [online]. 2019. [cit. 2022-1-2]. Available on the internet: https://patriotmagazin.cz/letiste-mosnov-ma-60-let-poprve-se-zde-zacalo-letat-v-rijnu-1959

[20] East Bohemian Airport a.s., 2020. Annual report 2020 [online]. 2020. Dostupné také z: https://airport-pardubice.cz/wp-content/uploads/2021/05/Vyrocni_zprava_2020.pdf

[21] Airport Karlovy Vary, 2022. About airport – history of airport [online]. 2022. [cit. 2022-1-10]. Available on the internet: https://www.airport-k-vary.cz/cs/historie-letiste/

[22] Evropský parlament, 2021. European Parlament data [online]. 2021. [cit. 2022-1-14]. Available on the internet: https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689346/EPRS_BRI(2021)689346_EN.pdf

[23] ACI EUROPE, 2021. ACI Europe impact of covid-19 [online]. 2021. [cit. 2022-1-15]. Available on the internet: https://aci.aero/2021/11/01/the-impact-of-covid-19-on-the-airport-business-and-the-path-to-recovery-3/

[24] IDnes.cz, 2021. Covid 2020 airport Mošnov [online]. 2021. [cit. 2022-1-16]. Available on the internet: https://www.idnes.cz/ostrava/zpravy/letiste-ostrava-mosnov-koronavirus-rok-2020.A210125_112018_ostrava-zpravy_dar

[25] IDnes.cz, 2022. Oživení nákladní spedice [online]. 2022. [cit. 2022-1-20]. Available on the internet: https://www.idnes.cz/ostrava/zpravy/letiste-letadla-doprava-propad-oziveni-naklad-spedice.A220119_646695_ostrava-zpravy_jst

[26] Brno Airport, 2022. Brno Airport: Statistics [online]. 2022. [cit. 2022-1-20]. Available on the internet: http://www.brno-airport.cz/letiste/statistiky/

[27] IDnes.cz, 2022. Pardubice airport during covid-19 [online]. 2022. [cit. 2022-1-21]. Available on the internet: https://www.idnes.cz/pardubice/zpravy/letiste-pardubice-cestujici-2021-propad-rust-covid.A220113_120000_pardubice-zpravy_lati

[28] Innsbruck Airport, 2020. Annual report 2020 [online]. 2021. Available on the internet: https://www.innsbruck-airport.com/fileadmin/userdaten/Jahresabschluss_2020.pdf

[29] Innsbruck Airport, 2022. Innsbruck Airport: Statistiky [online]. 2022. [cit. 2022-1-21]. Available on the internet: https://www.innsbruck-airport.com/fileadmin/userdaten/Zahlen_Daten_und_Fakten_2020_2021.pdf

[30] Innsbruck Airport, 2019. Annual report 2018 [online]. 2019. Available on the internet: https://www.innsbruck-airport.com/fileadmin/userdaten/docs/fhi-id3436-geschaeftsbericht2018-juni19-web-ds.pdf

[31] [31] Innsbruck Airport, 2017. Annual report 2016 [online]. 2017.

[32] Flughafen Graz, 2021. Annual report 2020 [online]. 2021. Available on the internet: https://www.flughafen-graz.at/fileadmin/user_upload/content/Annual_report_2020.pdf

[33] Flughafen Graz, 2019. Annual report 2018 [online]. 2019. Available on the internet: https://www.flughafen-graz.at/fileadmin/user_upload/content/Geschaeftsbericht_Annual_report_2018.pdf

[34] Flughafen Graz, 2017. Annual report 2016 [online]. 2017. Available on the internet: https://www.flughafen-graz.at/fileadmin/user_upload/content/Geschaeftsbericht_Annual_report_2016.pdf

[35] Salzburg Airport, 2022. Salzburg Airport corporate group [online]. 2022. [cit. 2022-2-6]. Available on the internet: https://www.salzburg-airport.com/en/thecompany/about-us/the-corporate-group/salzburger-flughafen-gmbh

[36] Salzburg Airport, 2022. Salzburg Airport: Statistics [online]. 2022. [cit. 2022-2-11]. Available on the internet: https://www.salzburg-airport.com/en/thecompany/about-us/statistics

[37] Salzburg Airport, 2021. Annual report 2020 [online]. 2021.

[38] Salzburg Airport, 2019. Annual report 2018 [online]. 2019.

[39] Salzburg Airport, 2017. Annual report 2016 [online]. 2017.

[40] Flughafen Linz, 2019. Annual report 2018 [online]. 2019.

[41] Letiště Brno a.s., 2020. Annual report 2019. 2020. Available on the internet: https://or.justice.cz/ias/ui/vypis-sl-detail?dokument=65819622&subjektId=534556&spis=685338

[42] Letiště Brno a.s., 2018. Annual report 2017 [online]. 2018. Available on the internet: https://or.justice.cz/ias/ui/vypis-sl-detail?dokument=53043106&subjektId=534556&spis=685338

[43] Ostrava Airport, 2021. Annual report 2020 [online]. 2021. Available on the internet: https://www.airport-ostrava.cz/p/vyrocni-zprava-2020

[44] Ostrava Airport, 2019. Annual report 2018 [online]. 2019. Available on the internet: https://www.airport-ostrava.cz/p/vyrocni-zprava-2018

[45] Ostrava Airport, 2017. Annual report 2016 [online]. 2017. Available on the internet: https://www.airport-ostrava.cz/p/vyrocni-zprava-2016

[46] East Bohemian Airport a.s., 2019. Annual report 2018 [online]. 2019. Available on the internet: https://airport-pardubice.cz/wp-content/uploads/2020/10/Vyrocni_zprava_2018.pdf

[47] East Bohemian Airport a.s., 2018. Annual report 2017 [online]. 2018. Available on the internet: https://airport-pardubice.cz/wp-content/uploads/2020/10/Vyrocni_zprava_2017.pdf

[48] Letiště Karlovy Vary s.r.o., 2021. Annual report 2020 [online]. 2021. Available on the internet: https://www.airport-k-vary.cz/download/file/375-Zprava_o_cinnosti_spolecnosti_2020.pdf

[49] ACI EUROPE, 2022. ACI Europe: About us [online]. 2022. [cit. 2022-4-6]. Available on the internet: https://www.aci-europe.org/about-1.html

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

[51] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

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

[53] REMENCOVÁ, T., SEDLÁČKOVÁ, A.N. 2022. The Approach to Evaluation of the economic and operational Indicators of selected Regional Airports in the Countries of Central Europe. Transportation Research Procedia, 2022, 59, pp. 154–165. ISSN 23521457.

[54] 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.

[55] REMENCOVÁ, T., SEDLÁČKOVÁ, A.N. 2021. Position of central european regional airports. Transport Problems, 2021, 16(3), pp. 163–172. ISSN 18960596.

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MORPHING WINGS OF AIRCRAFT

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Abstract

Goal of the paper is to describe use of morphing wings on aircraft and their possible use to increase aerodynamic efficiency of aircraft. Paper is divided into two parts. First part focuses on design and material requirements of morphing wings as well as describes some of studied concepts. Second part compares studied concepts using gathered data and proposes possible combinations of concepts with goal of further increase of aerodynamic efficiency.

Keywords

Morphing wings, Drag reduction, Aerodynamic efficiency, Aerodynamics, Comparison

1. INTRODUCTION

Flight performance differs in different parts of flight. Due to this aircraft are designed so that they reach optimal flight performance in part of flight where they remain for longest amount of time. This however means that in any other part of flight optimal flight performance is not reached. Reduction in flight performance results in increase of fuel consumption and emissions. To improve flight performance in certain parts of flight secondary control surfaces are used. These surfaces allow to increase lift generated by wing and thus improve flight performance during landing and take-off, however use of secondary control surfaces increases drag of aircraft. Ideal solution of flight performance optimalization is such that allows flight performance optimalization during full duration of flight without imposing sever disadvantages. Potential solution of flight performance optimalization is use of morphing wings. These wings are capable of changing their shape in plane and space. Changes in shape of wing allow aerodynamic optimalization of wing and thus allow improvement of flight performance in all parts of flight. Paper is focused on description of few concepts of morphing wings and then compares described concepts with goal of assessing practical use of these concepts.

2. HISTORY

Historically morphing wings are not new technology. These wings were first used in airplane of Wright brothers in year 1903. Airplane Wright flyer used bending of canvas wing to control roll of aircraft [1]. After this during 1930 till 1940 many more aircraft using morphing wings appeared. For example, Mak.10 which was capable of changing its wingspan [2], LIG-7 which was capable of changing its wing chord [3] and many more. Important airplane for morphing wings however was X-5 created in 1951. X-5 was a test bed for a variable-sweep wing. Data gained during testing performed on this aircraft were later used in construction of first aircraft equipped with variable-sweep wings such as F-14 Tomcat [4]. Variable-sweep is first concept of morphing wings successfully introduced into active service in history. More concepts of morphing wings were tested from 1964 till 2000. For example, folding wings of XB-70 [5], oblique wing of AD-1 [6] and mission adaptive wing of F-111. Result of morphing wings research conducted at that time was however that although these new wings bring aerodynamic improvements, their complexity and use of rare and special materials makes them unusable in practice with exception of variable-sweep wing, which was successfully used. Currently research in area of morphing wings focuses on creation of wing capable of changing its camber. Of course, there are many other concepts which focus on changing wing shape in different ways. For example, changes of wing chord, wingspan, wing thickness etc.

3. CONSTRUCTION AND METERIAL REQUIREMENTS

Morphing wings usually differ from regular wings with their elasticity. Elasticity is mostly necessary to allow easier change of wing shape. This however means that such wings will have special construction and material requirements. These requirements tend to differ between each concept however certain basic requirements can be set. Material used in construction or construction itself of morphing wings must be elastic, yet strong enough to resist to aerodynamic loads acting on the wing. After shape morphing construction must be capable of keeping its new shape and be capable of changing its shape back to original shape [7]. Shape change is mostly allowed by use of actuators located inside wing. Another way of inducing wing shape change is use of aeroelastic deformations. If actuators are used, they must meet certain requirements. They must be as small as possible, energy efficient and be capable of resisting loads acting on construction or be capable of transmitting these loads on other part of construction which can resist these loads. Question of material candidates that meet set material requirements was discussed in thesis from Virginia Polytechnic Institute and State University in 2003 [8]. This thesis set 4 material categories as potential candidates. These categories were polyurethanes, copolyesters, shape memory alloys and woven materials. Conducted testing on material deformation and load resistance resulted in incomplete results. Polyurethanes and copolyesters were successfully tested in single plane deformation, however during two plane deformation testing both categories ripped. Shape memory alloys were too brittle and thus could not be tested. Woven materials were ruled out based on load testing as this material was unable to resist aerodynamic loads. From these results it is apparent that finding material that could be used in construction of morphing wing is difficult. Despite of this such materials do exist. Materials from material category of smart materials are best candidates. Smart materials are materials capable to react to outside stimulation and change their characteristics based on this stimulation. For example, heating a shape memory alloy causes it to become more elastic. These materials can be used to create composites that are elastic, yet strong enough. They can be also used to create smart actuators which are lighter than regular actuators and generate enough force to change wing shape [9].

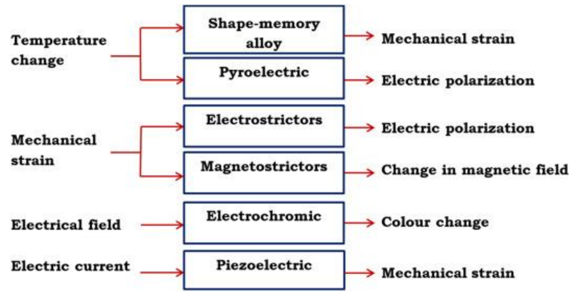

Figure 1: Groups of smart materials and their interaction on outside stimuli [Nabila Shehata, Mohammed a. Addelkarseem, Enes t. Sayed, Davidson e. Egirani, Alfred w. Opukumo, Smart materials: the next generation].

4. NEW CONCEPTS OF MORPHING WINGS

In this part paper focuses on description of new concepts of morphing wings that were chosen. These concepts are mission adaptive compliant wing (MACW), variable camber compliant trailing edge flap (VCCTEF), active aeroelastic wing (AAW) and adaptive aspect ratio (AdAR).

4.1. MACW a VCCTEF

Concepts MACW a VCCTEF are concepts of morphing wing that focuses on changes in camber. To achieve this both concepts change shape of continuous trailing edge. Shape change however is achieved differently. Trailing edge of MACW concept uses compliant structure which does not neede lot of force to change its shape [10].

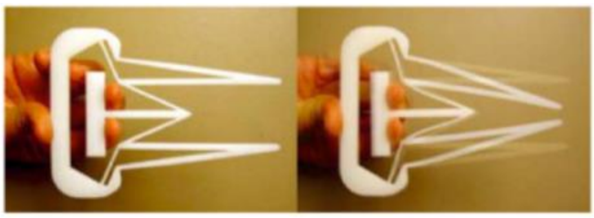

Figure 2: Functioning principle of compliant structure used in MACW. [10]

Concept VCCTEF uses continuous trailing edge that is divided into 12 sections. Each section is composed of 3 segments. Shape change is achieved by changing position of each of these segments [11].

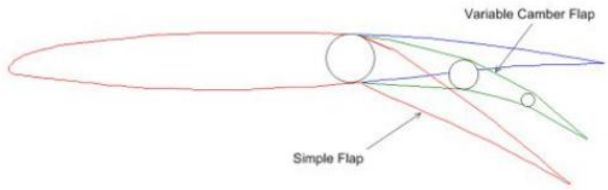

Figure 3: Comparison of VCCTEF wing with regular wing. [11]

Both solutions have their advantages. Compliant structure of MACW avoids creation of localised high stresses as entire structure changes shape. This means that structure is very unlikely to fail due to material fatigue. Compliant structure also allows use of common materials such as steel or aluminium. Since compliant structure does not have any joints there is no need for lubrication [10]. Construction of VCCTEF may be considered more complex, however it allows more precise aerodynamic optimalization as each segment may be positioned differently which allows for large variations of shapes of trailing edge [11]. Both concepts potentially allow optimalization of lift distribution on wing as both concepts are capable of variable trailing edge deflection [10], [11]. This optimalization would allow reduction in root bending moment which in turn allows reduction of construction strength. This means that wing construction would be lighter. Deflection of trailing edge of both concepts results in lesser drag increase than deflection of regular flap. Trailing edge of both concepts is continuous and thus generates less drag then regular trailing edge. Reduction of drag means increase in aerodynamic efficiency. Aircraft equipped with wings of either MACW or VCCTEF would thus have increased range and reduced fuel consumption.

4.2. AAW

Concept AAW uses aeroelastic deformation to induce changes in wing shape. Thin and elastic wing is deformed under aerodynamic load.

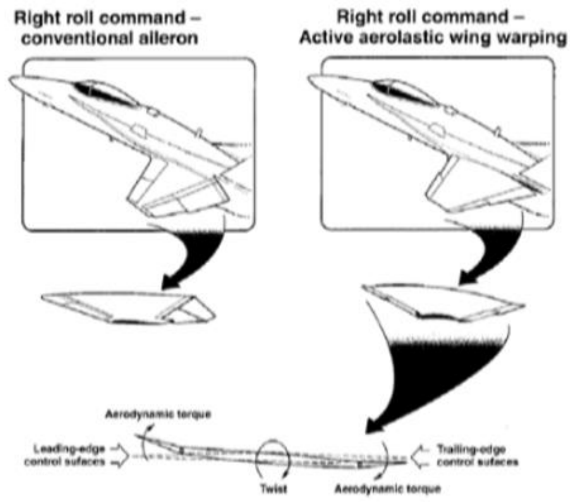

Figure 4: Function principle of AAW. [Syed Ali Hussain, The morphing wing]

This fact is usually undesirable as this leads to aeroelastic phenomena such as aileron reversal and flutter. Concept AAW uses primary and secondary control surfaces controlled by special flight control systems to induce controlled aeroelastic deformation. These deformation cause wings shape to change in desired which allows to use wing itself as a control surface. This leads to improvement of roll rate at high speeds and drag reduction as control surfaces do not need large deflections. Construction consists of regular primary and secondary control surfaces which is quite advantageous. For AAW to work however wing must be elastic. Concept was tested on F/A-18 Hornet which had wing retrofitted from prototype aircraft YF-17. Wing of YF-17 much thinner and more elastic than wing of F/A-18. Elastic wings have less robust construction than regular wings which leads to weight reduction of aircraft. Concept AAW thus allows for weight reduction, improvement of high-speed control authority and drag reduction [12], [13].

4.3. AdAR

Concept AdAR allows change of wingspan without large changes of wing chord while keeping wing skin continuous. Changes in wingspan allow to control lift generated by a wing, aircraft roll-rate and generated induced and parasitic drag. Concept AdAR can also be used to cause asymmetry in wingspan and can thus be used to control roll of an aircraft. Concept construction is relatively simple. It consists of moving and fixed spar and strap drive system. Strap drive is used to allow movement of movable spar on which sliding ribs are located. These ribs are connected to elastic wing skin consisting of elastomeric matrix composite. Sliding ribs are responsible for keeping fixed minimal and maximal distance from other ribs. This is necessary to keep the wing skin stretched when wing is not extended and to protect the wing skin from damage when wing is extended.

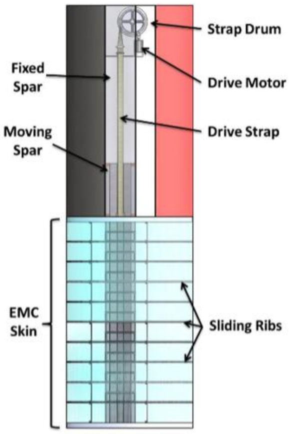

Figure 5: Construction of concept Adar. [14]

Wing skin must be stretched at all times to increase resistance to aerodynamic loads. Concept is currently still in development phase. Development focuses on finding an optimal number of sliding ribs. Number of sliding ribs dictates wings resistance to chord deformation. More sliding ribs increase this resistance however also increase actuation forces necessary to change wing shape [14].

5. COMPARISON OF MORPHING WINGS

Concept comparisons is conducted based on aerodynamic efficiency and construction complexity. Values of aerodynamic efficiency are taken from sources used in their description. If these values are unavailable, they are approximately set based on simulations crated and conducted in Autodesk CFD or if coefficient of lift and drag are known they are calculated. Values are set for angle of attack of 3° with full flap deflection with exception of concept AAW and AdAR. Values for AAW are set for 5° wing twist with +10° leading edge deflection and +3° trailing edge deflection. Values for AdAR are set for 3° angle of attack with no flap deflection at maximal wingspan.

5.1. Aerodynamic comparison

Set values of aerodynamic efficiency of concepts is given in table 1.

Table 1: Values of aerodynamic efficiency of concepts.

MACW	127 (12.7)
VCCTEF	17.2
AAW	4.32
AdAR (2 m)	3.38

Values for concept MACW are set based on graphs found in source for concept MACW [10]. Resulting value of aerodynamic efficiency is calculated to be 127. This value is absurdly high and is possibly so high due to use of lift and drag coefficients gained from 2D flow simulation. Approximate value of aerodynamic efficiency for this concept is 12.7 since all other values are in similar range. Aerodynamic efficiency for concept VCCTEF was set during testing of the concept. Maximal reached aerodynamic efficiency was 17.2 with lift coefficient of 0.51 that was used during concept testing. Values for concept AAW were unavailable and approximate simulation of concept was conducted in Autodesk CFD. Based on conducted simulation value of aerodynamic efficiency is 4.32.

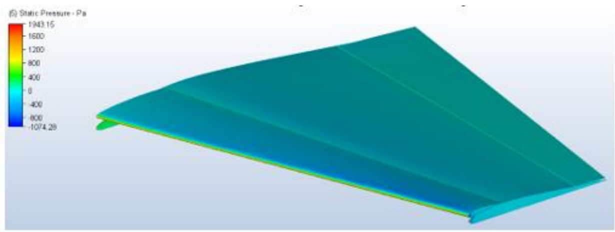

Figure 6: Pressure distribution of simulated AAW model. [authors]

Values for concept AdAR were also unavailable and approximate simulation was again conducted in Autodesk CFD. Based on results of simulation the aerodynamic efficiency of concept is 3.38 for wingspan of 2m.

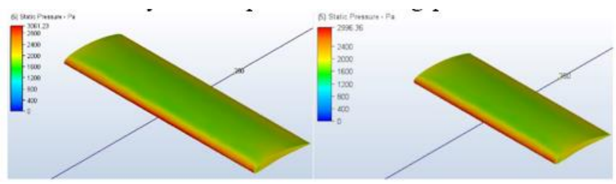

Figure 7: Pressure distribution of simulated ADAR models. [authors]

Based on gained values of aerodynamic efficiency can concept VCCTEF be determined as most aerodynamically efficient. In addition, by using optimalization of lift distribution can this efficiency be further increased. Despite not reaching highest values of aerodynamic efficiency concepts AAW and AdAR can be possibly combined with either concept VCCTEF or MACW on one wing to further increase aerodynamic efficiency.

5.2. Construction comparison

Concept VCCTEF is most complex of all the described concepts. It's segmented construction may prove difficult to maintain in service. Used actuators in this concept also are not uniform. For end segments of each section of trailing edge, electric actuators are used. For first two segments of each section, smart actuators are used. Sections of trailing edge are interconnected by elastic material. This material may not be readily available further complicating maintenance. Construction of concept MACW may be complex in terms of production however it may prove less difficult to maintain than concept VCCTEF. As the actuation force does not need to be large less powerful and lesser number of actuators may be used. This reduces number of components that may fail. Concept can also use common materials such as steel which is more readily available. Compliant structure does not use any joints and thus removes necessity of lubrication and reduces number of components that can fail yet again. Failure of compliant structure is also quite unlikely as structure avoids generating local high stresses and thus avoids material fatigue failure. One large problem however may be in case of damage of compliant structure as repair of this structure may prove complicated. Concepts AdAR and AAW have relatively simple construction. Concept AAW uses regular control surfaces and elastic wing. This means that it's maintenance will be similar to maintenance of regular wing. AAW however needs special flight control system to work properly. Software of this flight control must function properly at all times to maintain control of aircraft unless some backup control is installed. Construction of concept AdAR is also fairly simple. There are however two problems with this concept. First problem is that wing skin is made from elastomeric matrix composite which may be expensive or not readily available. Other one is that failure of sliding rib may lead to structural failure of wing skin. Other then those two problems concept AdAR should not prove to be difficult to maintain in service however large emphasis must be given on ribs maintenance.

Structural complexity of concepts VCCTEF and MACW is their main disadvantage however they bring larger aerodynamic advantages than concepts AAW and AdAR. On the other hand, simple structures of concepts AAW and AdAR allow for potential combination with concepts VCCTEF and MACW further improving aerodynamic efficiency.

5.3. Combination of concepts

Concepts AdAR and AAW may seem pointless in comparison to MACW and VCCTEF. However, despite they low values of aerodynamic efficiency in comparison to MACW and VCCTEF they still allow for aerodynamic improvement although small. Their simple construction is their biggest advantage in this case as it allows for possible combination with concepts VCCTEF or MACW. Such combination will lead to further increase of aerodynamic efficiency. Potential combinations are AAW and VCCTEF or MACW and AdAR and VCCTEF or MACW. Combination of AAW with either VCCTEF or MACW would allow replacement of regular control surfaces with morphing trailing and leading edge which generates less drag. Such combination would allow for AAW to work while generating less drag. Combination of AdAR with either MACW or VCCTEF would allow for roll control based on asymmetry of wingspan while regular flaps would be replaced by morphing trailing edge. This combination would also lead to further drag reduction and thus increased aerodynamic efficiency.

6. CONCLUSION

All described concepts have proven ability to improve aerodynamic efficiency of wings. In aerodynamic terms concepts VCCTEF and MACW have proven to be most capable. Concepts AdAR and AAW have proven to be less aerodynamically effective than VCCTEF and MACW however their relatively simple construction allows for possible combination with concepts VCCTEF and MACW. Such combination would possibly allow further improvement of aerodynamic efficiency. Research in terms of morphing wings should continue in the future. It is necessary to conduct testing of aerodynamic loading of such wings and to assess their aerodynamic efficiency. Based on results of such tests there should be focus of creating legislation and norms that would allow for such wings to enter service. Research of morphing wings should not be solely focused on creation of new concepts but should also focus on improving already existing concepts and their possible combination with other concepts with goal of further improvement in terms of aerodynamic efficiency.

REFERENCES

[1] Yue Wang, 2015, Development of Flexible-Rib Morphing Wing System, strana 15 [online] Available at: https://tspace.library.utoronto.ca/bitstream/1807/69163/3/Wang_Yue_201503_MAS_thesis.pdf

[2] Experimental aircraft I.I. Makhonina Mak.10 / Mak.101 (France) [online] Available at: https://en.topwar.ru/104295-eksperimentalnyy-samolet-ii-mahonina-mak10-mak101-franciya.html

[3] LIG-7 by G.I.Bakshaev [online] Available at: http://ram-home.com/ram-old/rk.html

[4] NASA, 2014, NASA Armstrong Fact Sheet: X-5 Research Aircraft [online], Available at: https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-081-DFRC.html

[5] NASA, 2014, NASA Armstrong Fact Sheet: XB-70 Valkyrie [online], Available at: https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-084-DFRC.html

[6] NASA, 2009, Past Projects: AD-1 Oblique Wing [online], Available at: https://www.nasa.gov/centers/dryden/history/pastprojects/AD1/index.html

[7] Silvestro Barbarino, Onur Bilgen, Rafic M. Ajaj, Michael I. Friswell, Daniel J. Inman, 2011, A Review of Morphing Aircraft, Strana 829 [online], Available at: https://www.researchgate.net/publication/228411238_A_Review_of_Morphing_Aircraft

[8] Michael Thomas Kikuta, 2003, Mechanical Properties of Candidate Materials For Morphing Wings, kapitola 2 a 4 [online], Available at: https://vtechworks.lib.vt.edu/bitstream/handle/10919/36152/mkikuta_thesis.pdf?sequence=1

[9] Jian Sun, Qinghua Guan, Yanju Liu, Jinsong Leng, 2016, Morphing aircraft based on smart materials and structures: A state of the art review (2016) , strana 1-7 [online], Available at: http://smart.hit.edu.cn/_upload/article/files/55/6e/81289810479f9ae976b75f056268/a90c032a-2bf3-4e1f-b5aa-2db7dd437d4d.pdf

[10] Sridhar Kota, Russell Osborn, Gregory Ervin, Dragan Maric, 2006, Mission Adaptive Compliant Wing – Design, Fabrication and Flight Test [online]

[11] Nhan Nguyen, Upender Kaul, Sonia Lebofsky, Eric Ting, Daniel Chaperro, James Urnes, 2015, Development of Variable Chamber Continoues Trailing Edge Flap for Performance Adaptive Aeroelastic Wing [online]

[12] Robert, Clark, Michael J. Allen, Ryan P. Dibley, Joseph Gera, John Hodgkinson, 2005, Flight Test of the F/A-18 Active Aeroelastic Wing Airplane (2005) strana 1-36 [online], Available at: https://ntrs.nasa.gov/citations/20050212234

[13] Ed Pendleton, Active Aeroelastic Wing [online], Archived at: https://web.archive.org/web/20060618092639/http://www.afrlhorizons.com/Briefs/0006/VA9901.html

[14] Benjamin King, Sutton Woods, Michael I. Friswell, 2014, The Adaptive Aspect Ratio Morphing Wing: Design Concept And Low Fidelity Skin Optimalization [online], Available at: https://www.researchgate.net/publication/269279276_The_adaptive_aspect_ratio_morphing_wing_Design_concept_and_low_fidelity_skin_optimization

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

[16] 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.

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

[18] 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.

[19] MATAS, M., NOVÁK, A. 2008. Models of processes as components of air passenger flow model. Communications-Scientific letters of the University of Zilina 10 (2), pp. 50-54.

[20] 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.

[21] ČERNAN, J., ŠKULTÉTY, F. 2020. Transport Means - Proceedings of the International Conference, 2020, 2020-September, pp. 942–945. ISNN 1822296X.

[22] LUSIAK, T., NOVÁK, A., JANOVEC, M., BUGAJ, M. 2021. Measuring and testing composite materials used in aircraft construction. Key Engineering Materials, 2021, 904 KEM, pp. 161–166. ISBN 10139826.

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PROPOSAL OF THE FI (S) SEMINAR PROGRAM FOR DTO ACCORDING TO THE CONDITIONS OF CAA-ZLP-161

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Abstract

The aim of this paper is to create a proposal for a seminar program for sailplane instructors. Since 2021, new European legislation has come into effect regulating the flight crew licensing. Part of this legislation is the obligation to attend a seminar for each instructor once every 3 years. The seminars can be organized by the declared training organizations (DTO), for which the organization of these seminars is new and have no experience with it, so this program proposal can help them organize the seminar. This research deals with current legislation, analysis of conditions imposed by EASA, analyses the current recommended flight instruction syllabus for new flight instructors together with the syllabus for training new pilots, analyses selected aviation accidents and finally analyses important chapters in aviation medicine.

Keywords

Seminar, Instructor, Program, Sailplane, Safety

1. ÚVOD

V dubnu 2021 vyšla v platnost nová verze českého dokumentu CAA-ZLP-161, který upravuje legislativní požadavky kladené na piloty s licencí SPL, tedy piloty kluzáků. Největší změny se však týkaly plachtařských instruktorů (dále jen FI(S)). Právě do dubna 2021 měli všichni instruktoři bezmotorového výcviku platnou licenci po dobu 3 let, kdy se následně mohla prodloužit splněním 2 ze 3 předepsaných požadavků. To se v současnosti změnilo a instruktoři tak musí splňovat tzv. rozlétanost. Jedním ze stěžejních bodů rozlétanosti je povinnost navštívit jednou za 3 roky udržovací seminář FI(S). Tento seminář se v minulosti konal pouze pod záštitou schválených výcvikových organizací (ATO) jako tzv. obnovovací seminář, avšak udržovací semináře mohou pořádat i tzv. ohlášené výcvikové organizace (DTO), pro které je ovšem pořádání takového semináře novinkou a nemají s tím zkušenosti. Zároveň mnoho DTO nezná přesné legislativní požadavky na seminář, případně nevědí, co by na něm mělo konkrétně zaznít. V rámci výzkumu byl vytvořen návrh programu udržovacího semináře FI(S), který splňuje požadavky ať už Evropské agentury pro bezpečnost v letectví (EASA) nebo Úřadu pro civilní letectví České republiky (ÚCL).

2. AKTUÁLNÍ LEGISLATIVNÍ POŽADAVKY NA FI(S) V PODMÍNKÁCH ČESKÉ REPUBLIKY

Jak bylo zmíněno v úvodu, základní změnou z pohledu udržení platnosti licence FI(S) je přechod z modelu datumového, kdy měla licence platnost do určitého data a pak se musela nechat prodloužit na ÚCL, na model rozlétanosti. To dle současných podmínek znamená, že pokud chce FI(S) vykonávat činnost instruktora, musí plnit několik požadavků, mimo jiné mít za poslední 3 roky dostatečný nálet, který lze obejít hodnocením odborné způsobilosti s letovým examinátorem a jednou za 9 let absolvovat cvičný let s instruktorem FI(S)+ - instruktorem s právy provádět výcvik nových instruktorů. Další podmínkou je povinnost za poslední 3 roky absolvovat seminář, na který se vztahují určité požadavky. Mimo jiné by měl zahrnovat minimálně 6 hodin vyučování (45 minut výuka a 15 minut diskuse – otázek). Zároveň by měl zahrnovat některý z doporučených předmětů dle Part-SFCL. V rámci České republiky považuje náš ÚCL za nejdůležitější oblasti tyto následující: národní požadavky a regulace, vyšetřování leteckých nehod a lidský faktor.

Kromě toho se zásadně změnila pravidla pro akrobacii na kluzácích, kdy se dosavadní licence rozdělila na tzv. základní – BASIC a pokročilou – ADVANCED. Hlavním rozdílem je rozsah povolených akrobatických prvků.

3. VÝBĚR TÉMAT NA ZÁKLADĚ OSNOV VÝCVIKU FI(S) A PART – SFCL

Současné doporučené osnovy pro výcvik nových FI(S), respektive oblasti výuky v rámci těchto osnov, mohou být zařazeny do programu udržovacího semináře. Jedná se primárně o oblasti sebevzdělávání, techniky a procesu vyučování, lidské výkonnosti a omezení ve vztahu k letovému výcviku, případně dalších oblastí jako filozofie výcviku nebo administrativa výcviku.

Je zřejmé, že tvorba uceleného programu udržovacího semináře je poměrně flexibilní záležitostí. Kromě požadovaných oblastí výuky (od ÚCL) si může každé DTO přizpůsobit zbytek programu semináře tak, aby byl pro přihlášené instruktory přínosný a zajímavý. Pro potřeby výzkumu byl instruktorům rozeslán dotazník, týkající se požadovaných oblastí výuky. Výstupem dotazníku je výběr několika předmětů, které instruktoři považují za nejdůležitější a kterým by se v rámci semináře chtěli primárně věnovat. Dotazník byl rozdělen na dvě části, kdy v první byly vyjmenovány jednotlivé doporučené oblasti výuky dle Part-SFCL a v druhé části instruktoři podrobněji popsali, co je v dané problematice zajímá. Jako příklad můžeme uvést oblast letecké navigace (zvolena jako předmět v první části), kde byla jako nejdůležitější zvolena pravidla letů přes řízené prostory (zvolena jako přesnější zaměření v letecké navigaci v druhé části dotazníku). Tento dotazník může posloužit jako vzor pro jednotlivá DTO, pořádající seminář. Na základě výsledků totiž mohou vytvořit samotný program semináře, který bude v každém DTO jiný. Jako příklad můžeme uvést 2 DTO – Prostějov a Brno – Medlánky. Pro piloty z Prostějova může být zajímavé a přínosné téma letů přes řízené prostory a s tím související pravidla a komunikace. Naproti tomu pro instruktory z Brna toto nebude velmi přínosné, protože letiště Medlánky se přímo nachází v CTR Brno – Tuřany a tak pravidla a komunikaci znají. Takových příkladů najdeme v ČR mnoho a tak může dotazník organizátorům semináře skutečně velmi pomoct při tvorbě programu.

4. NÁVRH PROGRAMU SEMINÁŘE NA ZÁKLADĚ VÝSLEDKŮ DOTAZNÍKU A POŽADAVKŮ DLE PART – SFCL

Podle analýzy výsledků modelového dotazníku shledali oslovení instruktoři jako nejdůležitější tyto oblasti výuky: Národní požadavky a regulace, lidský faktor, rozbor leteckých nehod a jejich prevence, letecká meteorologie a letecká navigace.

4.1. Národní požadavky a regulace

Nejdůležitější informace z této oblasti zazněly v kapitole II. „Analýza aktuálních legislativních požadavků v podmínkách České republiky“. Ovšem kromě požadavků na rozlétanost jako FI(S) musí instruktor splňovat několik dalších požadavků. Těmi jsou rozlétanost v rámci SPL, požadavky na nedávnou praxi a požadavky na zachování práva na způsob vzletu. V rámci udržovacího semináře se doporučuje instruktory seznámit s aktuálním dokumentem CAA-ZLP-161 a jeho legislativními podmínkami pro FI(S).

4.2. Lidský factor

Tento předmět by měla přednášet osoba dostatečně proškolená, například přímo letecký lékař. Nicméně se svolením autorů je možné využít na semináři videa z přednášek těchto odborníků na internetu.

V současnosti je nejčastější příčinou letecké nehody chyba pilota. Nikdo není neomylný, nicméně podle inspektorů Programu prevence nehod, spadajícím pod americkou FAA, jsou nejhoršími možnými lidskými přístupy k řízení letadla nezranitelnost, přílišná sebedůvěra, vzdor, zbrklost a rezignace při nouzové situaci.

Jednou z nejvážnějších leteckých nemocí je hypoxie. Je to stav, kdy se do těla nedostává dostatečné množství kyslíku na to, aby pilot mohl normálně fungovat a řídit letadlo. Setkáváme se s ní ve větších výškách, kde dochází k poklesu měrného množství kyslíku na 1 kg vzduchu. Společně s výškou také klesá tlak vzduchu. Příznaky hypoxie jsou pocit euforie, porucha logického myšlení, bolest hlavy nebo ztráta schopnosti bezpečně ovládat letadlo. Nakonec může dojít k úpadku do bezvědomí, které ale také může nastat hned jako první příznak. Právě v nevyzpytatelnosti této nemoci je její hlavní nebezpečí.

Další leteckou nemocí je hyperventilace. Nastává při nadměrném a rychlém dýchání, nejčastěji při krizových situacích. Při dýchání se nám do krevního oběhu dostává kromě kyslíku také oxid uhličitý ve formě kyseliny uhličité. Hlubokým dýcháním nezvyšujeme podíl kyslíku v krvi, ale pouze k vydechování příliš velkého množství oxidu uhličitého. Dojde ke změně stavu pH krve, která se stává zásaditější, neboť kyseliny uhličité ubylo. Tato disharmonie má velmi špatný vliv na lidský mozek, který je právě na změny pH velmi citlivý. Příznaky hyperventilace jsou podobné těm u hypoxie, nicméně řešení je opačné. Doporučuje se na 20 vteřin zadržet dech, případně dýchat chvíli do sáčku. Toto nezabrání hypoxii, ale pomůže při léčbě hyperventilace.

Z pohledu leteckého výcviku je důležité zmínit další nemoc, kterou je kinetóza. Lidově tuto nemoc označujeme jako letadlovou, případně mořskou nemoc. Hlavní příčinou kinetózy je tzv. nervový mišmaš. Při letu mozek dostává informace z různých smyslových orgánů, které jsou často protichůdné a tím pádem je mozek nedokáže správně vyhodnotit. V praxi se jedná o rozdíl mezi obdrženými smyslovými informacemi a očekávaným modelem pohybu uloženým v paměti. Nejčastěji tak ke kinetóze dochází například u pilota, který v daný okamžik letadlo neřídí a neví, jaký pohyb letadla má očekávat. S kinetózou se setkáváme také na nekvalitních pouťových atrakcích – simulátorech letu. Pilot totiž ví, jaký pohyb simulátoru by měl následovat. Nicméně tyto simulátory jen zřídka odpovídají realitě a tak se zde pilotům dělá pravidelně nevolno.

4.3. Rozbor leteckých nehod a jejich prevence

Z hlediska vyšetřování leteckých nehod doporučuje ÚCL pro tento seminář rozbor dvou konkrétních nehod kluzáků, které se staly na podzim 2019 velice krátce po sobě a shodně při vlnovém létání za Jeseníky. Piloti obou kluzáků utrpěli při nárazu do země zranění neslučitelná se životem. U obou kluzáků došlo k destrukci za letu, přičemž technický stav kluzáků se neuvádí jako nejpravděpodobnější příčina nehody. Tou je podle vyšetřovatelů možný výskyt hypoxie u pilotů vzhledem k faktu, že se kluzáky pohybovaly ve výškách, kde je potřebné kyslíkové vybavení a nebylo možné určit, jakým způsobem si piloti kyslík do těla dodávali. Piloti také podle pitvy byli před nárazem do země naživu.

4.4. Letecká meteorologie

Meteorologie je jedním z nejdůležitějších leteckých oborů. Pilot musí mít vždy přesný přehled o počasí na trati a v destinaci letu. Z pohledu pilota kluzáku se může jednat o plánování správné tratě s ohledem na nejpravděpodobnější výskyt stoupavých proudů. V rámci studia meteorologie existuje celá řada zajímavých témat, která by na semináři mohla zaznít. Z výsledků rozeslaného dotazníku však vyplynulo, že instruktory nejvíce zajímají bouřky a turbulence.

Bouřka je soubor elektrických, akustických a optických jevů vznikajících mezi oblaky druhu Cumulonimbus (Cb) navzájem, uvnitř nich nebo mezi těmito oblaky a zemským povrchem. Je zdrojem nejnebezpečnějších meteorologických jevů, jako například nárazů větru, silných vzestupných a sestupných proudů, vydatných přeháněk, tornáda, tromby a dalších. Vývoj bouřky prochází třemi stádii, konkrétně kupovitým stádiem, stádiem vrcholného vývoje s vnitrobuněčnou cirkulací a finálním stádiem rozpadu. Bouřky můžeme dělit na několik druhů podle různých kritérií. Podle synoptické situace dělíme bouřky na frontální, uvnitř vzduchové hmoty a bouřky na čáře instability. Podle složení oblaků Cb dělíme bouřky na jednobuněčné, vícebuněčné a supercely.

Existují další doprovodné jevy bouřky, které jsou pro létání vysoce nebezpečné. Mezi tyto řadíme například húlavu, downburst nebo supercelu. Húlava se vytváří na čele studeného vzduchu vytékajícího z bouřky. Je doprovázena silným větrem a velmi silnou turbulencí. Často způsobuje rozsáhlé škody na zemi. Downburst, neboli silný sestupný proud vzduchu, označuje doslova vylití velkého objemu studeného vzduchu z bouřkového mraku, který se v tomto mraku nedokázal jeho vnitřní cirkulací udržet. Downburst dělíme na macroburst a microburst. Posledním zde zmíněným nebezpečným jevem je supercela, která s sebou často přináší tu nejhorší možnou kombinaci všech nebezpečných jevů, které od bouřky očekáváme. Bývá tvořena jednou dominantní buňkou s jedním rotujícím vzestupným proudem a dvěma sestupnými proudy – předním a zadním. Často se u supercely setkáváme se vznikem tromby, tornáda nebo se vznikem velmi velkých krup.

Turbulence je piloty kluzáků pravidelně využívána. Na druhou stranu, stále se jedná o nebezpečný jev, který není dobré podceňovat. Turbulenci dělíme na slabou (do 0,2 g), mírnou (do 0,5 g), silnou (do 1,0 g) a velmi silnou (nad 1,0 g). Z hlediska způsobu vzniku dělíme turbulenci do tří kategorií: mechanickou, termickou a dynamickou. Nejčastěji se však setkáváme s turbulencí složenou, která vzniká kombinací dvou nebo všech tří druhů. Vždy je však jeden druh dominantnější než ostatní. Mechanická turbulence vzniká působením mechanických příčin, na kterých se podílí zejména vertikální střih větru, obtékání překážek, tření o zemský povrch nebo proudění přes velké aglomerační celky. Pro piloty kluzáků je zajímavé vlnové proudění, které vzniká nad rotorem za horskými masivy. Termická turbulence je pro plachtaře nejdůležitější. Je vyvolána konvektivními pohyby vzduchu. Její intenzita se liší podle povrchu, nad kterým letíme, přičemž nejslabší je nad vodními plochami, nejsilnější nad rozmanitým povrchem s ostrým kontrastem. Posledním druhem je dynamická turbulence, vznikající z dynamických příčin působením horizontálních a vertikálních střihů větru v oblasti tryskového proudění nebo atmosférických diskontinuit. Je častá v bezoblačné atmosféře, kde ji označujeme jako CAT neboli Clear Air Turbulence.

4.5. Letecká navigace

V tomto předmětu si instruktoři pro tento konkrétní návrh semináře navolili oblast létání v řízených prostorech. Existuje několik typů řízeného prostoru, například CTR (řízený okrsek kolem letiště) nebo TMA (koncová řízená oblast). Při vstupu do těchto prostorů se musíme nejméně 3 minuty před plánovaným vstupem ohlásit na příslušné frekvenci a ohlásit naši plánovanou činnost a žádost o vstup. Při vstupu do CTR musíme využít přesně stanovené vstupní body, na některých letištích dokonce přesně stanovené příletové trasy. TMA vstupní body nemá a tak ohlásíme místo vstupu do oblasti a plánovanou činnost. V okamžiku schválení vstupu do těchto prostorů se náš let stává řízeným, tedy předmětem letového povolení. To nás jako piloty kluzáku poměrně výrazně limituje, protože není jednoduché přesně naplánovat trasu, neboť se často pohybujeme tzv. od mraku k mraku. V tento okamžik je vhodné zmínit, že je výhodné mít na palubě odpovídač SSR, neboť nás řídící vidí na radaru a nemusí se nás několikrát ptát na naši polohu. Po skončení činnosti v řízeném prostoru musíme požádat o ukončení spojení, případně ohlásíme polohu na výstupním bodě z CTR a řídící nám přiřadí frekvenci, na kterou se máme přeladit. Nikdy nemůžeme frekvenci opustit bez povolení.

5. ZÁVĚR

Tento výzkum slouží jako pomůcka, případně příručka, pro pořádání udržovacího semináře FI(S) v podmínkách DTO. Někteří instruktoři povinnost absolvovat tento seminář kritizují a vidí v tom prakticky ztracený den, který mohli věnovat samotnému létání. V rámci tohoto výzkumu jsem se snažil vytvořit program semináře na základě zpětné vazby od instruktorů tak, aby byl skutečně přínosný a zajímavý. Tento navrhovaný program tak obsahuje jak témata, která požaduje ÚCL, tak témata vybraná samotnými instruktory. Další výzkum v této oblasti se může například věnovat analýze doporučených výcvikových osnov od ÚCL, které můžeme taktéž odprezentovat v rámci semináře. Další možností jak na tento výzkum navázat je provést výzkum s analýzou vlivu kinetózy na lidský organismus díky provedeným pokusům na pilotech. Cílem takového výzkumu by mohlo být upozornění na vliv kinetózy na jedince, doprovázené přímými důkazy o její existenci a následné využití výzkumu na seminářích, případně během výcviku.

REFERENCE

[1] ÚŘAD PRO CIVILNÍ LETECTVÍ, CAA-ZLP-161 Způsobilost pilotů kluzáků – dle nařízení Způsobilost pilotů kluzáků [online]. [cit. 07.12.2021]. Dostupné na internetu: https://www.caa.cz/wp-content/uploads/2021/11/4-161-SPL.pdf?cb=023960792419dc5d27cefd63a605c9c0

[2] EASA, AMC & GM to Part-SFCL – Issue 1 [online]. [cit. 15.12.2021]. Dostupné na internetu: https://www.easa.europa.eu/downloads/111522/en

[3] ÚŘAD PRO CIVILNÍ LETECTVÍ, Poradní materiál ÚCL pro zápis FI(S) do zápisníku letů [online]. [cit. 16.01.2022]. Dostupné na internetu: https://www.caa.cz/wp-content/uploads/2021/05/Poradni-material-UCL-pro-zapis-FI.docx?cb=e3b0a04bc05013a7cb65cb389f0c8871

[4] ÚŘAD PRO CIVILNÍ LETECTVÍ, CAA-VP-142-25 Výuka teoretických znalostí a letový výcvik FI(S) [online]. [cit. 15.01.2022]. Dostupné na internetu: https://www.caa.cz/wp-content/uploads/2021/04/CAA-VP-142-25-Vyuka-teoretickych-znalosti-a-letovy-vycvik-FIS.docx?cb=df8bf6d6ccb55dd0332218482e2b8acd

[5] MELECHOVSKÝ, D. Kapitoly z letecké medicíny, Jako hlupáci [online]. [cit. 02.02.2022]. Dostupné na internetu: https://www.leteckylekar.cz/kapitoly-z-letecke-mediciny/88-jako-hlupaci.html

[6] MELECHOVSKÝ, D. Kapitoly z letecké medicíny, Hypoxie při létání ve velkých výškách [online]. [cit. 08.02.2022]. Dostupné na internetu: https://www.leteckylekar.cz/kapitoly-z-letecke-mediciny/48-hypoxie-letani-ve-velkych-vykach.html

[7] MELECHOVSKÝ, D. Kapitoly z letecké medicíny, Hyperventilace [online]. [cit. 10.02.2022]. Dostupné na internetu: https://www.leteckylekar.cz/kapitoly-z-letecke-mediciny/46-hyperventilace.html

[8] MELECHOVSKÝ, D. Kapitoly z letecké medicíny, Kinetóza – Letadlová nemoc [online]. [cit. 20.02.2022]. Dostupné na internetu: https://www.leteckylekar.cz/kapitoly-z-letecke-mediciny/47-kinetoza-letadlova-nemoc.html

[9] KERUM, J. 2020 Bouřka. In Flying Revue SPECIÁL B Meteo. ISSN 1802-9027, 2020, s. 64-67

[10] KERUM, J. 2020 Doprovodné jevy bouřky a supercelární bouře. In Flying Revue SPECIÁL B Meteo. ISSN 1802-9027, 2020, s. 68-71

[11] KERUM, J. 2020 Turbulence. In Flying Revue SPECIÁL B Meteo. ISSN 1802-9027, 2020, s. 56-59

[12] DVOŘÁK, P. 2017 Letecká meteorologie 2017. Cheb: Svět křídel, 2017. 456 s. ISBN 978-80-7573-014-5

[13] ÚSTAV PRO ZJIŠŤOVÁNÍ PŘÍČIN LETECKÝCH NEHOD, 2021 Závěrečná zpráva o odborném zjišťování příčin letecké nehody kluzáku ASW-19 poznávací značky OK-4481, u obce Ludvíkov ze dne 3.11.2019 [online]. Dostupné na internetu: https://uzpln.cz/pdf/20210112121005.pdf

[14] ÚSTAV PRO ZJIŠŤOVÁNÍ PŘÍČIN LETECKÝCH NEHOD, 2021 Závěrečná zpráva o odborném zjišťování příčin letecké nehody kluzáku SZD-42-2 Jantar 2B poznávací značky SP-1492 na louce u obce Mnichov u Vrbna pod Pradědem ze dne 12. října 2019 [online]. Dostupné na internetu: https://uzpln.cz/pdf/20210427141711.pdf

[15] KLIMANT, R. 2018. Legislatíva a postupy na lety podľa prístrojov: diplomová práce. Žilina: Žilinská univerzita v Žiline, 2018. 167 s.

[16] ŘÍZENÍ LETOVÉHO PROVOZU ČESKÉ REPUBLIKY, VFR příručka – VFR-ENR-2: Pravidla pro lety za viditelnosti [online]. Dostupné na internetu: https://aim.rlp.cz/vfrmanual/actual/enr_2_cz.html

[17] 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.

[18] NOVÁK, A. 2011. Komunikačné, navigačné a sledovacie zariadenia v letectve. Bratislava : DOLIS, 2015. - 212 s. ISBN 978-80-8181-014-5.

[19] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A., JANOVEC, M. 2020. Komunikačné systémy v letectve. 1. vyd. - V Žiline : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 164 s.

[20] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

[21] NOVÁK, A., HAVEL, K., JANOVEC,M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

[22] NOVÁK, A., ŠKULTÉTY, F., KANDERA, B., ŁUSIAK, T. 2018. Measuring and testing area navigation procedures with GNSS. MATEC Web of Conferences 236, 01004

[23] NOVÁK, A., PITOR, J. 2011. Flight inspection of instrument landing system. IEEE Forum on Integrated and Sustainable Transportation Systems, pp. 329-332.

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THE INFLUENCE OF AIR ACCIDENTS ON LEGISLATION IN CIVIL AVIATION IN SLOVAK AND CZECH REPUBLIC

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Abstract

This paper deals with the influence of air accidents on legislation in civil aviation in the Slovak Republic and Czech Republic. Firstly, it focuses on defining essential terms, organizations, laws, and regulations which are affecting air accidents investigation. All these elements are based on the aviation regulation L13 (ANNEX 13). Then it deals with detailed analysis of chosen air accidents that happened in Czech or Slovak Republic. As a result of previous research have been defined categories of the most common causes of air accidents between the year 2016 and 2020 which occurred in Czech and Slovak Republic and created their classification. The main goal of the paper was to identify new legislation measures and changes, which have been propounded or adopted to prevent another air accidents with the same or similar causes in the future. Among those regulations belongs for example area 100 KSA, AUPRT or background checks. Lastly it deals with the upcoming legislation changes affecting civil aviation in Slovak Republic.

Keywords

Air Accidents, Annex 13, Civil Aviation, EASA, ICAO, Air Accident Investigation, Safety

1. INTRODUCTION

The probability of air accidents and incidents increases in proportion to the higher number of aircraft operated and the persons involved in air transport. With the gradual development of aviation technology and systems, it is also necessary to introduce safety measures and regulations, the role of which will be to ensure greater safety in aviation. Firstly, this work focuses on the definition of basic terms, organizations and legislation affecting the investigation of air accidents in the Czech and Slovak Republics. Besides, the paper also analyzes selected air accidents from the year 2016 to the year 2020 in the already mentioned area and to characterize their most common causes based on the analysis of all available final reports published by the Slovak Letecký a námorný vyšetrovací útvar and the Czech Ústav pro odborné zjišťování příčin leteckých nehod. The main objective of this study is to determine the impact of air accidents on legislation in civil aviation. Lastly, the work also focuses on the planned legislative changes in civil aviation in the Slovak Republic.

2. INVESTIGATION OF AIR ACCIDENTS AND INCIDENTS IN THE CZECH REPUBLIC AND SLOVAK REPUBLIC

To conduct research, it is necessary to first define the terms related to the investigation of air accidents and incidents. The key is to determine which event can be defined as an air accident or an incident. An air accident is an occurrence related to the operation of an aircraft defined by a time period which begins with the first person boarding the aircraft for the purpose of the flight and ends when all persons leave the aircraft, in which there has been serious or fatal injury to persons caused by the operation of the aircraft or any contact with it or parts of it, or serious damage to the aircraft, when damaged parts need to be repaired or replaced, or the aircraft is in a completely inaccessible location or is deemed missing [1].

An incident is an event other than an accident in which air safety is threatened or has already been affected. Unlike an air accident, the consequences of an incident do not require early termination of the flight or emergency procedures. Incidents are divided into several categories according to different types of causes. These categories include, for example, technical incidents in air traffic control, security technology, etc. [1].

In order to prevent the occurrence of air accidents and incidents or at least mitigate their consequences, it is necessary to carry out a detailed investigation of all reported events. This investigation is not intended to identify and pursue the culprit but to establish the cause and, if necessary, to issue appropriate safety recommendations. Therefore, he investigation is one of the most crucial elements for ensuring higher air traffic safety. In individual states, the investigation is entrusted to specialized departments, which, according to the applicable laws, regulations, and regulations, conduct investigations of incidents in air transport. In the Czech Republic, Ústav pro odborné zjišťování příčin leteckých nehod is authorized for this purpose, and Letecký a námorný vyšetrovací útvar is responsible for the investigation in the Slovak Republic. Investigation procedures are based on ICAO legislation, regulations, and decisions of the European Parliament and the European Council and from the individual states' laws. In the Czech Republic it is the act N. 49/1997 Sb., o civilním letectví as amended and in the Slovak Republic the act N.143/1998 Z.z. o civilnom letectve (letecký zákon) as amended [2] [3].

The act N. 49/1997 Sb,, o civilním letectví as amended by subsequent regulations, establishes the Ústav pro osborné zjišťování příčin leteckých nehod. ÚZPLN investigates all air accidents and incidents that happened in the Czech Republic. Professional investigators, in cooperation with an employee of the Vojenský ústav soudního lékařství and specialized workplaces conducting expertise in aircraft systems, such as aircraft power units, will issue a final report, which in some cases also contains safety recommendations for certain entities.

In the Slovak Republic, the Letecký a námorný vyšetrovací útvar investigates air transport incidents. The unit has a standing committee and contracted experts involved in the investigation. However, they are not direct employees of the LNVÚ. Compared to the Czech ÚZPLN, its Slovak counterpart does not have a permanent budget. As a result, it needs to obtain approval from the Minister of Transport and Construction of the Slovak Republic for the necessary expertise, the amount of which exceeds 5,000 euros.

The International Civil Aviation Organization (ICAO) issues Annexes that deal with individual areas in civil aviation. Today, there are 19 of these Annexes and in the Czech and Slovak Republics they are named as "L" type aviation regulations and a serial number that is identical to the Annex number. For this work, the most important regulation is L 13, which deals with the area and issue of professional investigation of the causes of air accidents and incidents. The regulation defines all the necessary concepts in this area, the procedure of investigation and prevention to prevent air accidents [1] [4].

Both examined countries are members of the European Union and the European Aviation Safety Agency (EASA), and therefore the legislation issued by the EU and EASA is legally binding on them. The key and most important EU regulation for individual investigative units is Regulation (EU) No 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC (O.J. EU L 295, 12.11.2010) as amended. The Regulation also addresses how evidence and sensitive information are being handled, explains how occurrences are to be reported and what the final investigation report should contain [5].

Another regulation in determining the causes of air accidents is Regulation (EU) No 376/2014 of the European Parliament and of the Council of 3 April 2014 on the reporting, analysis and follow-up of occurrences in civil aviation, amending Regulation (EU) No 996/2010 of the European Parliament and of the Council and repealing Directive 2003/42/EC of the European Parliament and of the Council and Commission Regulations (EC) No 1321/2007 and (EC) No 1330/2007 (O. J. EU L 122, 24.4.2014) as amended, defining which events are to be reported voluntarily and which are mandatory. It also deals with the procedure for reporting, collecting, storing, disseminating and exchanging information related to occurrences in air transport. This Regulation also deals with the European Central Repository, managed by the European Commission, and archives all occurrence reports in the territory of the EASA Member States [6].

3. ANALYSIS OF THE SELECTED AIR ACCIDENT IN THE CZECH REPUBLIC AND IN THE SLOVAK REPUBLIC

The basis for examining the direction of the change in legislation in this area and the reason for the necessary changes are precisely the events or accidents or incidents that have happened and finding a way to prevent them. Therefore, the first thing that was needed was to conduct a comprehensive and detailed analysis of all aircraft and ultralight aircraft accidents in the Czech and Slovak Republics from 2016 to 2020. Three specific accidents were selected to highlight the key moments of the investigation and to bring the entire process closer. One of the causes was human error. Determining the cause is also important for the possibility of proposing safety recommendations or resisting safety assurance. These recommendations are often the basis for a subsequent change in civil aviation legislation.

3.1. Accident of the OK-SAL05 Aircraft

In September 2018, an accident of an ultralight aircraft ASSO 4 WHISKY with the registration number OK-SAL05 took place in the northwestern part of the Czech Republic, near the town of Teplice. The plane was piloted by a man in his seventies with a relatively little experience. According to the conclusions of the forensic and medical expertise, there were no indications that his state of health caused the accident, even though the pilot was regularly treated for health complications, which he did not report to the relevant aviation doctor.

After the expertise of the aircraft power unit, it became clear that someone had carried out an unauthorized service intervention in the reducer. The meteorological situation was favourable at the time of the accident. However, according to the testimony of witnesses, there was relatively strong turbulence in the area of the third turn in the traffic pattern of the area of sport aviation facility Teplice, where the stone quarry is located.

There are several causes of the accident, but the main one is the incorrect technique of piloting the pilot caused due to low experience with the aircraft type. The pilot in flight at an exceptionally low speed in the area of SLZ Teplice got the aircraft into a great bank angle and thus caused reaching the stalling speed and then put the aircraft into a spin. Another factor was the engine failure, which could have been caused by not switching the pumping from the second tank. And thus, the fuel could have been depleted. Note that this is only a hypothesis since the engine expertise did not determine the exact reason for the engine failure [7].

3.2. Accident of the OK-TKF Aircraft

The September 2017 air accident of a six-seat Cessna 421B with the registration number OK-TKF is another event whose one of the causes was human error. This accident took place in the northern part of the Czech Republic and killed two people. The pilot was a 46-year-old man with a total flight time of more than 675 hours, 47 of which were on a Cessna 421B.

The flight was conducted according to the Instrument Flight Rules (IFR) as the meteorological situation did not allow visual flight (VFR). However, this fact was not allowed according to the Certificate of Airworthiness for several reasons. The first was the malfunction of the DME, then the expiration of the oxygen tank and the most important reason was the expired period, after which it was necessary to overhaul the left power unit. That deadline was exceeded by four years.

The immediate cause was the failure of the left power unit in flight, which could have been avoided by meeting the deadlines for overhauls and services. The subsequent expert examination discovered that the right engine was not working at the time of the impact of the aircraft with the ground, even the right engine was not working. According to conjecture, the pilot deliberately turned off the engine to stabilize and gain control over the machine since the aircraft was difficult to pilot during single-pilot operation with a malfunctioning engine, according to the testimony of witnesses. However, this version cannot be verified.

In connection with the accident, ÚZPLN issued a safety recommendation to the Civil Aviation Authority, according to which it should approve the Airworthiness Review Certificate in compliance with compliance with the limits of aircraft components and their systems prescribed by the manufacturer [8].

3.3. Accident of the OM-JLP Aircraft

The last accident in which detailed analysis was carried out in this work is the accident in March 2017 of the L-29 Delfin aircraft with the registration number OM-JLP. The accident took place at Sliač Airport (LZSL) in the Slovak Republic.

The pilot was a 49-year-old man with a total flight time of more than 861 hours. However, there was another person on board whose purpose is unknown. Its presence has disrupted the company's operating directive, which does not allow a person other than the flight instructor or examiner during the practice of emergency procedures onboard.

The accident took place on runway 36 when the pilot retracted the landing gear during a touch and go using the landing gear control lever. After retracting the landing gear, the aircraft sank at a height and hit the runway surface with its fuselage. According to the flight manual, the pilot reacted correctly and turned off the engine.

The primary cause of the event was improper piloting technique when the pilot did not consider the possibility of the aircraft sinking.

In connection with the air accident, the LNVÚ issued a recommendation to ensure safety for the Transport Authority of the Slovak Republic. According to the recommendation, the Authority should reconsider the conditions for conducting aerial work and tighten the restrictions for the presence of a second person on board [9].

4. CATEGORIZATION OF CAUSES OF AIR ACCIDENTS AND THEIR CHARACTERISTICS

In the characterization of the most frequent causes of air accidents in the Czech and Slovak Republics from 1 January 2016 to 31 December 2020, all aircraft and ultralight aircraft accidents, published on the official websites of the LNVÚ and ÚZPLN, were examined. Subsequently, they were analyzed in detail month by month, focusing mainly on their causes and the number of injured persons. Based on the research, the causes were divided into five categories:

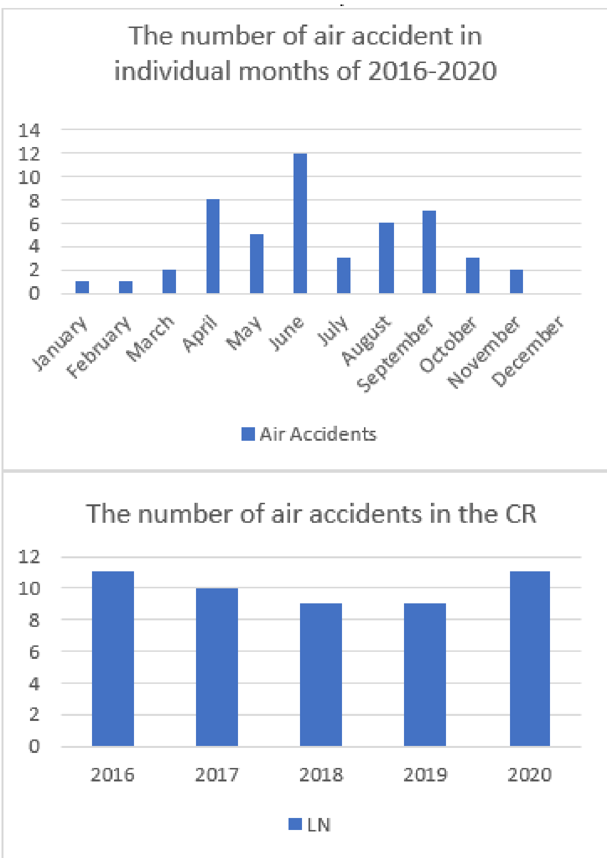
1. incorrect piloting technique,
2. non-compliance with procedures,
3. adverse meteorological phenomena,
4. technical fault,
5. imperfect pre-flight preparation and inspection of the aircraft.

4.1. Czech Republic

Approximately ten accidents were registered annually in the Czech Republic. A total of fifty of those accidents were examined during the period under review, which included twelve ultralight aircraft and forty-two other aircraft. Most accidents statistically took place in June and December. On the other hand, no event classified as a plane crash has been recorded.

The most common cause of air accidents was the incorrect piloting technique in the investigation reports. A total of twenty-eight accidents occurred due to this cause. The lowest number of accidents was caused by inconsistent aircraft inspection, precisely four.

A total of fifteen crew members and four passengers died due to air accidents during the entire period under review. The most deaths were in 2016, and the least in 2020.



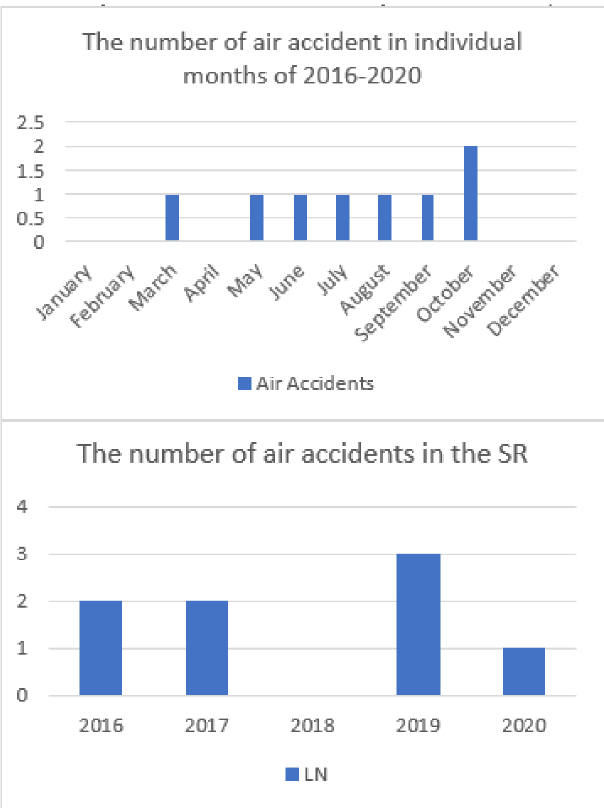
Graph 1: Number of air accidents in individual months and years in the Czech Republic.

4.2. Slovak Republic

In terms of the number of accidents in the analyzed period, the Slovak Republic is significantly better off. In sum, eight air accidents of eight aircraft took place in this area. In the context of the number of accidents, the worst month was November with two accidents. The most events classified as air accidents were in 2019, three to be precise. On the other hand, no aircraft accident was reported in 2018.

Incorrect piloting technology was, as in the Czech Republic, the most common cause of air accidents. It was one of the causes of five events. On the other hand, no accident was reported to have one of its causes incorrect pre-flight inspection or technical defect of any of the parts of the aircraft.

During the entire period, one person died from injuries after a plane crash. No other person was injured.



Graph 2: Number of air accidents in individual months and years in the Slovak Republic.

5. THE INFLUENCE OF AIR ACCIDENTS ON LEGISLATION IN CIVIL AVIATION IN SR AND CR

Due to the relatively low number of air accidents in the Czech and Slovak Republics in the period from 2016 to 2020, none of the air accidents had a direct impact on the legislative developments in the respective states, hence the research focused on the wider area of international civil aviation legislation concerning that these partial statistics from the Slovak Republic and the Czech Republic are also sent annually to the International Civil Aviation Organization (ICAO), which subsequently publishes a worldwide comprehensive report, the result of which, in the case of recurrent causes, is a subsequent change in legislation, e.g. in pilot training or even directly in operation. An example is Germanwings flight 9525 from March 2015. At that time, an A320-211 registered under D-AIPX crashed into the French Alps. All 144 people on board died because of the accident. The cause was the poor mental state of the co-pilot caused due to personal problems. He took the opportunity to be alone in the cockpit, locked himself and deliberately guided the aircraft to the ground. [10].

This unfortunate event can be regarded as crucial to establishing a new mandatory curriculum in the training of commercial and airline pilots called 100 KSA ("Knowledge, Skills and Attitudes").

Due to the high number of accidents caused by improper piloting technology, the work also focuses on the implementation of the AUPRT component in the training of airline and commercial pilots.

The pilots' unreliability can be the instigator of air accidents caused due to human error. Thus, the study also deals with the issue of reliability verification, done by the Civil Aviation Authority in the Czech Republic and the Transport Authority in the Slovak Republic.

5.1. 100 KSA

All pilots who commenced training after 31.1.2022 in approved ATO training organisations to obtain an airline or commercial pilot license and those who will take the exams in one of the EASA Member States shall have completed Area 100 KSA. It focuses on the evaluation of a student's skills, knowledge, and attitudes, whether technical or non-technical. Non-technical ones include, for example, the ability to self-reflect and general awareness of the situation in the cockpit and beyond. The implementation of the new training component must be conducted following the published syllabus. It defines the areas and topics that training facilities need to concentrate on. The assessment of students is organised through written and practical exercises, oral exams, projects, communication exercises or presentations. In the final report, there are weaknesses but also strengths of the student [11] [12].

5.2. AUPRT

Advanced upset prevention and recovery training (AUPRT) Is mandatory for all transport and business pilots who started training after December 20, 2019. This training consists of two parts. The first is theoretical preparation lasting at least five hours, in which the student is familiar with the instructions for the flight and subsequently with the analysis after the flight. The second part is practical and takes at least three flight hours. The content of this phase is a course of coping with deep pulling and pulling, preventing a fall during flight at stall speed, coping with spin, fall and spiral flight. In addition, the pilot should be familiar with the procedures for recognizing an upset and getting out of it adequately. This process is particularly relevant for flights in conditions requiring instrument flying (IMC where the pilot cannot rely on inspecting the state of the aircraft with the surrounding environment and is dependent only on aircraft instruments in the cockpit.

A graduate of this training does not go through any examination process but will receive a certificate of completion of the AUPRT course with unlimited validity [13] [14] [15] [16].

5.3. Background checks

In order to be authorized to enter airport security restricted areas, the person must have successfully completed the background check process. In this process, the national transport authorities are engaged in determining whether the person under consideration is convicted of crimes or certain offences. It also identifies its links to extremist or terrorist organizations that could endanger the safety of air traffic. Among the offenses for which a person might not obtain a certificate of verification of reliability are also offenses outside the field of air transport. For this reason, obtaining reliability for some individuals is quite complicated. In the Slovak Republic, the proof of reliability is valid for five years in the Czech Republic only three years. In addition to an extract from the criminal record, in some cases, the assessment of whether an individual is reliable or not is also served by checks carried out by the police at the place of residence of the examined person or extracts from other state authorities. [17] [18].

6. PROPOSAL FOR LEGISLATIVE CHANGES AND MEASURES

The necessity to update civil aviation regulations and laws is required worldwide. This requirement is mainly due to the increasing number of air passengers transported, as well as innovation in technology and training opportunities. The Slovak Republic is no exception. The current Civil Aviation Act has been in force here since 1998. A group of experts authorized by the Ministry of Transport and Construction of the Slovak Republic is currently working on a new version of the Law. The bill envisages modifications in the area of unmanned aircraft, aircraft register, protection of civil aviation against acts of unlawful conduct, and the performance of state supervision or investigation of aviation incidents [19].

From the point of view of this research, it was essential to focus primarily on the paragraph devoted to verifying the reliability of persons entering the restricted security areas of airports. Under the new proposal, the requirements for determining whether the person under assessment is of good repute and reliability should be changed. In the working group, there are different opinions on some points among representatives of individual areas of civil aviation, whether state administration or, for example, the pilots' association. However, the workgroup primarily aims to find a compromise that meets all European standards and requirements in the field and the context of the research carried out above, but at the same time does not cause something like "increased stress" in the normal personal lives of individuals working in civil aviation since they would lose their jobs due to offences that have no connection with the threat to air safety [19].

7. CONLUSION

One of this research's objectives was to examine the issue of aviation accident investigation and its impact on the emergence of new legislative elements in the Czech and Slovak Republics. Aviation accidents that occurred in this territory from 2016 to 2020 did not directly affect the creation of the new legislation, so it was necessary to expand the subject of research to a global level, where the impact of accidents on the change in legislation was confirmed. As the number of passengers carried is constantly increasing, it is undoubtedly necessary to ensure the safety of all persons involved in air transport. For this reason, the importance of a high-quality and professional investigation of air events is obvious. Specialized investigation institutions should be as independent as possible so that a high-quality investigation can be conducted as well as a safety recommendation. However, the topic of independence is debatable because the form of financing cannot be completely independent. Whether ÚZPLN or LNVÚ are in a way dependent on the government of the states under which they fall.

Legislative measures do not always satisfy the expectations of every civil aviation participant, including pilots, flight schools or airlines, as some changes cost them certain expenses and administrative complications, such as the expansion of training activities, which are necessary for maintaining civil aviation safety.

The investigation itself is a long-term process involving several complex and costly procedures. Therefore, cooperation between the individual EASA Member States, or ICAO or entities that can bring valuable experience to the investigation, is a crucial advantage. For example, the European Network for Civil Aviation Investigations (ENCASIA) is also used to exchange experience and cooperate in investigations.

Another purpose of the research was to highlight the dynamism of the aviation industry in the constant effort to ensure higher safety through the introduction of new procedures, regulations, or other measures.

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REFERENCES

[1] Letecký předpis L 13, Ministerstva dopravy ČR, Letecký předpis o odborném zjišťování příčin leteckých nehod a incidentů

[2] Ústav pro odborné zjišťování příčin leteckých nehod (ÚZPLN), Předpisy a dokumenty [online]. [cit. 25.4.2022] Available from: https://uzpln.cz/predpisy

[3] Ministerstvo dopravy a výstavy Slovenskej republiky, Letecký a námorný vyšetrovací útvar, Legislativa v civilnom letectve [online]. [cit. 25.4.2022]. Available from: https://www.mindop.sk/ministerstvo-1/doprava-3/letecky-a-namorny-vysetrovaci-utvar/legislativa-v-civilnom-letectve

[4] Ministerstvo dopravy a výstavby Slovenskej republiky, L 13 Bezpečnostné vyšetrovanie udalostí v civilnom letectve [online]. [cit. 25.4.2022]. Available from: https://www.mindop.sk/ministerstvo-1/doprava-3/civilne-letectvo/legislativa-v-oblasti-civilneho-letectva/pravne-predpisy-slovenskej-republiky-v-oblasti-civilneho-letectva/letecke-predpisy/vydane-letecke-predpisy-radu-l/l-13-bezpecnostne-vysetrovanie-udalosti-v-civilnom-letectve

[5] NAŘÍZENÍ EVROPSKÉHO PARLAMENTU A RADY (EU) č. 996/2010 ze dne 20. října 2010 o šetření a prevenci nehod a incidentů v civilním letectví a o zrušení směrnice 94/56/ES [online]. [cit. 25.4.2022]. Available from: https://uzpln.cz/upload/prepisy/nar_994_2010_CS.pdf

[6] NAŘÍZENÍ EVROPSKÉHO PARLAMENTU A RADY (EU) č. 376/2014 ze dne 3. dubna 2014 o hlášení událostí v civilním letectví, analýze těchto hlášení a navazujících opatřeních a o změně nařízení Evropského parlamentu a Rady (EU) č. 996/2010 a zrušení směrnic Evropského parlamentu a Rady 2003/42/ES, nařízení Komise (ES) č. 1321/2007 a nařízení Komise (ES) č. 1330/2007 [online]. [cit. 25.4.2022]. Available from: https://eur-lex.europa.eu/legal-content/CS/TXT/?uri=uriserv:OJ.L_.2014.122.01.0018.01.CES

[7] Ústav pro odborné zjišťování příčin leteckých nehod (ÚZPLN), ZÁVĚREČNÁ ZPRÁVA o odborném zjišťování příčin letecké nehody UL letounu ASSO 4 WHISKY poznávací značky OK-SAL 05 1,3 km severně obce Zábrušany, okr. Teplice ze dne 8. září 2018, CZ-18-0883, [online]. [cit. 25.4.2022]. Available from: https://uzpln.cz/pdf/20210125123147.pdf

[8] Ústav pro odborné zjišťování příčin leteckých nehod (ÚZPLN), ZÁVĚREČNÁ ZPRÁVA o odborném zjišťování příčin letecké nehody letounu Cessna 421B, pozn. značky OK-TKF, dne 26.9.2017 cca 1,5 km NE Noviny pod Ralskem, CZ-17-0932, [online]. [cit. 25.4.2022]. Available from: https://uzpln.cz/pdf/20190212152305.pdf

[9] LETECKÝ A NÁMORNÝ VYŠETROVACÍ ÚTVAR, Závěrečná správa o bezpečnostnom vyšetrovaní leteckej nehody lietadla typu L-29 Delfín poznávacej značky OM-JLP, Ev.č.: SKA2017002 [online]. [cit. 25.4.2022]. Available from: https://www.mindop.sk/ministerstvo-1/doprava-3/letecky-a-namorny-vysetrovaci-utvar/zaverecne-spravy/rok-2017/2017-zaverecne-spravy/ska2017002-27-03-2017-om-jlp

[10] BEA, Accident to the Airbus A320-211, registered D-AIPX and operated by Germanwings, flight GWI18G, on 03/24/15 at Prads-Haute-Bléone [online]. [cit25.4.2022]. Available from: https://bea.aero/en/investigation-reports/notified-events/detail/accident-to-the-airbus-a320-211-registered-d-aipx-and-operated-by-germanwings-flight-gwi18g-on-03-24-15-at-prads-haute-bleone

[11] Executive Director Decision, 2018/001/R of 6 February 2018 amending the Acceptable Means of Compliance and Guidance Material to Part-FCL and Part-ORA of Commission Regulation (EU) No 1178/2011, as amended, as regards the theoretical knowledge syllabi and learning objectives for airline transport pilot licence (ATPL), multi-crew pilot licence (MPL), commercial pilot licence (CPL), and instrument rating (IR) for aeroplanes (A) and helicopters (H) 'AMC/GM to Part-FCL — Amendment 4 AMC/GM to Part-ORA — Amendment 5' [online]. [cit. 25.4.2022]. Available from: https://www.easa.europa.eu/downloads/45281/en

[12] Úřad pro civilní letectví, Schválené organizace pro výcvik pilotů (ATO) CAA-ZLP-141, [online]. [cit. 25.4.2022]. Available from: https://www.caa.cz/wp-content/uploads/2021/01/CAA-ZLP-141-Schvalene-organizace-pro-vycvik-pilotu-ATO.pdf

[13] PROVÁDĚCÍ NAŘÍZENÍ KOMISE (EU) 2018/1974 ze dne 14. prosince 2018, kterým se mění nařízení (EU) č. 1178/2011, kterým se stanoví technické požadavky a správní postupy týkající se posádek v civilním letectví podle nařízení Evropského parlamentu a Rady (EU) 2018/1139, [online]. [cit. 25.4.2022]. Available from: https://eur-lex.europa.eu/legal-content/CS/TXT/PDF/?uri=CELEX:32018R1974&from=CS

[14] EASA, Frequently Asked Questions, Upset Prevention and Recovery Training, [online]. [cit25.4.2022]. Available from: https://www.easa.europa.eu/the-agency/faqs/upset-prevention-and-recovery-training

[15] EASA, Executive Director Decision 2020/013/R of 18 August 2020 issuing an amendment to ED Decision 2019/025/R amending ED Decision 2018/006/R of 3 May 2018 issuing the Certification Specifications for Aeroplane Flight Simulation Training Devices, as well as amending ED Decisions 2014/017/R of 24 April 2014 and 2019/005/R of 27 February 2019 on the Acceptable Means of Compliance and Guidance Material to Annex III (Part-ORO) to Commission Regulation (EU) No 965/2012, [online]. [cit. 25.4.2022]. Available from: https://www.easa.europa.eu/downloads/117147/en

[16] Úřad pro civilní letectví, Sekce letová a provozní, Odbor způsobilosti leteckého personálu, Výcvik týkající se prevence ztráty kontroly nad řízením a obnovování kontroly nad řízením (UPRT), [online]. [cit. 25.4.2022]. Available from: https://www.caa.cz/wp-content/uploads/2019/12/UPRT.pdf?cb=b889a9893197f08064330a4f094e4d85

[17] Zákon 143/1998 Z. z., o civilnom letectve (letecký zákon) a o zmene a doplnení niektorých zákonov [online]. [cit. 25.4.2022] Available from: https://www.epi.sk/print/zz/1998-143.pdf

[18] Dopravný úrad, Bezpečnostná ochrana civilného letectva, Previerka osoby – posúdenie spoľahlivosti, [online]. [cit. 25.4.2022]. Available from: http://letectvo.nsat.sk/bezpecnostna-ochrana-civilneho-letectva/posudenie-spolahlivosti/

[19] Pracovní návrh nového zákona o civilnom letectve, Pracovní skupina pro letectví pověřená Ministerstvem dopravy a výstavby Slovenskej republiky, [cit.25.4.2022]

[20] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

[21] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A., JANOVEC, M. 2020. Komunikačné systémy v letectve. 1. vyd. - V Žiline : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 164 s.

[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] 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.

[24] NOVÁK, A., HAVEL, K., JANOVEC,M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

[25] NOVÁK, A., ŠKULTÉTY, F., KANDERA, B., ŁUSIAK, T. 2018. Measuring and testing area navigation procedures with GNSS. MATEC Web of Conferences 236, 01004

[26] NOVÁK, A., PITOR, J. 2011. Flight inspection of instrument landing system. IEEE Forum on Integrated and Sustainable Transportation Systems, pp. 329-332.

[27] SEDLÁČKOVÁ, A.N., KAZDA, A., NOVÁK, A. 2022. Implementation of Knowledge Alliance in Air Transport into Educational System of Slovak Republic. Transportation Research Procedia, 2022, 59, pp. 260–270. ISSN 23521457.

[28] ŠKULTÉTY, F., JAROŠOVÁ, M., ROSTÁŠ, J. 2022. Dangerous weather phenomena and their effect on en-route flight delays in Europe. Transportation Research Procedia, 2022, 59, pp. 174–182. ISSN 23521457.

[29] NOVAK, A., SKULTETY, F., BUGAJ, M., JUN, F. 2019. Safety studies on gnss instrument approach at Žilina airport. MOSATT 2019 - Modern Safety Technologies in Transportation International Scientific Conference, Proceedings, 2019, pp. 122–125, 8944098.

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INFLUENCE OF METEOROLOGICAL CONDITIONS ON AIRCRAFT TAKE - OFF AND LANDING

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Abstract

The division of meteorology is an integral part of aviation that informs about meteorological phenomena and defines their nature. This article focuses on the types of meteorological conditions with which the aircraft comes into contact during the flight, with a closer focus on the take-off and landing phases of the aircraft. The topic of meteorological conditions and their effects was chosen due to the enormous importance of this segment of aviation for the safety and operation of air traffic. The paper has a theoretical character and approaches the connection between individual meteorological conditions and their effect on the behavior of the aircraft. For air safety, a proper interpretation and subsequent adaptation to the corresponding weather events and deviations from standard conditions is essential. The aim of the publication is to define the basic meteorological conditions, weather phenomena and to underline their considerable importance for air traffic. The final part is devoted to the analysis of air accidents during takeoff and landing, which were caused by adverse weather conditions and their underestimation.

Keywords

Flight phases, Take - off, Landing, Meteorological conditions, Operational procedures

1. INTRODUCTION

Meteorological conditions and related phenomena characterise the constantly changing state of the atmosphere. Based on the information provided about the current nature of the Earth's gaseous envelope and the more detailed knowledge associated with the occurrence of given weather phenomena, people can adapt their behaviour to the current conditions. It is of paramount importance for aviation to correctly record, evaluate and adapt its operations to the current meteorological conditions in order to maintain the continuity, safety and efficiency of flight operations.

The introductory part of the article deals with an introduction to the specific phases of flight: take-off and landing, which belong to the most demanding. The topic then moves smoothly to its meteorological part, with a definition of the Earth's atmosphere, specific meteorological conditions, their effects, and the ways in which information about the discussed meteorological conditions are provided.

The aim of the paper is to present the nature of the influence of basic meteorological conditions and to provide a comprehensive summary of information on the subject. Proof of the importance of the subject under discussion, highlight the accidents caused by the occurrence of adverse weather conditions during takeoff and landing.

2. FLIGHT MECHANICS

Flight mechanics is a scientific discipline dealing with the motion of aircraft, its laws and the causes of their motion. Aerodynamics together with flight mechanics define the fundamentals of flight - the theoretical principles and laws of flight. Classical flight mechanics deals with the basic summary of the problems of this discipline, flight characteristics and flight performance. According to performance, the flight of an aircraft is divided into 6 phases: take-off, climb, cruise, descent, approach and landing. Among the important observed performance values during takeoff and landing, the length of the takeoff and landing are particularly important [4] [6].

Take-off is a complex aircraft maneuver during which the aircraft is set in motion on the runway, accelerates and ends when it reaches a given altitude over a fictitious obstacle. It is divided into a ground part (ground roll) and an aerial part (rotation, transition, climb out) [4] [6].

Landing is the last phase of flight, which starts when the altitude at which the takeoff phase ends is reached, namely the minimum altitude above the fictitious obstacle. During landing, the aircraft gradually slows down in speed during both the airborne and ground parts. The aerial part consists of glideslope phase, flare out phase, touchdown and the ground part consists of after landing roll [4] [6].

3. EARTH'S ATMOSPHERE

The Earth's atmosphere forms a gaseous envelope around the entire surface of the Earth. It is characterized by its vertical stratification, as its medium, compressible air, is affected by the Earth's gravity. The individual layers of the atmosphere are thus compressed by the layers above them, concentrating about half of their mass to a height of 5.5 km. The height of the upper atmospheric boundary varies depending on the point of view under consideration. From an aeronautical point of view, the height at which the lift required for aircraft flight can still be generated is important. The composition of atmospheric air consists of three main components: clean dry air (99% oxygen-nitrogen mixture), water in all its states and atmospheric aerosol (gaseous and solid impurities). An important component of the atmosphere is ozone, which is most concentrated at an altitude of 25 to 30 km [1] [2] [5].

The basic division of the atmosphere is according to the vertical air temperature profile into the troposphere, stratosphere, mesosphere, thermosphere, and exosphere, which transitions smoothly into interplanetary space. In between the base layers there are transitional layers which are referred to as tropopause, stratopause, mesopause and thermopause [2] [5]. According to S. Krollová, other aspects of atmospheric partitioning include the division "according to chemical composition into homosphere and heterosphere, according to the concentration of atmospheric ions and free electrons into neutrosphere, ionosphere and magnetosphere, and according to the interaction with the Earth's surface into the boundary layer and free atmosphere," [2].

3.1. International Standard Atmosphere (ISA)

The International Standard Atmosphere is an ideal model of the Earth's atmosphere, which is not affected by any dynamic factors, and therefore the actual value of the air parameters almost always differs from the model values. Specified in 1952 by ICAO, the ISA defines air as a homogeneous ideal gas whose parameters at sea level are: air pressure 1013.25 hPa, air density 1.225 kg.m-3 and air temperature 15 °C. The vertical temperature gradient is 6.5 °C per kilometre [1].

4. METEOROLOGICAL CONDITIONS

4.1. Temperature

The temperature value indicates the thermal state of the atmosphere, and according to S. Kroll, temperature in physical terms expresses "the energy and thermal state of a body or environment, which is proportional to the mean kinetic energy of the molecules moving in it," [2]. The primary source of thermal energy acting on meteorological processes is the Sun. Air temperature varies due to several factors, these are divided into periodic (diurnal and annual course) and aperiodic (geographical distribution and horizontal movement of air masses) [2] [7].

The movement of air particles along the vertical line is accompanied by a change in temperature due to the conversion of internal energy into work or vice versa. The vertical temperature gradient expresses the change in air temperature with increasing height, with the ratio difference of the temperature to the height (mostly per 100 m) [2].

4.2. Density

Air density is an important meteorological parameter, expressing the ratio of the mass of air to its corresponding volume. It influences aerodynamic and aerostatic forces, but also the performance of aircraft, their propulsion units, etc. The effect of air compressibility is reflected in the variation of the density value with increasing altitude. It has a decreasing character similar to the parameters of temperature and atmospheric pressure. However, the curve of the decrease in the value of air density is logarithmic, as is the nature of the decrease in atmospheric pressure. The decrease of temperature with increasing altitude in the ISA troposphere has a linear character [1] [2].

4.3. Pressure

Air pressure is a scalar quantity that describes the amount of force applied per area unit. Depending on the motion of the air mass, pressure is divided into static and dynamic. The action of static pressure is uniform in all directions, under the condition of a resting air mass. If the air mass is moving, the pressure is applied to the area opposite to the direction of flow. In this case it is dynamic pressure. Atmospheric pressure, also referred to as barometric pressure, is a static pressure used in meteorology. The spatial distribution of atmospheric pressure is characterized by the pressure (bar) field. [1] [2].

The state of the atmosphere and the current values of air pressure, density and temperature affect the take-off speed, landing speed, take-off and run-up length. For aircraft with turbine powerplants, a 10 °C increase in temperature increases take-off length by up to 13%. A reverse decrease of 10% in temperature reduces the required take-off length by approximately 10%. With increasing altitude, the required take-off length also increases in connection with decreasing pressure and density value. When comparing the take-off length at an airport at sea level with an airport at an altitude of 1000 m above sea level, this value increases by up to 33% [3] [5].

4.4. Atmospheric flow

In the atmosphere, there are constant movements of air particles, both horizontally and vertically. Both components of the flow are the result of different applied forces. The horizontal component of the flow in the atmosphere is referred to as wind and is a vector quantity whose main parameters are its direction and velocity. These have a significant impact on air traffic, especially in terms of the use of a particular runway [1] [2] [7].

Turbulent airflow is characterized by the disordered movement of air particles in space and time. In contrast to laminar flow, during which the streamlines are parallel and smooth, turbulent flow produces vortices with different sizes, lifetimes, streamline orientations and variable velocities. Thus, when flying in turbulent conditions, it is possible that the aerodynamic forces acting on the aircraft are violated, with the consequence of changes in the aircraft altitude and a decrease in its controllability [1] [3] [5] [7].

4.5. Humidity

Humidity is a meteorological parameter that defines the proportion of water vapor in the air. The process of evaporation saturates the air, and once a certain level is reached, condensation, cloud formation and precipitation occur, returning some of the water back on the earth's surface. The cloudiness, otherwise known as clouds, are formed by clumps of water droplets, ice crystals, or both components at the same time. Atmospheric precipitation is the phenomenon of water in its various states falling to the Earth's surface. From an aviation point of view, precipitation has a significant impact, reducing visibility, polluting the runway, affecting the indication of aircraft instruments and under certain conditions, contributing significantly to the formation of icing. [1] [2] [7].

4.6. Visibility degrading phenomena

In the ground layer of the atmosphere, visibility is affected by dry particles and liquid particles, resulting in observable phenomena such as haze, mist and fog. In the free atmosphere, the visibility level is mainly influenced by the water content associated with cloud formation. The important parameters in this case are the height of the cloud base, its type, amount and density. Last but not least, it is necessary to mention the effects of volcanic activity [1] [5] [6].

4.7. Dangerous phenomena

The parameter values of all meteorological phenomena vary depending on location and time. The level of danger they represent, especially to air traffic, also varies. In particular, extreme values - temperature (both positive and negative), density, pressure, humidity and associated wind, cloud cover, precipitation, visibility - are a major problem. Special attention must be paid to phenomena such as thunderstorms, icing, gales, tornadoes and hurricanes.

Storm activity represents one of the most dangerous meteorological phenomena and is a significant threat to aviation, mainly due to the frequent occurrence of other accompanying meteorological phenomena: precipitation and high wind speeds, wind shear, icing and turbulence [1] [7].

Icing is a meteorological phenomenon in which water freezes on surfaces with a temperature of less than 0 °C. Icing forms when supercooled water droplets are in contact with each other, but also when surfaces come into contact with water vapor molecules. The atmospheric temperature that is most ideal for icing is between 0 and -12 °C. Small water droplets, unlike large droplets, freeze immediately upon contact with a supercooled surface. Large drops first spread on the surface and form a thinner film, which freezes afterwards [1] [7].

5. SOURCES OF METEOROLOGICAL INFORMATION

Meteorological observations provide information about the state of the atmosphere. These include measurements and qualitative assessments of meteorological elements. In order for the information to be comprehensive and comparable between different parts of the world, meteorological observations must be global in its character. The World Meteorological Organization (WMO) provides a complex form of observations within the meteorological service [2] [7].

5.1. METAR

The METAR (Meteorological Aerodrome Report) is one of the basic types of reports that provide information about the current weather conditions at the airport. It is issued at hourly or half-hourly intervals. In the event of an emergency, an emergency SPECI report is issued and is in the same format as a METAR report. The METAR is divided into several parts, describing the current state of meteorological elements and phenomena at the airport. Its form is not fixed, some parts may be omitted or modified if the phenomenon is not present in the airport area. [1] [5].

5.2. TAF

Terminal aerodrome forecast, TAF, is an airport forecast of selected meteorological elements. In Slovakia, it is being prepared for airports with controlled air traffic - Bratislava, Košice, Poprad, Piešťany, Žilina and Sliač. The frequency of the TAF forecast is either every 6 hours with a validity of 24 hours or every 3 hours with a validity of 9 hours [1] [12].

5.3. Take-off forecast

A special forecast issued at airports is the take-off forecast. The formulation of the forecast shall be determined by the air service provider and the user. They are issued hourly and contain data on wind direction, wind speed, air temperature and QNH pressure. The information from the take-off forecast is not only for the use of the flight crews, but it also derives the use of a specific runway and its direction [1].

6. ANALYSIS OF WEATHER AND ITS IMPACT ON THE SELECTED FLIGHT

Stockholm Arlanda Airport		→	Faro Airport
Date:	7. 4. 2022	*Duration of flight:*	4 hours 30 minutes
ETD:	15 UTC	*ETA:*	19:30 UTC

The ground pressure field map shows the distribution of pressure systems in Europe on the date of the planned flight. The airport from which the aircraft will take off towards Faro is Stockholm Arlanda Airport. The pressure formation influencing the nature of the meteorological phenomena at the take-off destination is the warm front of the low-pressure system Nasim centered over the North Sea with a minimum atmospheric pressure of 970 hPa. The low-pressure system Nasim is in a late stage of development due to the occurrence of an occluded front. The occluded front is the result of the merging of a warm front and a cold front as a result of the different speeds of the two fronts (the warm front is slower than the cold front).

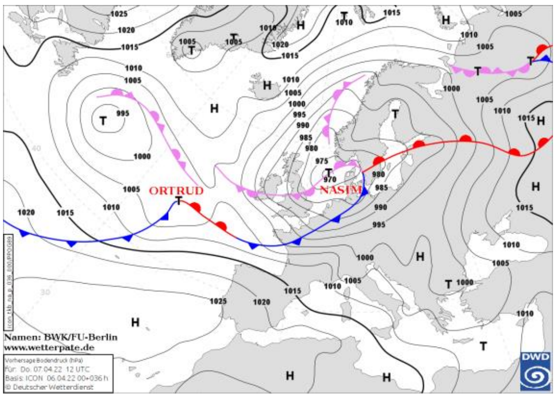

Figure 1: Surface pressure field map, date: 7.4. 2022. [http://www.met.fu-berlin.de/de/wetter/maps/emtbkna.gif]

Stockholm Arlanda Airport

METAR ESSA 071450Z 07014KT 5000 -SNRA BKN006 01/M00 Q0980 TEMPO 2000 -SN BKN012

Decoded report: 7th day of the month, 14:50 UTC, wind direction from 70°, wind speed 14 knots, visibility 5 km, light mixed precipitation, snow prevailing over rain, cloudiness BROKEN (5-7/8) at 600 ft above airport level, air temperature 1 °C, dew point temperature 0 °C, QNH at 980 hPa, temporary change in meteorological conditions within 2 hours, visibility 2 km, light snowfall, cloudiness BROKEN (5-7/8) at 1200 ft above airport level.

Faro Airport

METAR LPFR 071930Z VRB02KT CAVOK 16/13 Q1023

Decoded report: 7th day of the month, 19:30 UTC, variable wind direction, wind speed 2 knots, visibility more than 10 km, no significant clouds for air traffic, air temperature 16 °C, dew point temperature 13 °C, QNH at 1023 hPa.

The contrast in meteorological phenomena between destinations is significant and applies to all weather conditions. In addition to the differences in temperature and air density caused, among other things, by their different geographical locations, the two airports are affected by different pressure systems. In the Swedish capital, icing is possible as a result of low temperatures and precipitation. If not necessarily at the airport, then at least shortly after take-off, when the air temperature is below freezing point. There are three runways at Arlanda with designations 01L/19R, 01R/19L and 08/26. Due to the wind direction and runway orientations, runway 08 is the best choice for the flight. The wind would be head wind with a 10° deviation. In case of usage of other runway, it would be cross wind. At Faro airport, the use of runway 10/28 direction does not really matter in relation to the wind, as the wind direction is variable. In addition to temperature, density and air pressure, the length of take-off at Arlanda may be affected by runway pollution due to rainfall during the day.

7. TAKE-OFF AND LANDING ACCIDENTS CAUSED BY METEOROLOGICAL CONDITIONS

7.1. Delta Air Lines flight 191

Delta Airlines Flight 191 took place on August 2nd, 1985, and was part of a scheduled flight from Fort Lauderdale, Florida, to Los Angeles with a stopover at Dallas/Fort Worth International Airport. The operating aircraft was a Lockheed L-1011-385-1 TriStar [13].

In the early stages of the flight, adverse weather conditions were not encountered, but this changed as the aircraft overflew the area over the city of New Orleans. Scattered showers and thunderstorms were predicted at the arrival destination. Similarly, isolated thunderstorms were reported occurring over north and northeast parts of Texas and over the Oklahoma. On approach to the Forth Worth airport, the captain requested a storm go-around, which the controller agreed to. Subsequently, the controller asked the crew to reduce speed repeatedly to maintain separation between aircraft during the approach to land. As the descent began, the first officer observed lightning in the clouds ahead of the aircraft and the predicted precipitation were also occurring. Approximately 2 km from Forth Worth Airport, the aircraft subsequently impacted the ground after passing through a microburst, a downdraft of cold air beneath the thunderstorm clouds [13].

The National Transportation Safety Board (NTSB), after investigating the accident, listed the cause of the accident as the failure of the crew, who decided to land despite the occurrence of thunderstorms in the area of the airport. This failure was also attributed to insufficient procedures, guidance and training in the similar weather conditions. The provision of information on the strong wind shear associated with the occurrence of a microburst was also identified as inadequate [13].

7.2. Anchorage Airport collision

December 23rd, 1983, was marked by the crash of 2 planes at Anchorage International Airport. The first involved was a Korean Air Lines McDonnell Douglas DC-10-30 cargo plane. It was part of scheduled flight 084 from Anchorage to Los Angeles. At 14:06 YST, it struck a SouthCentral Air Piper PA-31-350 on runway 6L/24R while attempting takeoff.[14]

Adverse weather conditions significantly reduced visibility throughout the day, with fog occurring and overcast sky conditions. At the time of the accident, the weather was the same in all directions, visibility in fog was 250 m, wind was moderate at 3 knots from a 50° direction, and the RVR varied between 1000 and 1600 ft [14].

The cause of the accident was determined by the investigation to be a failure on the part of the Korean Air Lines crew who erred in the approach to the designated take-off runway. This was due to the reduced visibility caused by the presence of dense fog, which disoriented the DC-10 crew. After choosing an incorrect taxiway, the control tower was also unable to assist them due to the lack of visual contact [14].

7.3. USAir let 405

USAir flight 405 took place on 22nd March 1992. The operating Fokker 28-4000 crashed on take-off from Runway 13, LaGuardia Airport, New York, USA. LaGuardia was a stopover airport between Jacksonville, Florida and the final destination of Cleveland, Ohio [15].

The weather at the New York airport did not change significantly during the day. The cloud base height was at 700 m and visibility was at 1200 m. There was fog and light snow precipitation, due to the low temperature of 0°C. The wind was blowing at 13 knots from a direction of 60-70°, the QNH pressure was 1004,4 hPa [15].

Flight 405 was delayed from its start, due to severe weather in the New York area. Upon arrival, the aircraft was de-iced twice due to snow and cold temperatures. The time between the last de-icing and the commencement of take-off was determined by the investigation to be approximately 35 minutes, during which precipitation were falling at low temperatures on the aircraft. During take-off, the aircraft did get its fuselage airborne, but lost lift shortly afterwards and crashed. The cause was a layer of ice on the wings, which disrupted the flow around the airfoil [15].

8. CONCLUSION

The article provides a comprehensive analysis of meteorological conditions and phenomena that can occur in the atmosphere. It informs about their specific effects on the behaviour of the aircraft during take-off and landing. The nature of the assembly of the theoretical knowledge has been compiled in the form of deduction, from general term to specific weather conditions.

The influence of meteorological conditions on air traffic is great, whose proof are the accidents caused precisely due to the influence of weather conditions. Weather may not be the primary cause of accidents, but in many cases it is a decisive factor without which the accident might not have occurred. Weather represents the current state of the atmosphere in a particular place at a particular time, which we cannot control. It is therefore up to people to adapt to it, not to underestimate it, and thus avoid unnecessarily endangering the air traffic.

REFERENCES

[1] DVOŘÁK Petr. Letecká meteorologie. 1. vyd. Cheb : Svět křídel, 2017. 464 s. ISBN 978-80-7573-014-5.

[2] KROLLOVÁ Sandra. Meteorológia v leteckej doprave : Základné princípy. 1. vyd. Žilina : EDIS-vydavateľstvo Žilinskej univerzity, 2014. 303 s. ISBN 978-80-554-0850-7.

[3] NEDELKA Milan. Letecká meteorológia 2. 2 vyd. Bratislava : Alfa, 1982. 325 s.

[4] DANĚK Vladimír. Mechanika letu I : Letové výkony. 1. vyd. Brno : Akademické nakladatelství CERM, 2009. 293 s. ISBM 978-80-7204-659-1.[5] NEDELKA Milan. Prehľad leteckej meteorológie. 1 vyd. Bratislava : Alfa, 1984. 222 s.

[5] Učebnice pilota 2019. 1. vyd. Cheb : Svět křídel, 2019. 405 s. ISBN 978-80-7573-049-7.

[6] ZAHUMENSKÝ Igor. Meteorológia a oceánografia. 1. vyd. Žilina : Žilinská univerzita v Žiline, 1998. 201 s. ISBN 80-7100-527-4.

[7] BLAŠKO Peter. Prevádzkové postupy. 1. vyd. Bratislava : DOLIS s. r. o., 2015. 184 s. ISBN 978-80-8181-037-4.

[8] DANĚK Vladimír. Mechanika letu II : Letové vlastnosti. 2. vyd. Brno : Akademické nakladatelství CERM, 2021. 334 s. ISBN 978-80-7623-059-0.

[9] NEDELKA Milan. Letecká meteorológia : Organizácia, spravodajstvo, prostriedky a formy služieb meteorológie civilnému letectvu. 2. vyd. Bratislava : Alfa, 1980. 186 s.

[10] SHMÚ. Letisková predpoveď TAF. Available on the internet: https://www.shmu.sk/sk/?page=484 [cited 06.04.2022]

[11] NTSB. Aircraft accident report: NTSB/AAR-86/05. Available on the internet: https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR8605.pdf [cited 09.04.2022]

[12] NTSB. Aircraft accident report: NTSB/AAR-84/10. Available on the internet: https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR8410.pdf [cited 09.04.2022]

[13] NTSB. Aircraft accident report: NTSB/AAR-93/02. Available on the internet: https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR9302.pdf [cited 10.04.2022]

[14] 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.

[15] KAZDA, A., CAVES, R.E. 2007. Airport Design and Operation. Bingley: Emerald Group Publishing Limited, 2007. 538 s. ISBN 978-0-08-045104-6.

[16] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

[17] KAZDA, A. 1995. Letiská design a prevádzka. Žilina: Edičné stredisko VŠDS 1995. 377 s. ISBN 80-7100-240-2.

[18] ŠKULTÉTY, F., JAROŠOVÁ, M., ROSTÁŠ, J. 2022. Dangerous weather phenomena and their effect on en-route flight delays in Europe. Transportation Research Procedia, 2022, 59, pp. 174–182. ISSN 23521457.

[19] PECHO, P., JAROSOVA, M., DVORSKY, R., SKVAREKOVA, I., AZALTOVIC, V. 2020. Design of a Flight Instrument for Early Identification of Local Atmospheric Changes in the Operating Conditions of Glider. Proceedings of the 22nd International Conference on New Trends in Civil Aviation 2020, NTCA 2020, 2020, pp. 51–56, 9290809. ISBN 978-800106726-0.

[20] NOVÁK, A., HAVEL, K., JANOVEC, M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

[21] NOVÁK, A., ŠKULTÉTY, F., KANDERA, B., ŁUSIAK, T. 2018. Measuring and testing area navigation procedures with GNSS. MATEC Web of Conferences 236, 01004.

[22] NOVÁK, A., PITOR, J. 2011. Flight inspection of instrument landing system. IEEE Forum on Integrated and Sustainable Transportation Systems, pp. 329-332.

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METEOROLOGICAL INFORMATION RESOURCES FOR AIRCRAFT CREWS

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Abstract

This article addresses the issue of available meteorological information resources and their importance for aircraft crews, with special regard to the ways of disseminating meteorological information and the possibilities of providing it to crews. The aim of the article is to process a comprehensive set of information about meteorological information resources and methods of obtaining meteorological information in aviation. The article has a theoretical character. It summarizes the basic terminology and defined concepts of the processed issues, with an effort for a logical focus of the chapters that are adequately addressed. In the discussion and conclusion, we pointed out the importance of meteorological resources for aircraft crews, the need for proper assessment and evaluation of the obtained meteorological information, in order to ensure the safe course of the flight.

Keywords

Meteorological Resources, Meteorological Data, Meteorological Information, Weather, Meteorological Phenomena, Meteorological Elements, SHMÚ, Meteorological Reports, Satellite meteorological systems

1. INTRODUCTION

Knowledge from meteorology as an extensive field of science and aerial meteorology, which is an industry of applied meteorology, continues to be in demand for their wide practical use, and not only in air transport, even in the current time of rapid advancement of aviation.

For aviation meteorological provision, information on weather conditions is essential and the emphasis is mainly on making up-to-date information as accurate as possible. It is the meteorological information resources that are the means that ensure that accurate meteorological information is obtained in aviation and allow for the subsequent assessment of meteorological conditions and impacts before, during and after the flight.

The aim of the article was to process a comprehensive, concise set of information on meteorological information resources for aircraft crews and ways of obtaining meteorological information in aviation.

The knowledge was gained by analyzing the available book and internet Slovak and some foreign sources.

2. WEATHER - METEOROLOGICAL FACTOR CAUSING CRISIS SITUATIONS IN AIR TRANSPORT

2.1. Impact of weather on air traffic safety

Even in the age of modern aircraft equipment and ground technology, the weather still has a major impact on the safety of air transport and the comfort of those on board the aircraft. Air accidents, in which the weather was the co-operative cause, demonstrate to us the importance of the impact of the weather on air transport [1].

Such accidents have always occurred, and this will certainly not change for the foreseeable future. However, thanks to the competent approach of the aircraft crew, it is possible to reduce the risk of these accidents to a minimum. However, it is not just about knowing the risks of the weather, although aviation safety is certainly one of the first places [1].

The term weather means constantly changing atmospheric conditions that exist at a certain place at a certain time. The weather is the result of physical interactions between sunlight, air and water. Sunlight causes uneven heating of air on the Earth's surface, leading to different air pressures. The air tries to compensate for these differences in pressures by moving around the country in the form of wind. Thanks to sunlight, water evaporation also occurs. As the air with water vapor rises, it cools down, the water condenses again, forming clouds. Weather changes can be quick or slow. An example of a rapid change in the weather is a warm sunny morning, which turns into a cold and wet afternoon. Conversely, the transition between flight and winter is a slow change. From a long-term perspective, the weather does not change much. Summers are warm, cold and winters mild, but also frosty. These seasonal variations shall be eliminated over the years [2].

2.2. Meteorological phenomena and elements that affect the flight

We describe the weather using meteorological phenomena, meteorological elements and cloud cover.

Meteorological phenomena are among the weather phenomena that occur in the atmosphere or on the Earth's surface. Photometeors, lithoeteors, electrometeors and hydrometeors are included under meteorological phenomena. Meteorological phenomena do not include clouds. Meteorological phenomena can be of varying intensity - weak or very weak, moderate or strong [3].

A meteorological element is a physical quantity characterising the state of the atmosphere, expressed in specified units of measurement. It is measured directly or indirectly, or estimated or calculated (e.g. pressure, temperature and humidity of the air, wind direction and speed). The meteorological element is a function of place and time, F = F (x, y, z; t) and is a scalar or vector quantity. The set of values of a given meteorological element is called an array of meteorological element that characterizes the spatial distribution of a meteorological element in the atmosphere. We divide the fields of meteorological elements according to their nature into scalar and vector, continuous and disjointed [3].

Meteorological elements are air pressure, air temperature, humidity, sunlight, wind, cloud cover and precipitation [5].

3. METEOROLOGICAL INFORMATION PROVISION SYSTEMS IN AIR TRANSPORT

3.1. World Meteorological Organization (WMO)

The Geneva-based World Meteorological Organisation (WMO) is an authority for everything in terms of state and movement in the atmosphere. It examines the interactivity of the atmosphere with the oceans, studies airborne-related manifestations, hydrology and also geophysical phenomena. The World Meteorological Organisation examines everything related to meteorology, climatology, hydrology and also air and its protection [6].

3.2. Global Telecommunications System (GTS)

The Global Telecommunications System (GTS) is part of the World Weather Watch (WWW) programme. It serves to coordinate and quickly collect processed meteorological information, exchange and distribute it throughout the world. GTS enables its members to ensure the rapid flow of meteorological data in a reliable and cost-effective manner. It ensures full accessibility of meteorological and meteorology related data, forecasts and warnings. This secure communication network allows for the exchange of important information in real time, which must be correctly submitted in order to warn in a timely manner of meteorological and hydrological risks, in accordance with approved procedures [7].

3.3. World Area Forecast Center (WAFC)

The World Area Forecast Centre (WAFC) is a meteorology center that prepares and issues significant weather forecasts (SIGWX) as well as forecasts for certain elevation levels. These meteorological forecasts shall be distributed directly by appropriate means, in digital form and to a global extent, directly to the Member States that are part of the aeronautical fixed service. WAFC forecasts at node points refer to elevation wind, temperature and humidity in higher layers, geopotential altitude of flight levels, flight level and temperature of tropopause, direction, speed and flight level of maximum wind, cumulonimbus clouds, icing and turbulence [4].

3.4. World Area Forecast System (WAFS)

The World Area Forecast System (WAFS) is a worldwide system that works to provide aerial meteorological forecasts in a standardised format provided by the world's area forecast centers. In the event of inconsistencies in the significant weather forecasts (SIGWX), the meteorological service provider responsible for the area concerned shall immediately identify the inconsistencies and report them to the world area forecast centres. Inconsistencies are reported in the framework of icing phenomena, turbulence, cumulonimbus clouds, sand storms, or dust storms, volcanic eruptions, or releases of radioactive substances into the atmosphere which are significant for aircraft operation [4].

3.5. Aeronautical meteorological stations

A meteorological station is the place where meteorological observations are carried out at fixed time limits, according to agreed international procedures. The basic prerequisite is the corresponding technical, personnel and communication equipment [8].

The location of aeronautical meteorological stations at airports is most often in their vicinity, where they serve for meteorological observations for the needs of air traffic. Today, most aerial weather stations operate exclusively in fully automatic mode. All measurements are made via meteorological sensors and a computer. After recording the result of the automatic measurement, this output shall be re-sent to the central database in the form of encrypted messages or data files [1].

3.6. Synoptic stations

Synoptic stations are used to measure the development and condition of the weather, in the greatest possible frequency and range. Measurements from these stations serve the purposes of both synoptic and aerial meteorology. Synoptic stations also serve for the need to perform climatological measurements and observations, allowing for a large set of measurements with the required accuracy. Sensors located at synoptic weather stations shall be located in accordance with WMO recommendations. Based on measurements from synoptic meteorological stations, meteorological reports shall be compiled, e.g. SYNOP, METAR, SPECI and others requiring a high rate and high frequency of transmission of meteorological data [8].

3.7. Slovak Hydrometeorological Institute (SHMÚ)

The Slovak Hydrometeorological Institute (SHMÚ) is an organization specializing in performing meteorological and hydrological services at national and international level [9].

The SHMÚ monitors the quantitative and qualitative parameters of the state of air and water in the territory of the Slovak Republic, collects, verifies, evaluates, archives and interprets data and information on the state and regime of air and water, describes what is happening in the atmosphere and hydrosphere, creates and issues meteorological and hydrological forecasts, warnings and information [9].

Data, information and study results are provided by the SHMÚ to users and the general public [9].

4. METEOROLOGICAL INFORMATION RESOURCES AND THEIR IMPORTANCE FOR AIRCRAFT CREWS

In air transport, weather is one of the most important factors when it comes to safe flight progress. It is therefore necessary to know its current status and subsequent developments at the point of departure, during the course of the flight and also at the point of arrival. This is provided by meteorological information resources intended for aircraft crews. Within the framework of safety, it is necessary to carry out flawless pre-flight preparation and react in a timely manner to any changes in the weather. The correct design of the weather situation contributes to improving the safety of the crew or passengers during the performance of the flight.

4.1. OBTAINING METEOROLOGICAL DATA BEFORE THE FLIGHT

4.1.1. Airport meteorological report METAR and extraordinary report SPECI

The airport meteorological report METAR is a coded meteorological report issued by aeronautical meteorological station personnel or automatically. It is one of the main information resources for pilots in the framework of meteorology. The METAR message encodes the current weather situation at the airport [1].

These airport meteorological reports are issued at 30 or 60 minute intervals. They are coded in well-defined formats, according to ICAO standards. They are distributed to OPMET international meteorological databases and to telecommunications centres, from where they are extended to other airports. This ensures the rapid transmission of weather information within airports around the world [10].

The METAR report shall include the ICAO mark of the aerodrome at which the observation was carried out, the date and time of issue, the wind, visibility and runway visibility, the current weather, the current cloud cover, the air temperature, the dew point temperature and air pressure indication [1].

In the event of a change in an element that exceeds a specified value between regular observations, such as visibility, change in wind direction or speed, height or amount of cloud cover, the observer shall issue an extraordinary SPECI report [10].

```
SASQ LZSL 201800
METAR LZSL 201800Z 01002KT CAVOK 02/M09 Q1040=
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Figure 1: Airport meteorological report METAR from Sliač airport dated 20.3.2022. [20]

4.1.2. Airport forecast TAF

The airport forecast TAF is a forecast of certain weather elements at a particular airport. Most often, the airport forecast TAF is issued 4 times a day in 6-hour spacing. If the forecast is less valid than 12 hours, the TAF is issued every 3 hours. The validity of the forecast shall not be less than 6 hours or more than 30 hours. Only one valid TAF forecast must be issued for a certain period and an airport in particular. The coding of the TAF forecast is based on the coding of the METAR report, so the TAF forecasts and METAR reports are quite similar [1].

4.1.3. Information reports SIGMET and AIRMET

SIGMET information reports are information or warnings issued by the Meteorological Warning Service and shall indicate the possible occurrence of meteorological phenomena which may significantly affect the safety of air traffic in the aeronautical information area. SIGMET information is written in open speech, not encoded. They have a prescribed composition and use abbreviations as defined by ICAO [11].

The AIRMET information reports shall be issued by the Meteorological Warning Service and shall relate to the occurrence, expected occurrence or development of certain en-route meteorological phenomena which may affect the safety of low-flight air traffic. AIRMET reports shall be issued in the event that these meteorological phenomena have not been included in the forecast for low flight levels (FL) in a particular flight information area. In the case of low flight levels means operation under FL100 or FL150, in mountain areas [12].

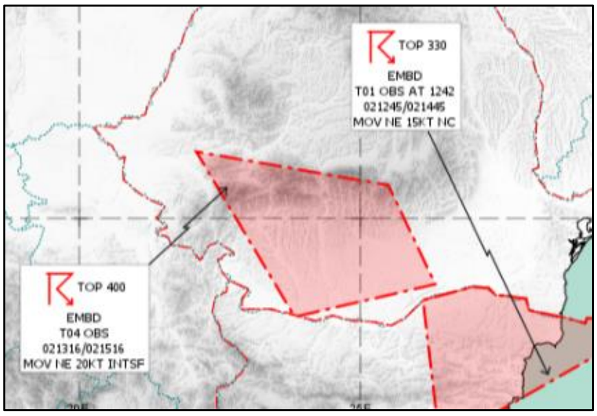

Figure 2: Information report SIGMET on the occurrence of storm activity over Romania and Bulgaria dated 3.4.2022. [21]

4.1.4. Area forecast GAMET

The GAMET area forecast is issued in the event of dangerous meteorological phenomena occurring in the flight information area that could endanger air traffic at low flight levels. The GAMET forecast is formulated in open speech, using ICAO abbreviations. It is issued 4 times a day and can be helpful not only to pilots, but also to air traffic controllers. The information from the GAMET area forecast serves as a basis for issuing AIRMET information reports [1, 13].

4.1.5. Weather forecast for takeoff

The shape of the take-off forecast shall be determined by mutual agreement between the user and the meteorological service provider. The weather service provider reports the weather forecast at hourly intervals. The take-off forecast shall include the expected wind direction and speed, air temperature and QNH pressure at the aerodrome of departure. Information from the take-off forecast is useful for both the pilots themselves and the support components. As example is the use of a wind direction and speed forecast when it is possible to determine the use of a particular runway to take-off. On this basis, the flight trajectory itself will be changed and the required amount of fuel required for the successful execution of the flight shall be determined [1].

4.1.6. Observations and reports from aircraft (PIREPS)

One other resource of meteorological information for aircraft crews is observations and reports from aircraft (PIREPS). It is the responsibility of each meteorological office to ensure that observations of dangerous meteorological phenomena from the deck of aircraft are carried out, recorded and reported. This is done by means of regular and extraordinary aircraft reporting. A radiotelephone connection, or a data link, may be used to perform these reports in the form of an ACARS data communication system. Aircraft reports shall include any dangerous meteorological phenomena occurring on the line [11].

4.2. OBTAINING METEOROLOGICAL DATA DURING THE FLIGHT

4.2.1. Automatic information service ATIS

The automatic information service ATIS shall provide up-to-date information to arriving or departing aircraft by means of repeated and continuous transmission throughout the day or during a certain part of the day [14].

ATIS allows aircraft pilots to obtain information on the possible closure of a particular aerodrome, bad weather conditions around it, runways used, types of approaches, or increased air traffic density, which may be crucial for safety. The use of automatic information service facilitates the work of air traffic controllers at busy aerodromes and reduces radio frequency congestion. They may devote themselves to other duties and do not have to spend time repeating the same information to a large number of pilots [15].

4.2.2. Meteorological radio report VOLMET

The meteorological radio report VOLMET (from the French VOL "flight" and MÉTÉO "weather") is a summary of the most up-to-date meteorological information from a particular airport and from the airports located in its surroundings [10].

The VOLMET message is broadcast continuously on the VHF waves and contains the current METAR airport meteorological report with TREND landing forecast, the SIGMET information report and, if available, the airport forecast TAF. The VOLMET weather radio reports may also be transmitted on HF waves (HF-VOLMET) or using a data link (D-VOLMET) [11, 13].

4.2.3. Reports from air traffic controllers

In the event of a reported adverse meteorological situation or meteorological phenomenon which is significant for air transport and could jeopardise the safe course of the flight, the air traffic controller may report this situation to the pilot, at its sole discretion or on the basis of the size of the risk posed by this meteorological situation or meteorological phenomenon to the flight. If the pilot is interested in specific information during the flight regarding the meteorological situation along the route, he shall request this information from the air traffic controller, who shall provide it to him.

4.2.4. Airborne weather radar

The development and deployment of airborne weather radar was an important step in terms of flight safety in adverse meteorological conditions. The airborne weather radar scans the cloud cover over a certain distance in front of the aircraft and is able to determine the saturation of this cloud cover with water droplets. This allows the pilot to provide information about the location of a possible storm cloud and assist him in making safe decisions, such as changing course, waiting or landing at a replacement aerodrome. Nowadays, airborne weather radar is a mandatory element of the navigation and communication equipment of modern airliner [16].

4.2.5. Data communication system ACARS

The data communication system ACARS is another important system that is used in air transport. This system allows the transmission of digital information between the aircraft and the ground station, as well as between the aircraft and the airline's operations centre. Using the ACARS system, pilots of an aircraft can request information about the meteorological situation in the vicinity, which will ensure that they quickly and seamlessly familiarise themselves with this situation during the performance of the flight. Against this background, the workload of pilots and air traffic controllers themselves decreases [17].

4.3. OBTAINING METEOROLOGICAL DATA BEFORE LANDING - LANDING FORECAST TREND

Just as it is important to know the development of the meteorological situation before and during the flight, it is also necessary before landing at the airport of the chosen destination. In the event of worsening weather at this airport, pilots, thanks to the resources of meteorological information, have time to react and possibly reconsider the next steps associated with the landing.

The landing forecast TREND is attached to the METAR report and its validity covers a period of two hours after the release of the METAR report. This forecast specifies the development of the weather during this period and is formulated in such a way as to record the expected changes in the critical meteorological elements. In the event of an expected change in the meteorological situation, the METAR report shall be followed by the BECMG or TEMPO change indicator. If no significant change in the weather is expected, such a message shall be terminated with NOSIG [1].

5. OTHER IMPORTANT FORMS OF OBTAINING METEOROLOGICAL DATA IN AIR TRANSPORT

5.1. Coded meteorological report SYNOP

The coded meteorological report SYNOP, obtained from the ground station, is the most comprehensive regular report on ground meteorological observations. It is used as a source of information for drawing synoptic maps, which are of general use but are somewhat important background material in the aviation. Coded meteorological report SYNOP is compiled according to the SYNOP code [18].

5.2. Meteorological radars

Weather radars are devices without which the use of modern weather service is unimaginable nowadays. They are used to detect the structure and composition of significant types of cloud cover [1].

Radars remotely detect the presence and position of various objects, based on a directed bundle of UHF electromagnetic waves, so-called microwaves [8].

Radars became more fundamentally applied during World War II, when they aimed to track planes in the sky. During this activity, there was noise that radar users wanted to remove. However, it later emerged that this noise came from reflections from meteorological targets, which represented cloud cover. On this basis, radars have started to be used as meteorological aids, which have been gradually introduced in individual meteorological services [1].

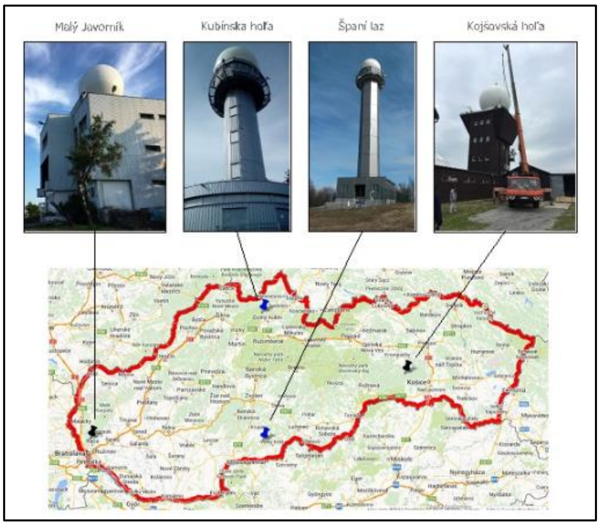

Figure 3: Location of meteorological radars of the Slovak Hydrometeorological Institute within the territory of Slovakia. [22]

5.3. Weather Information Service (WIS)

Honeywell's Weather Information Service (WIS) is a service that can greatly assist aircraft pilots in real time tracking the meteorological situation. This service also assists the crew of the aircraft in making decisions in the event of an unexpected change in the weather on the line. WIS provides the user with a weather forecast, along with up-to-date information about it in real time and at all stages of flight. It contains up-to-date weather forecasts at airports, using airport meteorological reports METAR, data automatic information service D-ATIS, airport forecasts TAF and others. In the case of en-route flights, WIS shall provide information on possible areas of occurrence of icing or CAT. It also provides information on the vertical range of Cb storm clouds, satellite data or reports from aircraft - PIREPS. In finals, this service makes it possible to design flight trajectory optimisation based on the availability of up-to-date weather information [19].

6. METEOROLOGICAL SATELLITE SYSTEMS

6.1. History of meteorological satellite systems

In the 1920s, the well-known sci-fi writer Arthur C. Clark designed the function of Earth's artificial satellites as telecommunications and meteorological devices. Later in 1945 he formulated the idea of placing satellites on a geostationary track [1].

The first ever meteorological satellite to be launched into Earth's orbit was the Tiros-1 meteorological satellite, which orbited the Earth along meridians along the so-called arctic orbit. The Tiros-1 weather satellite worked for 78 days, during which time it pointed to the high usefulness of such devices for the performance of the work of meteorologists. This satellite brought with it two television cameras into orbit with a recording device that captured the Earth's surface at a time when it could not broadcast online. It orbited the Earth at a height of 701 to 753 km and recorded approximately 23 000 images during its workload [1].

The first geostationary satellite launched into Earth orbit was the ATS-1 satellite, which was sent and deployed in 1966 [1].

In 1977, the geostationary satellite METEOSAT-1 became the first European satellite in orbit [1].

6.2. General characteristics of meteorological satellites

Nowadays, a global system of meteorological satellites is used for space monitoring of the Earth's atmosphere, which according to the work programme is divided into experimental and operational ones. The use of experimental meteorological satellites is not commercial and finds application in the exploration of the atmosphere and in the verification of theories and assumptions. On the contrary, operational meteorological satellites serve to provide continuous information, which is mainly intended for the needs of meteorological forecasts and is used by many institutions at set fees [8].

The meteorological satellite provides continuous global observations of atmospheric processes and phenomena in real time, allows sensing of cloud cover and earth surface in the visible and infrared spectrum, allows the detection of vertical profile of atmospheric temperature, water vapour content and ozone, which helps mainly in obtaining information from places with low density of aerological stations. The meteorological satellite shall also collect and disseminate the meteorological data given [8].

6.3. Geostationary satellites

The satellites orbiting the geostationary orbit are located at a height of 35790 km above the surface of the earth and are called geostationary satellites. The orbital time of these satellites is the same as the Earth's swivel time. As a result, geostationary satellites maintain a constant position above one and the same place above Earth. The location of the geostationary satellites is located above the equator and the system of these satellites covers the entire surface of the Earth. Meteorological personnel shall have at their disposal continuous surveillance of the cloud cover of our entire atmosphere, except for northern and southern latitudes larger than 81° [1].

Nowadays, several such satellites are in operation on the geostationary track. The US, Japan, Europe, Russia, China, Korea and India have their representations here [8].

7. CONCLUSION

Meteorological information obtained from meteorological information resources is undoubtedly a necessity for aircraft crews in flight planning, during flight and also during landing, given that the aircraft replicates all its manifestations (e.g. turbulence, thunderstorms, winds, or collisions) as it moves in the atmosphere.

In this article, in accordance with its objective, basic information on the possibilities of obtaining meteorological information from meteorological resources for aircraft crews was processed. The issue was described only marginally, using analysis of available bibliographical sources and materials in order to gain a broader knowledge of meteorological information resources and to describe their parameters and quality, taking into account their importance to aircraft crews.

Knowledge from the processing of the article can serve the unprofessional public to gain an overview of the processed theme, or they can be beneficial and usable to the author of the article in preparation for the future profession.

REFERENCES

[1] DVOŘÁK, P. 2017. Letecká meteorologie 2017. Cheb: Svět křídel, 2017. 456 s. ISBN 978-80-7573-014-5.

[2] LUHR, J. 2003. Earth. London: Dorling Kindersley, 2003. 520 s. ISBN 80-242-1225-0.

[3] ZÁHUMENSKÝ, I. 1998. Meteorológia a oceánografia: učebné texty. Žilina: Žilinská univerzita v Žiline, 1998. 200 s. ISBN 80-7100-527-4.

[4] JUNCKER, J.-C. (za komisiu EÚ). 2017. VYKONÁVACIE NARIADENIE KOMISIE (EÚ) 2017/373. In Úradný vestník Európskej únie. [online]. Brusel: 2017-03-01. [cit. 2022-03-14]. Dostupné na internete: https://eur-lex.europa.eu/legal-content/SK/TXT/HTML/?uri=CELEX:32017R0373&from=ES#d1e752-1-1.

[5] BALNAR, A. 2001. Meteorologie [online]. 2001. [cit. 2022-03-05]. Dostupné na internete: http://artemis.osu.cz/Gemet/meteo2/index.htm.

[6] TASR. 2020. Svetová meteorologická organizácia má 70 rokov. In TERAZ.SK. [online]. 2020-03-23. [cit. 2022-03-13]. Dostupné na internete: https://www.teraz.sk/zahranicie/svetova-meteorologicka-organizacia-m/454472-clanok.html.

[7] WORLD METEOROLOGICAL ORGANIZATION. 2022. Global Telecommunication System. [online]. 2022. [cit. 2022-03-13]. Dostupné na internete: https://public.wmo.int/en/programmes/global-telecommunication-system.

[8] KROLLOVÁ, S. 2014. Meteorológia v leteckej doprave. Základné princípy. Žilina: EDIS, 2014. 303 s. ISBN 978-80-554-0850-7.

[9] SHMÚ Slovenský hydrometeorologický ústav. 2022. O nás. [online]. 2022. [cit. 2022-03-20]. Dostupné na internete: https://www.shmu.sk/sk/?page=1793.

[10] DVOŘÁK, P. 2010. Letecká meteorologie. Cheb: Svět křídel, 2010. 481 s. ISBN 978-80-86808-85-7.

[11] KRŠKA, K. a kol. 2006. Meteorologie (050 00). Brno: Akademické nakladatelství CERM, 2006. 304 s. ISBN 80-7204-447-8.

[12] SKYbrary Aviation Safety. 2022. AIRMET. [online]. 2022. [cit. 2022-04-03]. Dostupné na internete: https://skybrary.aero/articles/airmet.

[13] ÚŘAD PRO CIVILNÍ LETECTVÍ. 2008 (v znení neskorších predpisov). Letecký předpis L3 Meteorologie. In: Ministerstvo dopravy České republiky. [online]. [cit. 2022-04-03]. Dostupné na internete: https://aim.rlp.cz/predpisy/predpisy/index.htm.

[14] NEDELKA, M. a kol. 1998. Slovenský letecký slovník terminologický a výkladový. Bratislava: Magnet-Press Slovakia, 1998. 494 s. ISBN 80-968073-0-7.

[15] Aeroclass.org. 2021. Automatic Terminal Information Service (ATIS) in Aviation. [online]. 2021. [cit. 2022-04-04]. Dostupné na internete: https://www.aeroclass.org/atis-aviation/.

[16] JŮN, F. 2015. Učebnica na lety podľa prístrojov. Bratislava: DOLIS, 2015. 191 s. ISBN 9788081810497.

[17] SKYbrary Aviation Safety. 2022. Aircraft Communications, Addressing and Reporting System. [online]. 2022. [cit. 2022-04-07]. Dostupné na internete: https://skybrary.aero/articles/aircraft-communications-addressing-and-reporting-system

[18] NEDELKA, M. 1984. Prehľad leteckej meteorológie. 1.vyd. Bratislava: ALFA, 1984. 222 s. 63-481-84.

[19] Honeywell Aerospace. 2015. Weather Information Service. [online]. 2015-03. [cit. 2022-04-08]. Dostupné na internete: https://pages3.honeywell.com/rs/honeywell3/images/WeatherInformationServiceBrochure.pdf.

[20] SHMÚ Slovenský hydrometeorologický ústav. 2022. METAR. [online]. 2022. [cit. 2022-03-20]. Dostupné na internete: https://www.shmu.sk/sk/?page=483.

[21] SHMÚ Slovenský hydrometeorologický ústav. 2022. *SIGMET.* [online]. 2022. [cit. 2022-04-03]. Dostupné na internete: https://www.shmu.sk/sk/?page=2464.

[22] SHMÚ Slovenský hydrometeorologický ústav. 2022. Slovenská rádiolokačná sieť. [online]. 2022. [cit. 2022-04-08]. Dostupné na internete: https://www.shmu.sk/sk/?page=1566.

[23] 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.

[24] NOVÁK, A. 2011. Komunikačné, navigačné a sledovacie zariadenia v letectve. Bratislava : DOLIS, 2015. - 212 s. ISBN 978-80-8181-014-5.

[25] KAZDA, A. 1995. Letiská design a prevádzka. Žilina: Edičné stredisko VŠDS 1995. 377 s. ISBN 80-7100-240-2

[26] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A., JANOVEC, M. 2020. Komunikačné systémy v letectve. 1. vyd. - V Žiline : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 164 s. ISBN 978-80-554-1737-0.

[27] ŠKULTÉTY, F., JAROŠOVÁ, M., ROSTÁŠ, J. 2022. Dangerous weather phenomena and their effect on en-route flight delays in Europe. Transportation Research Procedia, 2022, 59, pp. 174–182. ISSN 23521457.

[28] PECHO, P., JAROSOVA, M., DVORSKY, R., SKVAREKOVA, I., AZALTOVIC, V. 2020. Design of a Flight Instrument for Early Identification of Local Atmospheric Changes in the Operating Conditions of Glider. Proceedings of the 22nd International Conference on New Trends in Civil Aviation 2020, NTCA 2020, 2020, pp. 51–56, 9290809. ISBN 978-800106726-0.

[29] NOVÁK, A., HAVEL, K., JANOVEC, M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

[30] KAZDA, A., BADANIK, B., TOMOVA, A., LAPLACE, I., LENOIR, N. 2013. Future airports development strategies. Communications - Scientific Letters of the University of Žilina, 2013, 15(2), pp. 19–24. ISSN 13354205.

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DIGITAL TRANSFORMATION OF REGIONAL AIRPORTS

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Abstract

The digital transformation of airports has become more talked about in recent years. In the case of regional airports, digital transformation represents a challenge due to financing. The goal of this paper is to describe issues connected with digital transformation, especially at a selected group of airports, which are regional airports. Within the first part, there are defined terms as digitalization and digital transformation. There are also presented selected digital technologies used by airports all around the world, and the Smart Airport concept is explained. The second part is focused on terms such as airport, regional airport, and it describes the current level of digital transformation at regional airports. The main goal is to find out the level of digitalization at selected regional airports in the Czech Republic and the Slovak Republic. The output of this paper will be an evaluation of the current digital level of regional airports with regard to the effects of the Covid-19 pandemic.

Keywords

Regional airport, Smart airport, Digital transformation, Digitalization, Digital technologies at airports

1. INTRODUCTION

Air transport is a key infrastructure of modern society. Whether it is due to the transport of passengers or cargo. The speed of air transport plays an important aspect in its competitiveness. But air transport as such could not exist without airports, as it forms the basis of the entire air transport network. Therefore, it is important to develop further not only aircraft and airlines, but also airports. The implementation of new digital technologies is helping modernization in this direction, as is seen in various other sectors.

In the second part of this paper, the differences between the terms as digitalization and digital transformation are explained and a few examples of digital technologies that can be used at airports are mentioned. Of course, the benefits and disadvantages associated with them are mentioned as well. In the second half of this chapter, the concept of "Smart Airport" will be explained and the various levels of digitalization of airports. The third part deals with the current state of digital transformation of regional airports in the Slovak Republic and abroad. It is also important to address the issue of their finances because financing directly affects digital transformation. In the fourth part, the objectives and methodology of work are introduced. Finally, there are evaluated results of the survey, which consists of a sample of regional airports in the Czech Republic and the Slovak Republic. The last part contains a summary of the achieved goals and proposals for further research in the field of digital transformation of regional airports.

2. DIGITAL TRANSFORMATION

Digital transformation represents the integration of digital technologies into established digital ways of operations of companies or state institutions. It is a process where existing methods are changed, or new ones are created from the ground up to streamline working procedures [1].

Digitalization, or also called digitization, is the process of converting information from analogue way to digital way. It is the process by which information from papers began to be stored on hard disks, thus improving, and speeding up data accessibility. But in the real process, change is not always easy and without a failure, so digitization did not go smoothly. At the time when computers began to be used, many people were still not skilled enough to work with them efficiently. This means that operating systems and data storage systems have been designed to make working on them easier for computer users. Making it easier for the user may not immediately mean the most efficient way to store data. This aspect is one of many where digital transformation can help [2].

2.1. Benefits of Digital Transformation

Companies are undergoing a digital transformation mainly due to the economic reason of reducing operating costs while increasing profits. Other reasons include increasing operational efficiency and increasing customer experience [1].

2.1.1. <u>Improved Data Collection and Sharing</u>

Businesses and government institutions collect a lot of data, but the real benefit of them is based on optimizing this data for analyses that can move the business forward. Digital transformation can create a system that selects the most valuable data and processes, which are used in another analysis, and they can be used further and shared between several internal business departments. By processing these various data, it is possible to gain more specific insights into things such as customer needs, system operation, production, financing, or various business opportunities [1].

2.1.2. Unified System

Digitization is also accompanied by how data is being processed. Various applications are used for data processing, and in large corporations this number can be in the hundreds. A study from 2020 found, that businesses use up to 900 applications on average. This is a hassle for new employees who must learn to work in them, and that is a long and difficult process. For already working employees, this represents an inefficient use of working time [1].

The theoretical solution to this problem is to reduce the number of programs used. But these programs are necessary for the operation of the business. So, the real solution is to create a unified system that replaces multiple programs and implements them in its own style under one user interface.

2.1.3. Digital Presence of a Business

For a business to be successful, it needs to have a strong online presence. Have your business on the online stage. People love shopping from the comfort of home. Such visibility takes place through the digital transformation of websites, the development of mobile applications, regular social networking, and the simplification of business-to-customer communication [3].

The digital transformation helps the business's ability to adapt to current trends and take advantage of currently popular social networks easily and quickly. All this leads to greater popularity and awareness of the company among people and to a potential increase in profits [3].

2.2. Disadvantages of Digital Transformation

Just as digital transformation has its advantages, it has one major disadvantage that affects all electronic devices in the world. These are viruses.

2.2.1. Cyber Danger

Opening and connecting a business to the Internet means, that it opens an Internet communication back to it. If the path is not properly secured, just as employees can connect to the world, hackers or cybercriminals can also find a virtual path to the inside of people’s electronic devices. With such a breach of business or people’s privacy, there is a high risk of data leak such as personal data of customers, or inside information [4].

Fortunately, there are antiviruses and in-house businesses that try to protect their users from Internet threats. There are even companies that specialize in protecting their clients in this way. This is necessary as the speed at which the digital transformation progresses is great. It is an area that changes daily, and a cunning attacker can take advantage of the overlooked weaknesses in the system. The high rate of updates often results in security cracks being overlooked, and subsequently additional security patches must be issued to address this issue. The user, even if protected, must still be vigilant.

2.3. Digital Transformation of Regional Airports

Airport operations are an area where there is always room for an improvement. Operational efficiency seeks to optimize resources and improve processes associated with maintenance, security, and handling services. Air transport and airports have been pioneers of the digital transformation since the very beginning of the massive digitalization of the industry, which began about a quarter of a century ago. They actively participate in the improvement and refinement of services or operational efficiency. Efficiency in air transport must be at the highest level to keep the industry running smoothly. Several systems and technologies help us to do this [5] [6].

2.3.1. A-SMGS

The "Advanced Surface Movement Guidance and Control System" provides a range of ground routes, navigation on them and an overview of aircraft and vehicles at the airport. It seeks to maintain the required speeds of aircraft and vehicles during all possible meteorological conditions, while maintaining the required level of safety [7].

It is a modular system that is implemented in several stages and the air traffic controller has access to the airport map with the locations of individual objects. Such a top-down view of the airport provides a better up-to-date situation overview and thus increasing the situational awareness of the controllers which increases safety [7].

2.3.2. E-ticketing and Online Check-in

In 2004, there were several global crises and IATA decided to introduce 100 percent e-ticketing. Over the course of 4 years, they have succeeded in implementing this at all airports, from large to small regional airports in remote areas. The cost of processing a classic paper ticket was around $10. The cost of processing an electronic ticket is 10 times lower. With this, the aviation industry can save up to $3 billion a year. The passenger has the benefit of eliminating the possibility of a ticket to be completely lost. In the case of a loss, the tickets are simply duplicated [8].

2.3.3. Self-service Check-in Kiosks and Luggage Marking

Most airlines and airports have switched to self-service kiosks. The passenger must register for the flight with his luggage, which he will later hand over at the appropriate place. Although staff are still available to assist passengers in case of a problem. Self-service kiosks have lower operating costs than employees used at check-in positions. The initial investment is large, but in the long run there is a financial return. Employees can be relocated from their check-in positions to another work positions where they are needed the most. The advantage for passengers lies in not having to wait in long lines and increasing the speed of check-ins [9] [10].

2.3.4. Identification of Luggage Using Radio Waves

RFID technology is used at airports to mark passengers' luggage. This system works on the basis of electromagnetic fields, which transmits data of unique codes assigned to luggage. This method is much more efficient as it is much faster than using standard barcodes. Bar codes require that they be scanned individually, and direct visibility must be maintained. One RFID scanner can scan up to 1,000 individual tags per second and does not require direct visibility. It works by using radio waves and thus can take more luggage at once [11] [12].

2.3.5. A-CDM

"Airport Collaborative Decision-Making" improves the efficiency and resilience of airport operations by optimizing the use of different resources and improving air traffic forecasting. It is achieved by enabling cooperation between airports, aircraft, and ground operators. Transparency is promoted by exchanging accurate and up-to-date information and as well a more accurate departure information and scheduled take-offs in Europe is provided for the European ATFCM network [13].

2.3.6. Biometrics

This technology can provide a higher degree of identity verification than other methods. In the case of the use of staff in security checks, the failure of human factor must also be considered, which leads to errors. The machines eliminate this factor, which increases the safety and speed of passenger equipment. Standards for digital identity documents are being developed internationally, e.g., digital passport, thus eliminating the need to carry physical documents [14] [15] [16].

Biometrics can be used across multiple airport transfer segments. The speed of this technology is in seconds, if not milliseconds. Another great advantage of it, which was initiated by the current world situation, is the possibility of reducing human contact between several people, in order to protect against the spread of viruses and similar pathogens. The number of areas touched by travellers also decreases, thus reducing the chances of transmitting more types of diseases between people [14] [15] [16].

2.4. Smart Airport Concept

The digital transformation has taken place in several stages as different technologies have been introduced. Based on digital sophistication, which represents the level of adaptation of digital technologies, airports can be divided into individual categories. Currently, 4 stages of airport digitization are distinguished. The transitions between stages are driven by the various challenges the airport currently faces [17].

2.4.1. Airport 1.0

The first category of the airport is a classic, traditional airport, which still operates on the basis of analogue processes. Automated systems are not integrated and overall, no emphasis is placed on passenger experience and satisfaction. In the case of small airports, e.g., regional, which will serve fewer passengers, the traditional operating system is not a problem. However, if it were an airport where the number of passengers carried was in millions, the traditional airport concept would be absolutely unsatisfactory [18].

The integration of digital processes is very limited in this case. The most what can be found at an airport of the first category is CUTE. "Common Use Terminal Equipment" is digital transformation, which is a technological solution that allows multiple airlines to use existing airport infrastructure to equip passengers through their own servers [18] [19].

2.4.2. Airport 2.0

Important feature of this stage is the full deployment of CUTE, but the main factor that defines the second level of airports is self-service. CUSS technology is therefore added to CUTE, but not to such an extent and only for some airlines. “Common Use Self-Service” is an airline platform at airports that uses electronic self-service kiosks to handle passengers and eliminates the need for staffing. Kiosks are mainly used in check-in processes. Construction of a Wi-Fi network at the airport can be observed. In this case, it is a fundamental digital transformation if the airport wants to operate simpler and more efficiently [18] [19].

2.4.3. Airport 3.0

The penultimate level is trying to maximize its space capacity. Self-service kiosks can be found in all parts of the airport. Operational management is automated and portable intelligent devices such as tablets are used. A-CDM is also being used for this category, as digital maturity is at such a level that this system can be fully integrated and used. The airport's website is usually supplemented with 3D maps, and it also contains elements of online stores [18].

The first B2C models can also be seen. This means that airports try to get to know their passengers and find out their needs and preferences. In practice, airports often try to obtain information through various ways like “Passenger Name Record” of airlines, mobile applications, or providing free Wi-Fi and using cookies. Subsequently, they can create targeted advertising through which profits may increase.

2.4.4. Airport 4.0

Level 4 is considered to be the latest stage of development as it is a full-fledged smart airport that uses almost all the latest available digital technologies with the maximum possible efficiency. In the fourth level, analyses are created and processed in order to create maximum innovation. The airport seeks to generate valuable data from this information by tracking passenger flows, anticipating, and knowing customer needs. A clear shift of the business model from B2B to B2C is visible. The systems are fully integrated and can share a wealthy amount of data. The use of artificial intelligence and various automated machines can also be seen. Smart Airports 4.0 are located mainly in the areas of Europe, the Middle East and the region between Asia and the Pacific Ocean. These are mainly major hub airports. Air traffic in these places is very dense, which is why there are many delays at the airports. This problem is driving digital transformation forward very fast [18] [20].

3. CURRENT STATE OF THIS PROBLEMATIC IN SLOVAK REPUBLIC AND ABROAD

In this paper, digital transformation of regional airports is the main focus. Regional airports are a special group of airports that is very important in the air transport network. On the other hand, this group of airports is very specific. It is primarily a view of their operation, which is extremely costly. No matter how hard they try to prosper, their financial problems are deepening every year, which has a direct impact on their digital transformation, development, modernization, and overall operation. Of course, the regional airports can apply for financial support in the form of various subsidies and state grants, specifically investment and operating aid. However, in many cases, state aid is insufficient and regional airports fail to be profitable [21]. Therefore, they have to adapt to their local conditions and properly solve their financial situation and thus their own development.

3.1. Airports

The airport can be defined according to the L14 regulation. An airport is "a defined area on land or water (including buildings, facilities and equipment) intended either wholly or partly for departures, arrivals and ground movements of aircraft" [22].

Airports can be divided according to several criteria. They can be, for example, public or non-public, international, or national. However, in our case, we are interested in a group that considers the number of passengers transported per year:

- **Main airport** (carries more than 25 million passengers a year).
- **National Airport** (carries between 10 and 25 million passengers per year).
- **Large regional airport** (carries from 5 to 10 million passengers per year).
- **Small regional airport** (carries from 1 to 5 million passengers per year).
- **Small airport** (transports more than 200,000 per year) [23].

3.2. Regional Airport

According to the Commission Regulation of EU 2017/1084, a regional airport is defined as "an airport with up to of 3 million transported passengers annually in average" [45].

3.2.1. The Importance of Regional Airports

Regional airports are an important part of the European Union's aviation infrastructure. They provide access to certain areas that are remote from civilization and difficult to access for other types of transport. Regional airports ensure the economic development of the regions in which they are located, but also in the surrounding cities. From another point of view, they are able to attract various investors to the regions, who are building their industrial companies in these areas or investing in local businesses. Lastly, they help primary hub airports to regulate the overall influx of passengers, especially on busy days [24]. The importance of regional airports has also been confirmed by several studies. For example, Carballo-Cruz and Costa (2014) explained the success of Oporto Regional Airport in Portugal. According to the authors, the main advantage of this airport is its attractive geographical position. The expansion of airlines, expansion and improvement of airport facilities were able to attract more passengers, especially in the period from 2007 to 2011. The number of overnight stays of tourists in this region also increased by 16.5%. This is a clear evidence that a regional airport has positive effects on the economic development of the region in which it is located [25].

3.2.2. The Expansion and Problems of Regional Airports

The liberalization of the air transport market prompted the expansion of these airports. The original goal of liberalization was to increase competition, which led to greater demand for take-off and landing slots. National and major airports have failed to offer more of these slots, and thus the expansion of regional airports has been observed. Between 2005 and 2017, an increase of 39% in direct flights between regional airports was observed, and by less than 20% at larger airports. Low-cost airlines have started to use regional airports as their main airports. The expansion of low-cost airlines has brought changes in the form of cheaper flights, increased frequency, and a greater offer of destinations. In this way, air transport has become more popular and beneficial. The gates to economic growth have opened up, tourism has improved, and the regions have risen economically overall [24].

It can be said that regional airports are very beneficial for their regions. Unfortunately, their operation is not easy and brings several problems. Regional airports often experience financial problems, precisely because of the lack of passengers. Many regional airports have difficulties providing their services not only to passengers but also to airlines. Any airport without passengers and airlines will not survive financially. Without airlines, there will be no passengers, and without passengers, there is no income. Huderek-Glapska and Nowak (2016) dealt with the relationship between regional airports and low-cost airlines. According to the authors, the operation of the regional airport is significantly affected by the presence of low-cost airlines. Maintaining a long-term relationship with low-cost airlines brings several benefits to the airport. [26]. Lin et al. (2013) examined the business relationship between low-cost airlines and airports in Southeast Asia. The results showed that the more the airport's survival depends on the airline, the more compromises it makes. However, this may not be beneficial for the airport, as low-cost airlines are in a better position to negotiate lower airport charges [24] [27].

Regional airports are mostly loss-making and difficult to maintain economically. In this case, too, several studies are enclosed here that confirm this fact. In his study, Červinka (2019) looked at whether a regional airport is a business that can generate profit. According to the author, regional airports can profit, but the most unprofitable are the airports that carry under 3 million passengers a year. Low-cost companies complicate the situation. As a solution, the author proposes to provide airport services to several airlines to generate more profit from airline activities. He also introduced another option, where he proposes to make a profit from non-aviation activities. However, many regional airports do not have the potential to build significant infrastructure to generate profit from non-aviation activities. But if such possibility exists, it must be used. An example of this is the Ostrava regional airport, which has built an aircraft repair shop and a cargo terminal. As a result, the long-term loss of Ostrava Airport may not be permanent. Zuidberg (2017) focused on the financial performance and profitability of regional airports in the EU. The economic performance of the local region contributes in particular to the local regional airport profits [28] [29].

Due to the problems mentioned above, regional airports can apply for state aid and various subsidies for the operation and construction of infrastructure. However, this is not a long-term solution to the problem and is not always enough. The study

Sedláčková and Švecová (2018) examined the problems of regional airports in the Slovak Republic. The study notes that the problems of airports are demonstrably mainly due to insufficient subsidies. Airports with less than 200,000 passengers a year have been shown to be unable to cope with their operating costs. Financing of small regional airports is not only a problem in the Slovak Republic, but also a nationwide problem within the EU [30] [31].

3.2.3. Digital Transformation of Regional Airports

The pandemic has accelerated the development and application of many technologies. Therefore, several experts address this issue. Kováčiková et al. (2021) dealt with the current level of digital transformation of airports in the Slovak Republic and in the European Union. Within the results, they found that the airports in the Slovak Republic are below the EU average. However, these figures are based on 2019. Airports in the Slovak Republic have at most online check-in or websites that have sections for business partners and passengers. Košice airport, e.g., is currently preparing an application for passengers [32].

The DESI index shows the level of digitization in EU countries, which is also reflected in the aviation industry. The data of index 2021 shows that Slovakia is currently ranked 22nd. Denmark, Finland, and Sweden lead in digital maturity [33] [34].

For regional airports that are not successful in their business, it is difficult to allocate money for digital transformation. On the other hand, it is necessary if they want their operation to be more efficient and if they care about customer experience from using their services. Passenger experience is a very important factor in this case. Halpern et al. (2021) in their study addressed passenger preferences regarding the use of digital technologies at Norwegian airports. The results showed that a large proportion of passengers want to have more control over their travel through the use of kiosks and personalized options. Specific examples include interest in boarding passes, mobile payments and services, permanent digital baggage tags and the use of biometrics at checkpoints. They are less concerned about their privacy and the impact on human pride in the use of digital technologies. The study concludes that the public is interested in using digital technologies [35]. The study done by Remencová and Sedláčková (2021) also took a look at the digital transformation of regional airports in Slovakia. Introducing new digital technologies at regional airports is more complex, slower, and costly than at a larger airport. For example, investing in self-check-in kiosks may seem costly at first glance, but on the other hand it can speed up the movement of passengers through the airport. At the same time, it can reduce daily operating costs, which in the long run brings a return on investment [36]. Stark (2020) focused on the digital transformation of Springfield Regional Airport, one of the first airports to introduce e-ticketing, automatic baggage sorting and websites. The reason behind the digital transformation of this airport was to increase capacity, safety, operational efficiency and at the same time reduce emissions with lower financial costs and achieve the maximum possible passenger satisfaction. Given the airport's experience with several innovations, a few basic rules are recommended by the management for a successful implementation of new technologies. There is a need to work more closely and address the issue with all stakeholders, such as key airport partners (airlines, airport shops). It is also very important to determine what the airport management wants to achieve with its digital transformation. As soon as strategic goals are defined by the airport, it can gradually start working on digital transformation. Without good management and proper planning, the process will not be possible [37].

3.3. Current State of Air Transport

The year 2020 can be considered as one of the most difficult in air transport. The Covid-19 pandemic and related anti-pandemic measures have taken their toll in the form of an overall decline in air transport demand. Travel restrictions have left some airports with almost no passengers, which in some cases has led to the closure of airports. Many airlines have announced their closure. The financial implications of the pandemic are also huge. ACI Europe said that European airports lost a total of 1.72 billion passengers in 2020, a decrease of 70.4% from the previous year. Some small regional airports, which depend on local tourism, have seen an even steeper drop in passenger numbers. In the case of the Dubrovnik regional airport, in Croatia, this represented a drop of up to 88.6%. However, not all segments of air transport have been affected by such a significant drop in flights. Freight transport fell in Europe, by only 12.1% [24].

The beginning of 2021 was also in a similar vein to the previous one, with continuing restrictions on travel. Today is the year 2022 and the air transport sector is opening up to the public again. Many measures have been phased out, as well as travel restrictions, and air traffic is slowly recovering. The overall recovery of air transport takes time, but the results will gradually show [38] [39].

In addition to the decrease in passengers, there was, of course, an overall decrease in flights. Fig. 1 shows EUROCONTROL forecast of the number of IFR flights over Europe until 2027, compared to 2019. The figures are in millions, and a decrease in air traffic in 2020 of 55% is visible. In 2021, traffic over Europe reached 56% of total capacity compared to 2019. From there, a forecast with a continuous increase in the number of flights can be seen. Achieving pre-pandemic levels is expected as early as 2024 [40].

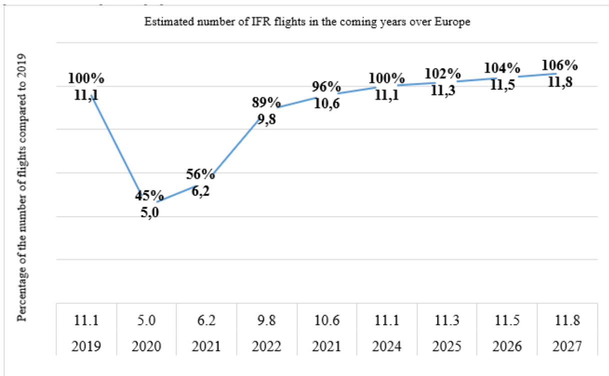

Figure 1: Estimated number of IFR flights over Europe in the following years from October 2021. [40]

In the beginning of 2022, air traffic over Europe was expected to decline by 21% over the same period in 2019, based on more recent calculation models. However, real figures showed that air transport reached only 68% compared to the overall level of 3 years ago in the same period. An increase to 71% in February has been seen, but on the 24th of February an armed conflict broke out in Ukraine. This war closed the airspace between the EU and Russia on the 28th of February, which led to the cancellation of numerous flights or a change in flight paths. It is too early to say what impact this war will have on Europe in the long term, but it is more than certain that it will slow down the resurgence of air transport [41].

The total number of flights fell by more than half in 2020 [42]. This means that fewer aircraft were handled each year than usual, resulting in a surplus of staff in the air transport sector. This fact of staff surplus was reflected in the redundancies of airport staff as well as airline staff due to cost reductions. This, of course, has a negative impact on the regeneration of the aviation sector. From another point of view, the loss of professionals has put pressure on even faster digital transformation and modernization of airports in general. The digital transformation should result in increased work efficiency as well as automation of airport processes [38]. Therefore, it could be said that the pandemic has pushed regional airports into the corner, and it can be expected that these airports will have to be digitized in the future. It is mainly about passenger protection and cleanliness in the airport. The introduction of new digital technologies can eliminate the spread of viruses and various diseases. This issue was addressed by Amankwah-Amoah (2021), who examined innovations in air transport that were to act as countermeasures against the spread of Covid-19. He also noted an acceleration in the adaptation of contactless technologies at airports to minimize the number of areas that passengers have to touch [43]. A good example is the use of facial biometrics or solutions and processes used in hospitals, laboratories, and other health centres. For example, an intelligent air filtration and purification system, where this properly applied system can help reduce pathogens, allergens, and other air pollutants [44]. In the future, it can be expected regional airports to adapt to the digitalization trend. However, the question remains as to how these digital changes will be financed given the unfavourable economic situation of these entities. The EU could be interested in this issue and offer regional airports solutions on how to finance this modernization.

4. GOALS AND METHODOLOGY OF OUR REASEARCH

This paper is focused on the digital transformation of regional airports. As it was clarified in the previous section, these airports represent a specific group of airports that need to be addressed separately. Therefore, the main goal of this paper is to determine the level of digitization of regional airports in the Czech and the Slovak Republic, which often have a low level of digitization. In their case, it is most often the use of self-service check-in kiosks, and that is all. So, a survey was decided to be made, that was targeted at regional airports in the Czech and Slovak Republics, because there was a need to clarify the current state of their digital level. A very widespread method of "questioning" was used, which consists in obtaining information from respondents by asking questions. In our case, a form in Google Forms was created, and it was distributed electronically to selected regional airports to find out the current level of digitization. This form contained several questions focusing on the technologies already in use and the potential benefits or challenges of digital transformation. We also asked about the digital technologies that airports plan to implement in the near future. At the same time, it is considered important to find out how the Covid-19 pandemic has affected the implementation of digital technologies at these regional airports.

4.1. Sample

The sample consisted of 9 regional airports in Czechia and Slovakia. The Prague Airport was not included, since it has more than 3 million transported passengers a year, and the airport Sliač was also not included, considering it was closed for civil aviation and is open only for the military.

- Slovak Republic
  a. Bratislava Airport
  b. Piešťany Airport
  c. Žilina Airport
  d. Poprad Airport
  e. Košice Airport
- Czech Republic
  a. Brno Airport
  b. Karlove Vary Airport
  c. Ostrava Airport
  d. Pardubice Airport

5. RESEARCH RESULTS

In this part, the results that were received in our survey are analysed. We managed to obtain only 5 responses out of the 9 regional airports we contacted.

5.1. Žilina Airport

The airport is not currently digitalized and does not use any digital technology to operate. It was added that they plan to introduce self-service check-in kiosks, self-service baggage marking, e-ticketing, online check-in, and mobile application for passengers.

The reason for the implementation of digital technologies is mainly to increase operational efficiency and reduction of current operating costs. It has already been mentioned that the biggest barrier to starting a digital transformation is the initial cost. The airport confirmed this and stated, that their biggest obstacles were the initial investment and current technical equipment.

As can be seen from the previous answers above, the airport has not implemented any digital technology due to the pandemic. However, Covid-19 launched its digital transformation, and they consider it beneficial in the digital development of the airport. This regional airport can be considered as level 1.0 airport from the answers provided, and after the planned digital transformation it will gain the Airport 2.0 status. But it all depends just on the initial investment and also on whether this airport will operate flights.

5.2. *Bratislava Airport*

According to the results, the airport only uses e-ticketing and the online check-in. They do not plan to implement any new digital technologies in the near future. However, the study by Kováčiková et al. (2021), found that the Bratislava Airport had plans to implement mobile application for passengers. In the current situation, it can be seen that this airport has already given up the implementation of the mobile application. We can only assume that the plan was disrupted by the pandemic, as the survey found that the pandemic was seen as an obstacle to their digital development. This claim is also supported by the fact that they did not implement any technology due to the pandemic.

One of the main reasons for implementing new digital technologies is to increase the speed of passenger check-in. The initial investment represents the biggest challenge for the airport.

As the airport has undergone a minor digital transformation in the past, they provide e-ticketing and online check-in, they have also been able to respond to whether they have seen positive changes in their airport operations. They answered yes to this question, arguing that they had seen positive changes, especially in increasing passenger satisfaction. This airport can be classified as the airport in level 1.0 for now.

5.3. *Brno Airport*

The regional airport Brno currently uses only e-ticketing and online check-in, as it is in the case of Bratislava Airport. In the near future, the airport plans to implement self-service check-in kiosks, RFID bag tags and self-service baggage tagging. For now, this airport is defined as Airport 1.0. After the implementation of these digital technologies, it will be possible to move this regional airport to level 2.0.

In this case, new technologies are implemented for several reasons, namely: increasing passenger satisfaction, increasing passenger handling speed, increasing operational efficiency, and reducing operating costs. The biggest challenge for Brno Airport in the implementation of new digital technologies is the initial investment.

As part of the fact that they had implemented e-ticketing and online check-in in the past, they answered yes to the question whether they observed changes in their operation. There were positive changes in all 3 mentioned categories: increased passenger satisfaction, increase operational efficiency, and increase staff satisfaction.

When asked if they considered the Covid-19 pandemic to be a benefit or an obstacle, the airport services manager answered following "Definitely not. The reduction in operations and thus in revenues has delayed the implementation of new technologies due to a lack of funds."

For this reason, they did not even implement any digital technology due to the pandemic.

5.4. *Ostrava Airport*

Based on the results, the airport Ostrava uses, as in the case of Brno Airport, only e-ticketing, and the online check-in. In the next years, they plan to implement self-service check-in kiosks and biometrics of the face and fingers. For this reason, the airport can only be defined as Airport 1.0 for now.

The reason for implementation is first and foremost to increase passenger satisfaction, then to increase passenger handling speed, increase operational efficiency and improve safety and security. However, in this case, they answered, that they do not do so due to a reduction in operating costs. In the case of the challenges of implementing digital technologies, they gave the following reasons: initial investment, technical equipment, and the necessary trained staff.

As for whether they were able to observe positive changes at the airport-related to the previous digital transformation, they answered yes, stating that they observed these positive changes in increased operational efficiency. However, they did not observe changes in the satisfaction of staff and passengers.

In the last part of the form, they stated that they considered the Covid-19 pandemic to be an obstacle and therefore did not implement any new digital technologies.

5.5. *Piešťany Airport*

This airport did not respond to our form. Instead, they issued a statement made through an e-mail. A Member of the Board said: "I have no doubt about the need for gradual (reasonable) digitization, which in most cases will make operations more efficient and increase the level of security."

Unfortunately, he added that he would only be able to answer our questions satisfactorily to a very limited extent, as most of the questions are related to the airport's investment plan. For this reason, he provided us with a contact to the CEO, and we subsequently received a reply again through an e-mail. The airport does not currently use any digital technologies, and the director stated: "We will start thinking about them only at a time when we would have regular flights and the number of transported passengers will increase. High financial investment in the systems must have a meaningful return in time, but at the same time, we know that we will have to invest in the systems if regular flights will be operated."

From the answers he provided, we can conclude that they would like to implement new digital technologies to increase operational efficiency, but the current situation does not allow them to do so. In an e-mail communication, a board member also mentioned how the Covid-19 pandemic had negatively affected the situation at the airport. It also takes note of the current Russo-Ukrainian war, which has incredible implications for the economy, respectively crushing impact on their finances.

5.6. *Summary of the Results*

The survey shows that regional airports in the Czech Republic and Slovakia are not well digitized. E-ticketing and online check-in are more a matter of airlines, but also airports that allow you to work with these services. The digital transformation that involves technologies such as self-service kiosks or biometrics, which are implemented mainly to improve airport operations, are not located at any of our requested regional airports. However, in the near future, these regional airports are going to implement these technologies, but everything requires time and investment. Therefore, we think that after a while, it will be possible to contact them again and find out if they have noticed the benefits of digital transformation.

Table 1 shows a summary of used and prepared digital technologies at regional airports in our region, namely in Žilina, Bratislava, Brno, and Ostrava.

Table 1: Used and prepared digital technologies at selected regional airports in the Czech and Slovak Republic. [authors]

Digital Technologies	Žilina	Bratislava	Brno	Ostrava
A-SMGC	X	X	X	X
A-CDM	X	X	X	X
Self-service check-in kiosk	Preparing	X	Preparing	Preparing
Self-service baggage handling	Preparing	X	Preparing	X
RFID bag tags	X	X	Preparing	X
Biometrics	X	X	X	Preparing
Artificial Intelligence	X	X	X	X
Automated robots	X	X	X	X
E-ticketing	Preparing	Using	Using	Using
Online check-in	Preparing	Using	Using	Using
Mobile application for passengers	Preparing	X	X	X

6. CONCLUSION

The digital transformation of airports has more advantages than disadvantages. In particular, it brings benefits in the form of more efficient operations, reduced operating costs, and increased passenger satisfaction. In the current situation, it can be confirmed by several studies that the existence of such airports has a positive impact on the local economy, and the larger the airports, the greater the effect itself. However, if there are not enough passengers, the regional airports are not able to cover their high operating costs. If there is only one low-cost airline operating at a regional airport, these problems only get worse. However, there are several ways to solve the problems. The first is, e.g., construction of cargo terminals, but only if they are usable for the regional airport region. The second is the already mentioned digital transformation, which reduces the airport's operating costs, increases passenger satisfaction and, of course, increases the airport's cleanliness from pathogens. Some studies showed that passengers are willing to take advantage of the new digital technologies, but the initial investment in these changes is too large in many cases and regional airports are unable to finance this development on their own.

As for the goals, it can be said, that they were only partially achieved. The cooperation from the side of regional airports was limited because a lot of airports did not respond. Despite the smaller number of responses, we were able to find out the current situation at 5 regional airports. Regional airports in the Czech Republic and the Slovak Republic are minimally digitized and do not reach higher levels of maturity than Airport 1.0. In the future, it would be appropriate to repeat a similar survey, in order to get a more up-to-date and better overview of the digitization of regional airports in our region. As part of the survey, it is possible to expand the sample of regional airports with a focus on other Central European countries. This will make it possible to compare individual regional airports and analyse differences in the use of digital technologies.

To conclude, the digital transformation makes sense in terms of increasing operational efficiency, reducing operating costs and increasing passenger satisfaction. Regional airports see a sense of moving forward in digital development, but they have a funding problem that only prolongs the whole digital transformation.

REFERENCES

[1] Virtru. 2021. What are the Benefits of Digital Transformation? [online]. Available on the Internet at: https://www.virtru.com/blog/8-benefits-digital-transformation/ (cited 2022-04-23)

[2] Salesforce. What is digital Transformation? [online]. Available on the Internet at: https://www.salesforce.com/products/platform/what-is-digital-transformation/ (cited 2022-04-23)

[3] BHAGAT, V. 2021. How Does Digitalization Benefit Your Business – a Quick Overview! [online]. Available on the Internet at: https://customerthink.com/how-doesdigitalization-benefit-your-business-a-quick-overview/ (cited 2022-04-23)

[4] Cyber Detect Pro. 2021. Advantages and Disadvantages of Digital Transformation to the Cybersecurity Business [online]. Available on the Internet at: https://cyberdetectpro.com/advantages-and-disadvantages-of-digitaltransformation-to-the-cybersecurity-business/ (cited 2022-04-23)

[5] ZAHARIA, E. S. and PIETREANU, V. C. 2018. Challenges in airport digital transformation. In Transportation Research Procedia [online]. 2018, vol. 35 [cited 2022-04-23]. Available on the Internet at: https://www.sciencedirect.com/science/article/pii/S2352146518303569. ISSN: 2352-1465

[6] BURBAITE, R. 2019 Digital transformation in aviation: Big data, IoT, AI & mobility [online]. Available on the Internet at: https://www.aerotime.aero/articles/23948-digitaltransformation-in-aviation-big-data-iot-ai-mobility (cited 2022-04-23)

[7] Skybrary. Advanced Surface Movement Guidance and Control System (A-SMGCS) [online]. Available on the Internet at: https://skybrary.aero/articles/advanced-surfacemovement-guidance-and-control-system-smgcs (cited 2022-04-23)

[8] IATA. 2008. Industry Bids Farewell to Paper Ticket [online]. Available on the Internet at: https://www.iata.org/en/pressroom/pr/2008-31-05-01/ (cited 2022-04-23)

[9] PARODE, N. 2020. How to Use the Airport's Self-Service Check-In Kiosk [online]. Available on the Internet at: https://www.tripsavvy.com/airports-self-service-checkinkiosks-2973028 (cited 2022-04-23)

[10] Materna IPS GmbH. Check-in kiosk: Professional hardware and software for fast passenger services [online].

Available on the Internet at: https://www.maternaips.com/check-in-kiosk/ (cited 2022-04-23)

[11] IMPINJ. Transforming a Global Industry Through RAIN RFID Baggage Tracking [online]. Available on the Internet at: https://www.impinj.com/solutions/baggage-tracking (cited 2022-04-23)

[12] IATA. Radio Frequency Identification (RFID) [online]. Available on the Internet at: https://www.iata.org/en/programs/ops-infra/baggage/rfid/ (cited 2022-04-23)

[13] EUROCONTROL. Airport collaborative decision-making [online]. Available on the Internet at: https://www.eurocontrol.int/concept/airport-collaborative-decisionmaking (cited 2022-04-23)

[14] FRANKLIN, B, J. 2021. How Airports Are Using Biometrics So You Can Spend Less Time Waiting in Lines [online]. Available on the Internet at: https://www.cntraveler.com/story/how-airports-are-using-biometrics-so-you-canspend-less-time-waiting-in-lines (cited 2022-04-23)

[15] GLUSAC, E. 2021. Your Face Is, or Will Be, Your Boarding Pass [online]. Available on the Internet at: https://www.nytimes.com/2021/12/07/travel/biometrics-airportssecurity.html (cited 2022-04-23)

[16] VISSER, R. 2021. Biometrics at Airports [online]. Available on the Internet at: https://www.intervistas.com/biometrics-at-airports/ (cited 2022-04-23)

[17] NAGY, E. and CSISZAR C. 2016. Airport Smartness Index – evaluation method of airport information services. In Austrian Journal of Transport Sciences [cited 2022-04-23]. Available on the Internet at: https://www.researchgate.net/publication/313826929_Airport_Smartness_Index_-_evaluation_method_of_airport_information_services.

[18] NAU, J. B. & BENOIT, F. 2017. Smart Airport, How technology is shaping the future of airports [online]. Available on the Internet at: https://www.wavestone.com/app/uploads/2017/12/Smart-Airport-2017.pdf (cited 2022-04-23)

[19] DCS.aero. Common Use Platforms [online]. Available on the Internet at: https://dcs.aero/common-use-platform/ (cited 2022-04-23)

[20] MOHAMED, A. 2018. Embracing future of travel with Airports 4.0 [online]. Available on the Internet at: https://themalaysianreserve.com/2018/09/25/embracingfuture-of-travel-with-airports-4-0/?__cf_chl_jschl_tk__=BylplgOhsRLb_omaNU6ucFB59poHPwoZphh_._0UMJc1640875904-0-gaNycGzNCOU (cited 2022-04-23)

[21] REMENCOVÁ, T. 2020. Ekonomicko – právne aspekty regionálnych letísk SR v podmienkach EÚ: Master Thesis. Žilina: Žilinská univerzita v Žiline, 2020. 88 s

[22] Ministerstvo dopravy, pôšt a telekomunikácií Slovenskej republiky. 2006. Letiská: I. zväzok Navrhovanie a prevádzka letísk. 2. vyd. Bratislava: Letové prevádzkové služby Slovenskej republiky, štátny podnik, 2006. 239 s. ISBN 80-969299-8-4.

[23] TOMOVA, A. and KIRSCHNEROVA I. and HAVEL K. 2016. Ekonomika letísk. Žilina: Žilinská univerzita v Žiline EDIS-vydavateľské centrum ŽU. 2016. 219 s. ISBN 978-80-554-1257-3.

[24] NIESTADT, M. 2021. The future of regional airports: Challenges and opportunities [online]. Available on the Internet at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689346/EPRS_BRI(2021) 689346_EN.pdf (cited 2022-04-23)

[25] CARBALLO-CRUZ, F. and COSTA, N. V. 2014. Success factors of regional airports: The case of Oporto airport. In Tourism & Management Studies. [online]. 2014 [cited 2022-04-23]. Available on the Internet at: https://www.researchgate.net/publication/290390554_Success_factors_of_regional _airports_The_case_of_Oporto_airport. ISSN 2182-8466

[26] HUDEREK-GLAPSKA, S. and NOWAK H. 2016. Airport and low-cost carrier business relationship management as a key factor for airport continuity: The evidence from Poland. In Research in Transportation Business & Management. [online]. 2016, vol. 21 [cited 2022-04-23]. Available on the Internet at: https://www.sciencedirect.com/science/article/abs/pii/S2210539516300724. ISSN 2210-5395.

[27] LIN, E. and MAK, B. and WONG, K. 2013. The business relationships between LCCs and airports in Southeast Asia: Influences of power imbalance and mutual dependence. In Transportation Research Part A: Policy and Practice. [online]. 2013, vol. 50 [cited 2022-04-23]. Available on the Internet at: https://www.sciencedirect.com/science/article/abs/pii/S0965856413000438. ISSN 0965-8564.

[28] ČERVINKA, M. 2019. Is a regional airports business a way to make a profit? In Transportation Research Procedia. [online]. 2019, vol. 43 [cited 2022-04-23]. Available on the Internet at: https://www.sciencedirect.com/science/article/pii/S2352146519305897. ISSN 2352- 1465.

[29] ZUIDBERG, J. 2017. Exploring the determinants for airport profitability: Traffic characteristics, low-cost carriers, seasonality and cost efficiency. In Transportation Research Part A: Policy and Practice. [online]. 2017 [cited 2022-04-23]. Available on the Internet at: https://www.researchgate.net/publication/316873181_Exploring_the_determinants_ for_airport_profitability_Traffic_characteristics_lowcost_carriers_seasonality_and_cost_efficiency. ISSN 0965-8564.

[30] European Commission. 2014. State aid: Commission adopts new guidelines on state aid to airports and airlines (Aviation Guidelines) – Frequently asked questions

[online]. Available on the Internet at: https://ec.europa.eu/commission/presscorner/detail/sk/memo_14_121 (cited 2022-04-23)

[31] NOVÁK SEDLÁČKOVÁ, A. and ŠVECOVÁ, D. 2018. The Regional Airport's Problems in the Slovak Republic: The Case Study of Žilina Airport. In MATEC Web of Conferences. [online]. 2018 [cited 2022-04-23]. Available on the Internet at: https://www.researchgate.net/publication/329096944_The_Regional_Airports'_Pro blems_in_the_Slovak_Republic_The_Case_Study_of_Zilina_Airport. ISSN 2261- 236X.

[32] KOVÁČIKOVÁ, M. and JANOŠKOVÁ, P. and KOVÁČIKOVÁ, K. 2021. The comparison of digitalization of Slovak Airports within the digital transformation of European Union countries. In Transportation Research Procedia. [online]. 2021, vol. 55 [cited 2022-04-23]. Available on the Internet at: https://www.sciencedirect.com/science/article/pii/S2352146521005263. ISSN 2352- 1465.

[33] European Commission. The Digital Economy and Society Index (DESI) [online]. Available on the Internet at: https://digital-strategy.ec.europa.eu/en/policies/desi (cited 2022-04-23)

[34] European Commission. 2022. The Digital Economy and Society Index – Countries' performance in digitization [online]. Available on the Internet at: https://digitalstrategy.ec.europa.eu/en/policies/countries-digitisation-performance (cited 2022-04-23)

[35] HALPERN, N. and MWESIUMO, D. and BUDD, T. and SUAU-SANCHEZ, T. and BRATHEN, S. 2021. Segmentation of passenger preferences for using digital technologies at airports in Norway. In Journal of Air Transport Management. [online]. 2021, vol. 91 [cited 2022-04-23]. Available on the Internet at: https://www.sciencedirect.com/science/article/pii/S096969972030586X. ISSN 0969-6997.

[36] REMENCOVÁ, T. and NOVÁK SEDLÁČKOVÁ, A. 2021. Modernization of Digital Technologies at Regional Airports and its Potential Impact on the Cost Reduction. In Transportation Research Procedia. [online]. 2021, vol. 55 [cited 2022-04-23]. Available on the Internet at: https://www.sciencedirect.com/science/article/pii/S235214652100346X. ISSN 2352-1465.

[37] STARK, J. 2020. Digital Transformation of Springfield Regional Airport. In Digital Transformation of Industry. [online]. 2020 [cited 2022-04-23]. Available on the Internet at: https://link.springer.com/chapter/10.1007/978-3-030-41001-8_14. ISSN 2197-6589.

[38] ACI. 2021. The COVID-19 pandemic, an accelerator for airport digitalization [online]. Available on the Internet at: https://blog.aci.aero/the-covid-19-pandemic-anaccelerator-for-airport-digitalization/ (cited 2022-04-23)

[39] ICAO. 2022. 2021 global air passenger totals show improvement from 2020, but still only half pre-pandemic levels [online]. Available on the Internet at: https://www.icao.int/Newsroom/Pages/2021-global-air-passenger-totals-showimprovement.aspx (cited 2022-04-23)

[40] EUROCONTROL. 2021. Forecast Update 2021-2027 [online]. Available on the Internet at: https://www.eurocontrol.int/publication/eurocontrol-forecast-update2021-2027 (cited 2022-04-23)

[41] EUROCONTROL. 2022. Comprehensive Assessment EUROPEAN AVIATION [online]. Available on the Internet at: https://www.eurocontrol.int/sites/default/files/2022-03/eurocontrol-comprehensive-air-traffic-assessment-20220317.pdf (cited 2022-04-23)

[42] SALAS, B. E. 2022. Number of flights performed by the global airline industry from 2004 to 2022 [online]. Available on the Internet at: https://www.statista.com/statistics/564769/airline-industry-number-offlights/#:~:text=Global%20air%20traffic%20%2D%20number%20of%20flights%202004%2D2022&text=The%20number%20of%20flights%20performed, reached%2038.9%20million%20in%202019 (cited 2022-04-23)

[43] AMOAH-AMANKWAH, J. 2021. COVID-19 pandemic and innovation activities in the global airline industry: A review. In Environment International. [online]. 2021, vol. 156 [cited 2022-04-23]. Available on the Internet at: https://www.sciencedirect.com/science/article/pii/S0160412021003445. ISSN 0160- 4120.

[44] CIRIG, T. 2021. The acceleration of digital transformation in airports [online]. Available on the Internet at: https://blog.aci.aero/the-acceleration-of-digitaltransformation-in-airports/ (cited 2022-04-23)

[45] Commission Regulation (EU) 2017/1084 of 14 June 2017 amending Regulation (EU) No 651/2014 as regards aid for port and airport infrastructure, notification thresholds for aid for culture and heritage conservation and for aid for sport and multifunctional recreational infrastructures, and regional operating aid schemes for outermost regions and amending Regulation (EU) No 702/2014 as regards the calculation of eligible costs. Eur-Lex [online]. Available online: <https://eur-lex.europa.eu/legal-content/SK/TXT/PDF/?uri=CELEX:32017R1084&from=en>. (cited 2022-05-02)

[46] 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.

[47] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

[48] KAZDA, A., CAVES, R.E. 2007. Airport Design and Operation. Bingley: Emerald Group Publishing Limited, 2007. 538 s. ISBN 978-0-08-045104-6.

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METHODS OF IMPLEMENTATION PIV SYSTEM IN THE WIND TUNNEL OF THE DEPARTMENT OF AIR TRANSPORT

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Abstract

In the early days of aviation, wind tunnels were developed to investigate whether an aircraft is capable of flying, and how capable it was of doing so.They are mainly used as a part of research of aerodynamic forces applied to a model of an aircraft or its parts. There are several methods of measuring the airflow inside a wind tunnel, however this manuscript is concerned with implementation of Particle Image Velocimetry (PIV), especially the software part, in the conditions of the wind tunnel of the Department of Air Transport.

The functions of the software were investigated on the basis of a simple experiment. The poppy seeds were blown on white paper and the images were captured by the camera in slow motion as it moved from side to side and then the images were processed and analyzed. The amount of poppy seeds used varied.The results showed successful use of PIV software and it's application directly in the wind tunnel of the Department of Aviation for research of the effects of aerodynamic forces in aviation, but also in other areas.

Keywords

Wind tunnel, PIV, Implementation, Software

1. INTRODUCTION

Since the beginning of aviation, it was necessary to know the characteristics of the aircraft in the air. The designers realized that if they wanted to build a machine that would be able to fly, they must first understand how the air bypassed its surfaces. Although the first machines were built based on the flight of birds, these attempts were never successful. They did not provide the data they needed to build a flight-capable aircraft. To obtain the necessary data, they had a choice of 2 options, either to get their test aircraft at the required speed, or to blow a static model through the air. The Wright brothers have already used a wind tunnel to study the properties of the various wing profiles of their first Wright Flyer aircraft [1].

A wind tunnel is a device used to measure the aerodynamic properties of bodies. It is currently used not only in aviation, but also in the automotive industry, construction, ecology and the like. By suitable shaping of bodies, we can reduce resistance, energy consumption or design buildings more resistant to adverse weather conditions. The basis of every wind tunnel is also the technique of visualizing the flowing air. The most important techniques used are tufts, smoke, oil paint, Schlieren photography and laser sheet / PIV [2]. The main advantage of PIV is the non-invasiveness of the measurement system and its reliability.

PIV is an optical method for measuring the direction and velocity of a fluid. This method is relatively new and suitable for use in research and education. We insert indicator particles, or particles small enough to follow the dynamics of the fluid flow, into the examined liquid. The liquid with the flowing particles is illuminated by a laser so that the particles are visible in it. We then monitor these particles and, according to the change in their direction and velocity, we can calculate the direction and velocity of the investigated liquid [3].

A typical PIV device consists of a camera, a laser, optics that create a plane of light, a synchronizer that acts as an external trigger to control the camera and the laser, indicator particles and the fluid being examined. The PIV software and a suitable computer are then used to process the generated images [3].

All these things would be useless if we had nowhere to use them. The wind tunnel at the Department of Air Transport in Žilina should have been used for this purpose

"Fig. 1" [4]. Instead, the measurements were made at home, because the tunnel of the Department of Air Transport was in the process of being completed at the time of writing, and the results were processed and evaluated using PIVlab software.

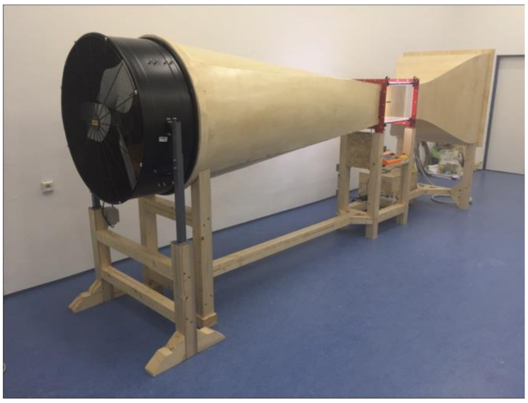

Figure 1: Wind tunnel of the Department of Air Transport.

2. MATERIALS & METHODS

2.1. Equipment

The experiment required at least 15 grams of poppy seeds, an accurate weight, a camera stand, slow-motion camera, white paper of A4 format , PIVlab software and computer. The camera stand was built from Lego and served as a camera holder in a position over the white paper. Little adjustment were added to the camera stand to hold the paper in a fixed position and to protect it from being blown by the air. As a slow-motion camera, iPhone X was used.

2.2. Setup

The camera stand together with white paper were placed on a wooden table. The sight of the camera had to cover the whole white surface. Poppy seeds were put at the bottom of the paper "Fig. 2".

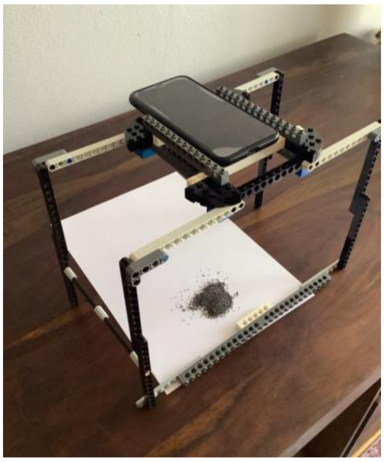

Figure 2: Apparatus setup.

2.3. Measurment methodology

The amount of poppy seeds was first weighted and then divided into 3 groups according to weight: 5 grams, 10 grams and 15 grams group. The experiment proceeded as follows. Each group of poppy seeds was placed separately on the paper to be displayed at the bottom of the camera display "Fig. 3". Slow-motion mode on the camera was chosen and recording started. Stream of air was applied to the amount of poppy on the paper. After application of the air recording stopped. The videos recorded in this way were further edited and analyzed in PIVlab software.

Figure 3: The amount of poppy seeds. 5g (left), 10g (center), 15g (right)

2.4. Data preprocessing and processing

Each recorded video was cut to only show the starting position and the process of poppy seeds being blown away. To maintain the same conditions, 300 frames of video were determined for processing, with the first frame capturing the initial blow. The coordinate system had its origin in the lower

left corner, where the x-axis increased to the right and the y-axis increased upwards. Every group was supplemented with a calibration image of the ruler placed on the corner of the paper to determine the same scale in the program. Image adjustments were set the same, adding CLAHE, Auto contrast stretch and Subtract mean intensity. Speed limits were not adjusted. The 150th image of the vector "Fig. 4"and velocity magnitude "Fig. 5" was selected for comparison.

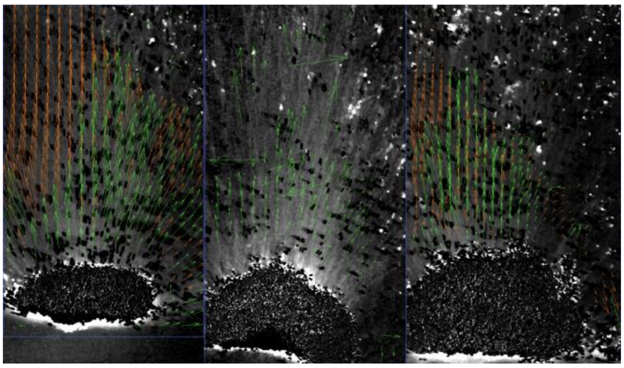

Figure 4: Displayed vectors in groups of poppy seeeds 5g (left), 10g (center), 15g (right) in the 150th image.

Analysis of images with more poppies took more time to process. For every extra 5 grams, it lasted about an extra 2-4 minutes, with a calculation time of about 11 minutes for a group of 5 grams. Based on that a larger number of particles requires more computational operations and this equates to a larger total time.

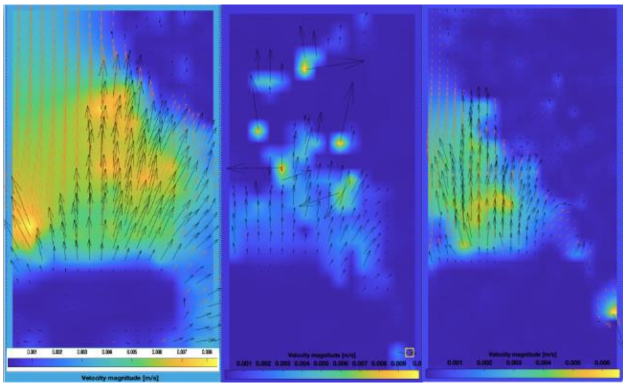

Figure 5: Velocity magnitude in groups of poppy seeds 5g (left), 10g (center), 15g (right) in the 150th image.

The software had trouble correctly determining the vectors of some particles if they were already somewhere on the paper in the initial images. The software had the most troubles in determining directional vectors in a group of 10 grams. In the group with the largest or smallest amount, similar problems did not occur.

3. RESULTS

results showed that the most suitable group for processing is group of 5 grams. The particle saturation ratio of the area and the distance of the camera from the paper was the most ideal for this option. The option with the largest amount of poppy came in second, but it is likely that a measurement error occurred with this option. With such a large amount of poppy, only the particles on the surface of the total amount shifted during the blowing, and therefore there was less surface saturation and better processing than in the case of the 10-gram option.

Therefore, in a wind tunnel, it should be taken into account that with the camera fitted from the test part, a smaller amount of particles will be better for the overall capture and subsequent processing. When analyzing in the software, make sure that the images are edited from the very beginning. Processing in the middle of the sequence can cause incorrect determination of vectors and thus affect our entire research.

4. CONCLUSION

The main goal of the presented manuscript was to investigate the effect of the amount of particles on the processing and analysis in the software PIVlab. Due to the completion of the wind tunnel of the Department of Air Transport, the practical part was carried out at home.

The results of the practical part showed that a higher number of particles meant a longer time for the overall processing. At 10 grams, the software had trouble determining the directional vectors of some poppy grains. The reason was the high saturation of the area in relation to the placement of the camera from the area of paper. This problem did not occur at 15 grams because a large amount of poppy prevented some particles from passing onto the paper during blowing.

It follows from the above that, when researching in a wind tunnel, care must be taken not to overflow with particles. Smaller quantities are easier to analyze and faster to process. Processing may also be affected by the time of initial analysis. For more accurate measurements, it is important to adjust the images from the very beginning.

Although the practical part did not take place in a wind tunnel, it can be concluded that the PIVlab software is sufficiently capable of research and suitable for use in it.

The goal of the work however would lose its meaning if the software was not applied to the wind tunnel. Due to the financial demands of the individual components of the system, the laser was not yet available at the Department of Air Transport at the time of writing. After its delivery, it is planned to connect it together with the camera and the computer and place it so that it illuminates the test part “Fig. 6” of the wind tunnel. Testing of the system will take place first by selecting suitable indicator parts, which must meet the conditions for working with them and will be easily accessible. The conditions are their size so that they can properly follow and copy the air stream and not disturb it, and the ability to reflect light so that the particles are visible on the camera. Additional conditions may be encountered during system implementation. We can verify the functionality of the system by comparing the already existing results of airflow bypass on different wing profiles from other wind tunnels with a wind tunnel at the Department of Air Transport. The comparison determines if the system is set up correctly. Once an agreement has been reached, it can be stated that the PIV has been applied successfully.

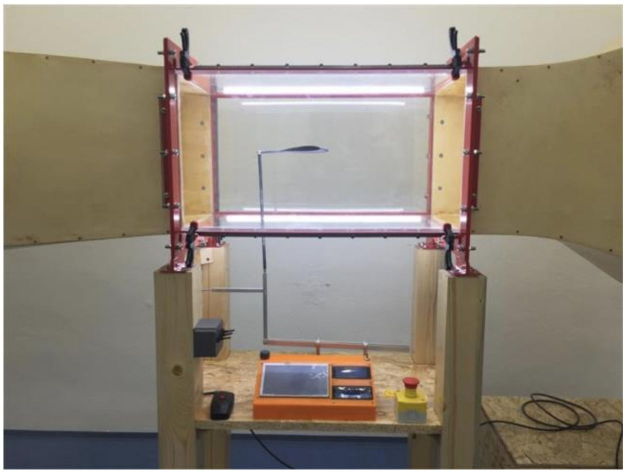

Figure 6: Test part of the wind tunnel at the Department of Air Transport.

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REFERENCES

[1] RUMERMAN, J., The First Wind Tunnels, [Online], https://www.centennialofflight.net/essay/Evolution_of_Technology/first_wind_tunnels/Tech34.htm

[2] Grc.nasa.gov, Flow Visualization, [Online], https://www.grc.nasa.gov/WWW/K-12/airplane/tunvis.html

[3] RITCHIE, Z. 2016. Particle Image Velocimetry Design & Installation. Fayetteville: University of Arkansas, 2016. 32p. https://scholarworks.uark.edu/meeguht/58

[4] HRÚZ, M. 2020, Návrh a konštrukcia modelu demonštračného tunela

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

[6] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

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

[9] 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.

[10] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A., JANOVEC, M. 2020. Komunikačné systémy v letectve. 1. vyd. - V Žiline : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 164 s. ISBN 978-80-554-1737-0.

[11] LUSIAK, T., NOVÁK, A., JANOVEC, M., BUGAJ, M. 2021. Measuring and testing composite materials used in aircraft construction. Key Engineering Materials, 2021, 904 KEM, pp. 161–166. ISBN 10139826.

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CONSTRUCTION DESIGN OF A THREE-CYLINDER TWO-STROKE RADIAL ENGINE

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Abstract

The goal of modern society is to improve efficiency in all areas. Our goal is to convert the old engine parts into a functional power unit that is more efficient than the donor parts. Modern electric motors with high efficiency are our main competitors, but our motor has an advantage in a simple design that is easily serviced. We achieve low weight by using lightweight aluminum air-cooled cylinders. In my work, I deal with the fundamentals of two- and four-stroke internal combustion engines. The importance of primary and secondary forces caused by the movement of the crankshaft and pistons is also discussed. Of course, we'll go over how to fill the engine while it's running (carburetor/injection). Following that, I'd like to go over the overall functionality of the drive unit as well as the significance of specific components. In practice, we concentrate on simulating our experimental engine. The purpose of this entire article is to provide the foundational documentation for the subsequent construction of this power unit.

Keywords

Trabant radial engine, Trabant three-cylinder engine, Trabant aircraft engine.

1. INTRODUCTION

Air force propulsion units have been in development for a very long time. The primary goal has always been to make the drive unit powerful, light, dependable, and efficient in a variety of other ways. The four-stroke engine, which has been used by the air force since its inception, excels in the majority of the features mentioned. Although the two-stroke engine is described as being unfriendly to the environment, it is more efficient than the four-stroke engine in many ways. These areas include, for example, the final product's weight to power ratio and ease of construction. These are the benefits we want to emphasize when designing our three-cylinder engine, which will primarily use components from Trabant 601 engines P60, P63, P65, and 5B. Since its inception, this type of engine has been used in air transport, as many designers of paragliders and other ultralight aircraft-capable devices have recognized the engine's potential. The engine's power ranges from 23 to 26 horsepower, but by fine-tuning it with a few simple adjustments, you can increase its power while also lowering its consumption. Unfortunately, a design suitable for a car is not perfectly suitable for aviation.

The benefits were also noticed by the STRX 1200 engine designer, who used the so-called engine top to combine two P63 engines to create a four-cylinder boxer engine. Unfortunately, the STRX 1200 engine and the original Trabant engine are not as efficient as they could be. This is primarily due to the designers' available options at the time. As a result, we decided to use all of our knowledge and modern technologies, as well as suitable engine components P60, P63, P65, and 5B, to create a design that will outperform the original design in every way.

2. TRABANT ENGINE

The Trabant 601's two-stroke powertrains have evolved significantly over the course of its production. The designers relied on knowledge gained from the development of previous types of engines used in the first P50 vehicles. This machine also had a power unit with the same name. It was a two-cylinder, air-cooled, two-stroke engine with a straightforward design.The P50 engine had a volume of 500 cm3 and produced 13 kW at 3750 rpm in the first versions. While maintaining the volume, the power was gradually increased to 15 kW at 3960 rpm. The drive unit was able to provide us with significant torque in the form of torque, up to 45 Nm at 2750 rpm, due to the relatively large stroke. The development was quite limited in order to keep the same structural elements.

The P50 engine was replaced by the P60 engine, named after the new Trabant model. A significant change was the increase in volume from 500 cm3 to 594 cm3 (rounded to 600 cm3), which increased our torque to up to 51 Nm at 2700 rpm. Our power increased to 16.9 kW as a result of the higher torque value, particularly at higher speeds. This engine was used in the Trabant P60 / 600 as well as the early Trabant 601.

With further evolution, to the P63 type, a significant developmental leap occurred. The modified geometry of the discharge channels increased the torque to 54 NM around 2800 rpm and the power to 19.12 kW at 4200 rpm. This engine also stopped using M18 threaded spark plugs, which were less common, so it was an important spare part. Sparkplugs with a much (more frequent) M14 thread took their place.

The engine's subsequent evolution occurred in 1974 on the P65 model, with the most significant changes being the use of needle bearings in the upper eyes of the connecting rod. In the upper connecting rod eyes of all previous types, bronze bushings were used. Because this type of bearing necessitates a larger oil supply, an oil dilution ratio of 1:33 was used. Because needle roller bearings do not require such a constant supply of oil, the lubrication ratio has been reduced to 1:50. The engine has become much more efficient and environmentally friendly as a result of these modifications. Unfortunately, production quality has gradually declined since the early 1970s, and despite the use of components that should theoretically increase engine performance, reality has revealed that the power ratings set in 1969-89 have not changed.

The 5B engine was the most recent evolution, with designers attempting to solve the problem of gradual leakage of rubber seals on the crankshaft. They were able to solve this problem by using so-called sealing rings (Labyrinth). It is a construction in which steel rings in grooves that touch the inner steel structure ensure tightness. These seals allow the crank to freely move relative to the block, while their tight tolerances and the oil contained within them ensure the block's tightness. Pistons with a design that provided adequate strength while being light in weight began to be used. Heads with a compression ratio of 7.8 were eventually used, which were supposed to improve performance parameters, but the quality of production was so poor that it could not be proven [1][2][3][4][5].

Figure 1: Trabant engine. [authors]

3. EXPERIMENTAL ENGINE

The following are the conditions for our experimental engine: Engine capacity is limited to 1,000 cm3, design of a construction that ensures the engine's smoothest operation and longest possible service life, and use of modern technology to increase its parameters. Our primary criterion is the correct balance of the experimental unit. As a result, we decided to space our three cylinders at 120-degree intervals. All three pistons will move at the same time, ensuring these outcomes.

The correct operation of the engine is dependent on the creation of a sudden and uniform vacuum, which ensures the correct suction of the mixture as well as the uniform compression of the mixture for the engine's correct and most efficient operation. This also ensures the proper balance of primary and secondary forces, resulting in minimal engine vibrations and, as a result, the longest possible service life for the entire experimental unit. Even cooling will be ensured, resulting in uniform wear of the individual components.

To keep the volume constant, we decided to use three cylinders from the engine, P63, P65, and 5B, which have better geometry in the discharge channels. A "cut" is made when the rollers' dimensions change due to wear after extended use. This procedure expands the piston's bore. As a result, we'd like to go with a 74 mm bore, which will increase the engine capacity from 892 cm3 to 942 cm3. However, we still have enough material for any major drilling that would be required in the event of a seizure that would cause significant damage to the cylinder wall. In addition, I intend to use a more modern carburetor than what was used in the original engines. The PWK, Keihen, and Mikuny carburetors of the 1980s were already advanced enough to compete with modern electronic injection if properly set up.

However, due to the ever-improving electronic injection molding technology, their development has largely stalled. These carburetors, on the other hand, are significantly more efficient than any carburetors used in the Trabant car. This is also due to the fact that the original carburetors used a constant diffuser size and thus have the highest efficiency only at a limited range of speeds or with a specific volume of air flowing at a specific time. Carburetors with a more modern design allow us to change the size of the diffuser as needed. Furthermore, the overall construction is designed so that the channels are as short as possible in order for the fuel to travel as quickly as possible.

4. HOW IT WORKS

Many aviation enthusiasts may mistakenly compare our experimental engine to star engines, which operate on a four-stroke principle. It would not work if we converted our experimental engine to a four-stroke engine. This is because such engines are designed to keep the crankcase pressure constant, as increased pressure from poor piston movement design would cause increased stress on the rubber seals, causing them to fail and the engine to leak oil. In our case, however, the pressure in the crankcase must change as sharply as possible in order for the required flushing to be as efficient as possible.

The design itself, which would behave like a four-stroke engine, could be created, but the individual cylinders would need to be sealed. We'd also have to split the crankshaft into three parts, each of which would be sealed. As a result, it is unnecessarily expensive and difficult to produce. Simultaneously, the current operation of the pistons ensures that we experience minimal vibrations as a result of mutual interference of primary and secondary forces. These forces occur as a result of the piston changing the direction and force of acceleration.

The primary forces act on us once per crankshaft turn. We can get rid of them by using a counterweight that is positioned exactly opposite the axis of rotation of the lower connecting rod. The asymmetrical acceleration of the piston generates secondary forces. It is caused by the crankshaft, connecting rod, and piston design. As a result, when the crank rotates 90 degrees, the piston naturally travels a greater distance in the upper half of the stroke than in the lower half of the stroke. For every crank rotation, these forces are generated twice. Primary forces are more powerful than secondary forces. Both primary and secondary forces are significantly unpleasant in the original two-cylinder engines and are manifested by vibrations. The significant advantage of our design is the elimination of these forces as well as the reduction of vibration to a bare minimum.

Figures ABC depict an engine section. This cut is designed to go through all of the cylinders, which are offset from one another, as shown in Figure 1.

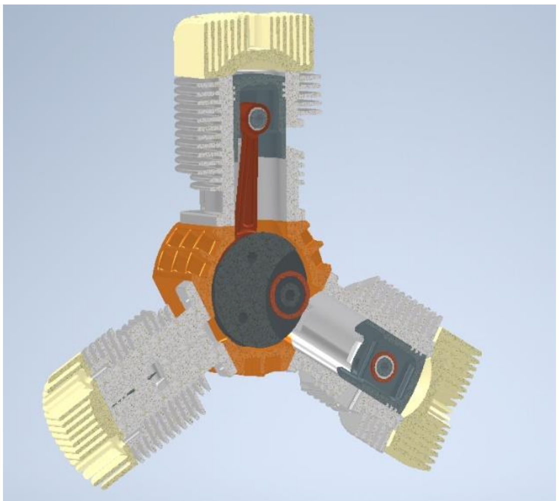

Figure 2: Model of experimental engine. [authors]

Because I want to explain the engine's operation to a new audience, I decided to use illustrations to describe the individual phenomena. The suction process is depicted in Figure 3 by the green arrows. The suction is created by the pistons moving towards the top dead center. They generate a negative pressure as a result of this movement, which causes the suction reed valve to react and open as a result of the negative pressure. The pistons simultaneously compress the fresh mixture enclosed in the combustion chambers during this process. The flywheel supplies us with energy for this story.

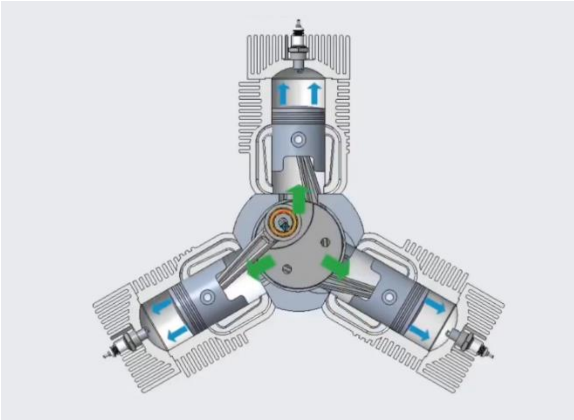

Figure 3: Suction process. [authors]

Figure 4 depicts the following expansion process in the combustion chambers: the pressure on the individual pistons, which creates work. The space under the pistons begins to contract, and the suction reed valve closes, causing an overpressure to form, which will be explained in the following paragraph.

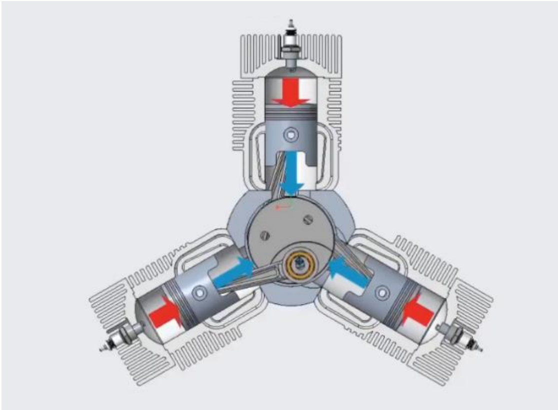

Figure 4. Expansion process. [authors]

We can see in Figure 5 that the individual pistons got under the holes in the individual cylinders. First, the exhaust ducts open, allowing the combusted mixture to leak in. After a while, the overflow channels open, allowing the necessary mixture from the crankcase to flow. The discharge channels are shaped in such a way that the burnt mixture is flushed into the exhaust. Following that, the pistons begin to move toward the top dead center, and the cycle is repeated.

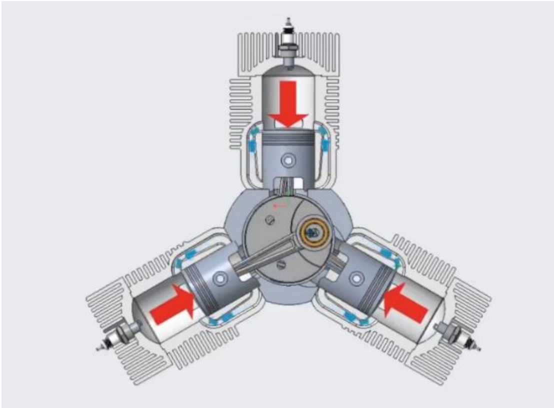

Figure 5: Exhaust process. [authors]

5. USAGE

During the development of this paper, many people inquired about the purpose of our engine. Let's begin where similar engines have been used for a long time. Hang gliders are aircraft in which we attempt to use simple propeller engines. Trabant engines have served in this capacity for over 60 years. As a result, we believe that our engine will be well received, as the increased volume will result in higher performance, which is always desirable in aviation. Its design also ensures simpler assembly and eventual service, as well as improved and more even cooling of all cylinders. Another application for these engines is in ultralight aircraft. It would be considered a lower-power engine, but its light weight would appeal to many aircraft builders. As the final category of flying machines, I'll mention the UAV.

Figure 6: Engine for ultralight aircraft. [authors]

6. CONCLUSION

We declare that we have met all of our objectives. One of the goals was to make the construction as efficient as possible in order to ensure the best possible reliability, consumption, and functionality of the entire drive unit. We can make a functional unit at a low cost thanks to the design, which makes use of many components that we already own. The most difficult challenge will be producing the engine block, which will require a five-axis milling machine, also known as a CNC, but we are confident that the background of our University of Zilina will assist us in producing this part and the entire unit, which can become a functional addition to the Department of Air Transport. It would also be possible to apply motorsports knowledge to the production of a given unit, thereby increasing the performance of our unit to the highest possible level. We would like to express our enthusiasm for the issue in this manner, and in the future, we would like to be a part of a group of people who build this type of engine. We believe we have persuaded you of the importance of this paper.

REFERENCES

[1] KMEŤ, Martin, 1979. *Trabant 601*. Martin: Alfa, 1979. ISBN: 63-222-79.

[2] PREUSCH, Eberhard, 1969. *Jezdíme trabantem.* Praha: Naše vojsko, n. p., 1969. ISBN: 28-006-69.

[3] ŠLEHOFER, Vlastislav, 1973. *Údržba a opravy vozu Trabant 600 a Trabant 601.* Praha: SNTL, 1973. ISBN O4-213-73.

[4] ŠLEHOFER, Vlastislav, 1984. *Údržba a opravy vozu Trabant 600 a 601.* Praha: SNTL, 1984. ISBN O4-238-84.

[5] TUČEK, Jan, 2009*. Auta východního bloku.* Praha: Grada, 2009. ISBN: 978-80-247-2585-7.

[6] 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.

[7] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

[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] JANOVEC, M., ČERŇAN, J., ŠKULTÉTY, F., NOVÁK, A. 2022. Design of batteries for a hybrid propulsion system of a training aircraft. Energies, 2022, 15(1), 49. ISSN 19961073.

[10] JANOVEC, M., BUGAJ, M., SMETANA, M. 2019. Eddy Current Array Inspection of Riveted Joints. Transportation Research Procedia, 2019, 43, pp. 48–56. ISSN 23521457.

[11] ČERŇAN, J., JANOVEC, M., HOCKO, M., CÚTTOVÁ, M. 2018. Damages of RD-33 Engine Gas Turbine and their Causes. Transportation Research Procedia, 2018, 35, pp. 200–208. ISSN 23521457.

[12] 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.

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ANALYSIS OF SMART SOLUTIONS IN THE FIELD OF AIRPORT MAINTENANCE WITHIN INTERNATIONAL AIRPORTS

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Abstract

The paper deals with the analysis of various smart solutions that can be implemented in airport maintenance. The aim of this paper is to compare the current situation in Slovakia with smart solutions that have been used in the world and to suggest which of the solutions could be implemented in Slovakia. The theoretical part describes the purpose of smart airports and conventional methods of airport maintenance. The next part of the paper is devoted to the description of the current state at the airport in Bratislava and a description of smart solutions used around the world. These may include: scaring birds with drones, snow removal with autonomous ploughs, mowing lawns with robotic mowers, inspection of the Instrumental Landing System ILS with drones and inspection of the Precision Approach Path Indicator PAPI with drones. The last part of the paper compares conventional maintenance methods used at the airport in Bratislava with their smart solutions used around the world. The evaluation includes a proposal for smart solutions which could effectively be used at Bratislava Airport.

Keywords

Scaring birds, Drone, Snow removal, Autonomous ploughs, Robotic mowers, ILS maintenance, PAPI maintenance

1. INTRODUCTION

Air transport is developing very fast and is being used by more and more people. New technologies are constantly being developed in airport maintenance to ensure high security, improved services, reduced costs and, finally, environmental friendliness. Some of the many types of airport maintenance are bird scaring, airport snow removal, lawn maintenance, ILS inspection and PAPI inspection. The aim of this paper is to compare conventional maintenance methods with their smart solutions and to suggest which of the smart solutions should be implemented at the airport in Bratislava. This paper describes selected types of airport maintenance. The next chapter contains the current situation at the airport in Bratislava and presents the possibility of using smart solutions in the field of airport maintenance on examples of those used at various airports around the world. The airports where smart airport maintenance solutions have been used are Brussels, Oslo, Victoria, Zurich and Geneva. The final part of the article is devoted to the comparison of conventional and smart methods of airport maintenance and their evaluation.

2. THEORETICAL BACKGROUND OF THE PROBLEM TO BE ADDRESSED

2.1. Scaring birds

The occurrence of birds varies from airport to airport and depends mainly on the local habitat, weather, or season. In Europe and North America, seagulls, swans, geese, gray herons and cormorants are the most common [1,2].

The method of scaring birds has to be adapted due to the presence of different species. The following methods can be used for scaring:

- Trained birds of prey and dogs, which are most effective in focusing on a small area with a specific goal, but their disadvantage is the high cost of training and breeding.
- The use of pyrotechnics is one of the most used tools. Propane cannons work similarly, but shotgun shots are also used.
- Playing sounds, whether artificial or predator, can create a zone in a strategic deployment, where most birds are uncomfortable to stay.
- Hand-held lasers, despite the enormous threat to aviation safety, can be very effective if used correctly [1,2,3].

2.2. Snow removal

When removing snow, machines are used that can, at first glance, resemble those used on roads. Equipment includes ploughs, brooms, ploughshares, blowers, or vehicles with chemical tanks. However, the difference is in the method of cleaning. The snow plough is the same as the one used on the roads, but the left snow is additionally swept by a roller broom, blown by a stream of air and then the surface is finally treated by applying a defrosting agent [4,5].

2.3. Grass surface maintenance

The grass surface must be carefully maintained, and not just because of its appearance. The grass must be mowed regularly at airports so as not to block the visibility of the runway and the lights placed. The grass must also not be so long as to prevent pilots, who do not know the aerodrome terrain thoroughly, in visual contact with the taxiway navigation elements, which are the various guidance signs. Tall grass can even affect the transmission of data communication data between the aircraft and the ground. Several types of machinery are used for mowing. These can be mowers of various shapes and sizes, wide-area mowers, or mowers with the option of grass collection and cleaning [6,7].

2.4. ILS maintenance

The quality control of ILS signal transmission must be checked regularly for security reasons. To maintain ICAO ILS certification, airport operators, subcontractors, or government agencies must perform dynamic measurements. Calibration, testing, or inspection of radio navigation equipment may be performed by ground or flight inspection. Flight inspection is performed using a manned aircraft, which requires preparation for ground measurements to optimize flight intervention [8,9,10].

2.5. PAPI maintenance

In order to maintain the operating conditions and accuracy of the system, their maintenance is performed either by ground lifting equipment or by air control. The system is very precisely set to the required angle and deflection can occur, for example, due to the expansion of the structure due to a change in outdoor temperature. Routine visual inspections are performed daily and, if necessary, the external parts must be cleaned of dust or other impurities. The optical parts of the unit must be inspected approximately once a month to confirm that they are free of mechanical damage. At the same time, the correct attachment of the unit to the base is checked. Once a year, a detailed system check is performed, the angles are set correctly, and the optical parts are cleaned [11,12].

3. CURRENT STATE OF THE SOLVED PROBLEM IN SLOVAKIA AND ABROAD

3.1. Current situation at Bratislava Airport

Smart solutions have not yet been used at Slovak airports and therefore the situation in Slovakia will be described at the airport in Bratislava.

Conventional methods are used here for maintenance. Falcons or shotguns are used for scaring birds, ordinary plows and other vehicles are used for snow removal, mowers and tractors are used for mowing grass and a calibration aircraft is used for ILS and PAPI calibration.

3.2. Drone scaring birds at Brussels Airport- Zaventem

A bird control unit in Brussels regularly scares flocks to eliminate aircraft-bird interaction, but their vehicles are unable to reach all parts of the airport. In order to explore the possibilities of innovative use of drones, they organized test days when drones were used to scare birds in safe conditions. The tests did not affect the operation of the airport and the use of runways. The drone was piloted at a safe distance from the aircraft and only in the period between take-off and landing of the aircraft. During the test days, the drone was used to control the birds, which includes their detection, monitoring and, if necessary, their guidance outside the dangerous areas of the airport. Ideally, Brussels Airport will train the staff of the existing bird control unit for drone flying, as they already know the local terrain thoroughly [13,14,15].

3.3. Snow removal with autonomous ploughs at Oslo Airport-Gardermoen

Autonomous snowploughs have shown great potential for cost reduction during testing. With a length of 20 meters and a width of 5.5 meters, they had sufficient capacity to be able to clear an area of 357,500 m2 per hour from snow. Robotic vehicles are also able to perform airport maintenance in formations, with several vehicles cooperating with exceptional accuracy, regardless of the weather. The new solution meets high security standards. The system is developed with the possibility of condition monitoring, where a complete overview of the condition of equipment and possible service needs is provided. Following a series of successful tests, it is planned to expand the snow removal machines with plough, brush, blowing and spraying functions to the ten largest airports in Sweden, while the machines will be equipped with the latest technology for autonomous operation [16,17,18].

3.4. Lawn maintenance with robotic lawnmowers at Victoria Airport

There are several advantages to using robotic lawnmowers. Automating the lawn maintenance process eliminates some of the risks to staff, and thus mowing in critical areas, helping to reduce the number of employees who have more time to deliver value-added services to Victoria Airport and become technicians in new, innovative facilities. One of the main advantages, therefore, is the resulting cost reduction. The time required to inspect and maintain the robotic lawnmower and its peripherals, including charging stations, is negligible compared to the time required for conventional mowing. Last but not least, it is necessary, especially today, to take into account the production of carbon dioxide emissions. Fuel requirements cannot be underestimated with conventional mowing methods. The introduction of an electric alternative makes it possible to radically reduce the airport's carbon dioxide emissions and carbon footprint [19,20,21].

3.5. Maintenance of the ILS system by drones at Zurich Airport

The idea of a systematic and automatic comparison of ILS flight checks and ground measurements in order to reduce the frequency of flight checks in Switzerland dates back to 2002. Along with the rapid advances in drone technologies, their use for measurement purposes began to be considered. The first step was to test whether the drone could carry the required load, which was almost 8 kg. A positive factor was the first assessment of flight stability and the ability to manoeuvre with the load. After successful tests, a measuring receiver and antennas were mounted on the drone. The positive evaluation of the new measurement method was concluded by positive results in terms of repeatability and accuracy. It was no longer just the idea of using a drone, but this new method of measuring techniques became a reality [22].

3.6. Maintenance of the PAPI system by drones at Geneva Airport

The PAPI drone calibration solution began to be commercialized in early 2018. Since then, we have seen positive feedback on the use of drones from the affected markets. At the end of 2019, Drone Canard successfully inspected visual aids at Geneva Airport in Switzerland. In addition to the PAPI control, the Canard solution was also used to inspect the approach lighting system on both sides of the runway in real time. With the least impact on the normal operation of the airport, Canard cites the possibility of flying a calibration drone day and night as an example of flexibility. The planned window for the flight at Geneva Airport was set between 00:00 and 05:30, with all activities ending by 2:30. The actual occupation of the runway took only a few minutes [23,24].

4. WORK RESULTS AND EVALUATION

The following part compares the current situation at the airport in Bratislava with smart solutions that are used or tested at airports around the world. Subsequent evaluation of the work contains a proposal for solutions that could be effectively implemented at the airport in Bratislava.

4.1. Comparison of bird scaring methods

As it was during flying with drones found, drones act on the animals disruptively. After several attempts and efforts to replicate birds of prey by remote-controlled models, it turned out that a classic drone can be used for this purpose. For more efficient scaring, it can be equipped with a speaker that replicates the sounds of predators that act as a deterrent. Compared to the classic method of scaring with predators, it brings several advantages as an additional tool to support biological protection units. In addition to immediate deployment, the advantage of using a drone is that it can be operated from a bigger distance and biological protection units do not have to be transported often to inaccessible places within the airport. As demonstrated during testing at Brussels Airport, the drone does not pose a threat to the flow of air traffic when flying in safe conditions.

4.2. Comparison of snow removal methods

One of the advantages of using autonomous snow ploughs is that they can perform airport maintenance in formations with great accuracy in any weather. The result of the ability to ride in formations together with their width of 5.5 m is their ability to clean a large area from snow in a short time, which results in a reduction in the number of ploughs and a reduction in the number of ploughs results in reduced environmental burden and operating costs. As a result of the introduction of autonomous operation, staff do not have to be exposed to adverse weather conditions and can monitor the whole process from the control station, communicating with the control tower staff and selling them up-to-date information on the state of the track. The orders are sent from the control station to the autonomous ploughs based on current information and permission to perform work from the control tower.

4.3. Comparison of grass surface maintenance methods

Lawnmowers drive internal combustion engines and are therefore not the optimal solution in an active effort to reduce the burden on the environment. Driving lawn mowers is provided by airport staff, who are exposed to the risk of a collision with the aircraft during work. The solution can be the use of robotic lawnmowers. Unlike conventional vehicles, robotic lawnmowers are fully autonomous and airport staff only assign tasks to the lawnmower through the application. Easy operation helps to reduce the number of employees whose job is no longer to drive, but to take care of the maintenance of the mower and its peripherals, which is less time-consuming than manual mowing. The reduction in the number of employees also results in a reduction in personnel costs. Autonomous mowers are also able to work during the rain, which can be an unpleasant factor for airport staff. Because robotic lawnmowers are powered by an electric motor, they run quieter and can work at night. At the same time, electric propulsion reduces the airport's carbon footprint.

4.4. Comparison of ILS maintenance methods

In order to reduce the number of required flights, it is possible to be inspired by the use of a drone at Zurich Airport. This allows the preparation of the calibration aircraft before its flight. The result of using drone is the saving of costs for expensive and time-consuming operation of the calibration aircraft. At the same time, as the drone is incomparably smaller than the aircraft, the overall process noise also decreases. As a result, the measurement activity can also be performed at night, and during low traffic times, which results in the elimination of unpleasant events in connection with the need to temporarily decommission the ILS system. Another important fact is the reduction of carbon dioxide emissions, as the drone is powered by electricity compared to the internal combustion engines present in the calibration aircraft. As it turned out, progress in the design of drones can ensure trouble-free drone flight capabilities in the event of a load in the form of a measuring system and antenna. The solution therefore appears to be a suitable way to extend the performance of control measurements.

4.5. Comparison of PAPI maintenance methods

Drone testing of PAPI system is less time consuming than flying a calibration aircraft. It only takes a few minutes to occupy the runway during a drone inspection, which is reflected in the shorter time required to take the runway out of service. Due to the lower drone noise compared to the noise of the calibration aircraft, the inspection can be performed even at night, when the operation is less busy. The electric drive of the drone, as mentioned earlier, reduces the total production of carbon dioxide, which is not negligible when using a calibration aircraft. The present software allows the control to be performed with a high degree of automation, which reduces the intervention of the crew.

4.6. Evaluation

To evaluate the aspects of the implementation of individual smart solutions at airports, it is necessary to compare the number of passengers handled at airports, which may reflect their initiative in development. The table shows the number of passengers handled per year before the outbreak of the COVID-19 pandemic, so that the data as accurately as possible reflect the reality and not be affected by different measures to prevent the spread of the disease in each country.

Table 1: Number of passengers handled at airports in 2019. [25,26,27,28,29,30, processed by the author]

Airport	Number of handled passengers
Bratislava	2,2 mil.
Brussel	26,4 mil.
Oslo	28,5 mil.
Victoria	1,9 mil.
Zurich	31,5 mil.
Geneva	17,9 mil.

In the case of evaluating the effectiveness of autonomous snow ploughs and their possible introduction at the airport in Bratislava, it is also important to compare the average amount of precipitation in the form of snow in Bratislava and Oslo.

Table 2: Characteristics of snowfall in Bratislava and Oslo. [31,32, processed by the author]

Airport	Average amount of snow precipitation	Length of snowfall period in months
Bratislava	7 cm	4
Oslo	22 cm	6

In most cases, smart devices are used at busier airports than Bratislava Airport. An exception is Victoria Airport, where robotic lawnmowers were used. The efficiency of robotic lawnmowers does not have to be conditioned by the large number of checked-in passengers, which is associated with the airport's efforts to implement innovative maintenance methods. Their deployment can therefore be very advantageous in Bratislava as well. As pointed out, they offer several advantages, and their implementation does not require extensive preparation or demanding training for staff.

Another smart solution that would positively affect the operation of Bratislava Airport is the deployment of drones to scare away birds. Drones are more reliable than birds of prey used at Bratislava Airport. In the case of Bratislava airport, the use of a drone would be a good way to expand the methods of scaring birds.

The last smart solution that could be implemented at the airport in Bratislava and would show efficiency is the use of a drone to inspect the PAPI system. As the method of inspect using a drone would completely replace the need to carry out the flight with a calibration aircraft, this inspect could be carried out by the airport itself. As with the use of a drone to scare birds, airport staff would be trained to measure with a drone.

The inspect of the ILS system with a drone is only a pre-flight preparation of the calibration aircraft, which is still necessary. Although the use of a drone will speed up the measurement and reduce the required number of flights performed by the calibration aircraft, it is only an additional factor in the inspect of the ILS signal and does not have much potential at the airport in Bratislava. The investment in a drone to inspect the ILS system in the case of Bratislava Airport is not as advantageous as in the case of using a drone to inspect the PAPI system.

Of the selected smart solutions, the use of autonomous snow ploughs at Bratislava Airport is the least efficient. Compared to Oslo, where autonomous plows are used, there is a period in Bratislava when precipitation in the form of snow can be expected by two months less. Like the shorter length of the snowfall period, the amount of precipitation is a key factor. In the month with the highest amount of precipitation in the form of snow, which in the case of Bratislava and Oslo is January, about a third of snow falls in Bratislava compared to Oslo. Climatic conditions remain the main reason why the use of autonomous snow ploughs in Bratislava is not efficient.

5. CONCLUSION

Rapid advances in technology enable the introduction of new and innovative solutions also in airport maintenance. New smart solutions can speed up the maintenance process, reduce costs and reduce the burden on the environment, which is currently in high demand.

More and more new, smart solutions for airport maintenance are being used around the world, especially at large international airports. However, there are also solutions that have found application at smaller airports, which are at a similar level in terms of the number of passengers handled per year as the airport in Bratislava.

The potential to introduce new smart solutions in airport maintenance in Slovakia is undoubtedly. Some smart solutions are less suitable, while others show a favourable level of compatibility with local conditions. Robotic lawnmowers have proven to be the most suitable smart solution in the field of airport maintenance in the case of Bratislava Airport. At the same time, there is an opportunity to examine whether the use of robotic lawnmowers would be suitable at other, not only international but also regional airports in Slovakia. With a strong emphasis on streamlining processes, increasing safety, and reducing the burden on the environment in air transport, it is only a matter of time before we see more and more similar smart solutions used in Slovakia.

REFERENCES

[1] Piotr Matyjasiak. 2008. Methods of bird control at airports. [cit.2022-05-02] https://www.researchgate.net/publication/233389769_Methods_of_bird_control_at_airports

[2] Dawi Musa Hamed. Bird strike hazards. [cit.2022-05-02] https://www.icao.int/MID/Documents/2018/WHMC-December/2-1%20Bird%20strikes%20hazard.pdf

[3] 9 Ways to Deter Birds at Airports. Medium.https://medium.com/faa/9-ways-to-get-rid-of-birds-at-airports-555582625363 (cited 2022-05-02)

[4] Pavel Rejlek. 2020. Against the clock: Removing snow from the runway within half an hour. International Airport Review. [cit. 2022-05-02] https://www.internationalairportreview.com/article/117833/removing-snow-runway/

[5] Snow removal. Fly Denver. https://www.flydenver.com/about/media_center/snow_removal (cited 2022-05-02)

[6] Noel Oman. 2021. Mowing not just a chore at risk-conscious Little Rock airport. Arkansas Democrat Gazette. [cit. 2022-05-02] https://www.arkansasonline.com/news/2021/oct/18/mowing-not-just-a-chore-at-risk-conscious-airport/

[7] TRILO Multifunctional Grass Cutters and Collectors, and Flail Mowers. Airport Technology. https://www.airport-technology.com/contractors/apron_clean/trilo/ (cited 2022-05-02)

[8] Feasibility of More Flexible ILS Ground Inspection (OPUS). KDC Mainport Schiphol. https://kdc-mainport.nl/2020/12/21/feasibility-of-more-flexible-ils-ground-inspection/ (cited 2022-05-02)

[9] PECA Public Authority for Civil Aviation. 2020. Flight Inspection Manual For Radio Navigation Aids. [cit. 2022-05-02] https://www.caa.gov.om/upload/files/Flight%20Inspection%20Manual_Final_Approved%26form.pdf

[10] Airport automatic landing systems: ILS, calibration using drones. AltiGator. https://altigator.com/en/ils-calibration-drone-air-traffic-management-uav/ (cited 2022-05-02)

[11] Elistair. 2017. Airport Maintenance PAPI calibration at Paris-Le Bourget. [cit. 2022-05-02] https://elistair.com/wp-content/uploads/2017/03/Use-Case-Airport-Maintenance-PAPI-Calibration-at-Paris-Le-Bourget.pdf

[12] ADB Safegate. 2022. PAPI- Precision Approach Path Indicator (PU3L) User Manual. [cit. 2022-05-02] https://adbsafegate.com/documents/4710/en/manual-pu3l

[13] MARK FINLAY. 2021. How Brussels Is Tackling The Issue Of Airport Birds. Simple Flying. [cit. 2022-05-02] https://simpleflying.com/brussels-airport-birds-drones/

[14] Brussels Airport and skeyes test use of drones for bird control during normal operations. Brusel-Zaventem airport. https://www.brusselsairport.be/en/pressroom/news/drones-for-bird-control (cited 2022-05-02)

[15] LISA BRADSHAW. 2021. Brussels Airport tests use of drone to chase away birds. The Bulletin. [cit. 2022-05-02] https://www.thebulletin.be/brussels-airport-tests-use-drone-chase-away-birds

[16] No more stranded passengers at airports in the winter thanks to self-driving snow clearing vehicles. European comission. https://digital-strategy.ec.europa.eu/en/news/no-more-stranded-passengers-airports-winter-thanks-self-driving-snow-clearing-vehicles (cited 2022-05-02)

[17] Next step in autonomous snow removal at Norwegian airports. Cision. https://news.cision.com/semcon/r/next-step-in-autonomous-snow-removal-at-norwegian-airports,c3321638 (cited 2022-05-02)

[18] Yeti – world's first autonomous snowploughs at airports. Semcon. https://semcon.com/yeti/ (cited 2022-05-02)

[19] Robotic Mower Being Tested at Victoria International Airport. Victoria airport. https://www.victoriaairport.com/news/2018/robotic-mower-being-tested-at-victoria-international-airport (cited 2022-05-02)

[20] Automatic Robot Mower for Airports: Revisit: Case Study. Belrobotics. https://www.belrobotics.com/en/blog/case-study/automatic-robot-mower-for-airports-revisit-case-feedback/ (cited 2022-05-02)

[21] Robotic mowing for Airports and Airfield Green Areas. AMS Robotics. https://www.amsrobotics.co.uk/robotic-mowers-for-airport-mowing/ (cited 2022-05-02)

[22] HERVÉ DEMULE, KLAUS THEIßEN. 2018. Using UAV multicopters as an extension of ILS ground measurements: This innovative idea has already become reality in Switzerland! [cit. 2022-05-02] http://www.icasc.co/sites/faa/uploads/documents/20th_IFIS_Papers/Papers/IFIS18-0024.pdf

[23] PAPI & ALS Inspection at Geneva International Airport. Canard Drones. https://canarddrones.com/portfolio/papi-als-geneva/ (cited 2022-05-02)

[24] CANARD Introduces Complete Airport Lights Inspection And Calibration Package. Airport Technology. https://www.airport-technology.com/contractors/airfield-safety/canard-drones/pressreleases/lights-inspection-calibration-package/ (cited 2022-05-02)

[25] Number of terminal passengers at Oslo Airport in Norway from 2009 to 2021. Statista. https://www.statista.com/statistics/797383/number-of-terminal-passengers-at-oslo-airport-in-norway/ (cited 2022-05-02)

[26] Štatistické údaje. Letisko M.R. Štefánika. https://www.bts.aero/o-letisku/o-spolocnosti/profil-spolocnosti/statisticke-udaje/ (cited 2022-05-02)

[27] Brussels Airport in numbers. Brusel-Zaventem airport. https://brusselsairportinnumbers.brusselsairport.be/ (cited 2022-05-02)

[28] Victoria International Aiport Passenger Statistics. Victoria airport. https://www.victoriaairport.com/pdfs/stats/1_February_2022_Total_Passengers_BySector_Stats.pdf (cited 2022-05-02)

[29] Key Figures Dezember 2019. Zurich Airport. https://www.flughafen-zuerich.ch/newsroom/key-figures-dezember-2019/ (cited 2022-05-02)

[30] Slight Rise in Passenger Numbers and Decrease in Aircraft Movements in 2019. Genève Aéroport. https://www.gva.ch/en/Site/Geneve-Aeroport/News/2024-2015/Passagers-et-mouvements-2019 (cited 2022-05-02)

[31] Climate and Average Weather Year Round in Bratislava. Weather Spark. https://weatherspark.com/y/82397/Average-Weather-in-Bratislava-Slovakia-Year-Round (cited 2022-05-02)

[32] Climate and Average Weather Year Round in Oslo. Weather Spark. https://weatherspark.com/y/68697/Average-Weather-in-Oslo-Norway-Year-Round (cited 2022-05-02)

[33] KAZDA, A., CAVES, R.E. 2007. Airport Design and Operation. Bingley: Emerald Group Publishing Limited, 2007. 538 s. ISBN 978-0-08-045104-6.

[34] KAZDA, A. 1995. Letiská design a prevádzka. Žilina: Edičné stredisko VŠDS 1995. 377 s. ISBN 80-7100-240-2

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

[36] 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.

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ANALYSIS OF SATELLITE NAVIGATION SYSTEMS USABLE IN GENERAL AVIATION

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Abstract

This paper is mainly focused on solving the current issues of satellite navigation systems and subsequent analysis. The paper is systematically divided, while the first chapter focuses mainly on the definition of satellite navigation systems, their use in general aviation and introduction of specific examples, their division in terms of operation and a description of advanced satellite navigation systems. The second chapter deals with the methodology of work, analyzes the sources and the chosen procedure for solving and researching the issue. The third chapter is the main one and is focused on the analysis and research of satellite navigation systems, defining input parameters such as: accuracy, continuity, or integrity of navigation services. It also compares research with the current state of the issue and evaluates analyses, suggests possible changes and directions of further research in satellite navigation industry.

Keywords

GNSS, Accuracy, Integrity, Continuity, Availability, Analysis, Comparison, Starlink, Multi-GNSS

1. INTRODUCTION

Satellite navigation systems - this is the convenience of civilization of the 21st century. They are the pinnacle of cutting-edge science and technology and are currently part of our lives. They make our functioning easier and many of us can no longer even imagine life without them. These systems allow us to navigate quickly, accurately and, in addition, easily. Positioning with them is very accurate and easy. The advantage is that the determination does not only apply to the earth's surface, but satellite navigation systems are also able to determine the position in the air. That is why they are widespread globally and we will meet them in every industry. GNSS (Global Navigation Satellite System) today includes the following systems: NAVSTAR GPS, GLONASS, GALILEO, COMPASS, IRNSS, QZSS. This huge development of satellite navigation systems has been caused by the huge growth of aviation, whether civil or military. Operators therefore needed to reduce fuel consumption, emissions, and eliminate flight delays. All this resulted in a huge increase in the number of aircraft in the air, which required an increase in airspace capacity. In addition, the enormous increase in airspace use by aircraft has created a significant need to improve communication, navigation, and surveillance equipment. As a result of all these requirements, a GNSS global navigation system has been developed that supports positioning applications and is also the basis for performance-based navigation (PBN), automatic dependent tracking (ADS-B and ADS-C). GNSS also offers us a time reference that is used to synchronize systems, avionics, communications networks, and operations. In addition, it supports a myriad of opportunities for use outside the aviation sector. In my paper, I will focus on the above-mentioned satellite navigation systems, in which we will approach their use, describe the procedure, which I will then follow with practical examples. We will also divide them all from the point of view of operation, into civilian and military. We will also look at what advanced satellite navigation systems are. Subsequently, we move on to the practical part of my paper, whose task will be to analyze satellite navigation systems in terms of usability in general aviation, where we define the input parameters, which include accuracy, continuity of navigation services. After completing this analysis, we interpret all the results. At the end of this paper we will create a discussion where we will compare our findings with the current state in the world of satellite navigation systems and think about how these devices and systems could be improved in the future to work more efficiently, faster and easier, and also where we should direct our future research so that we can achieve our stated goals.

2. MATERIALS & METHODS

I used several methods to create my paper. First it was necessary to study the literature and then in the next stages I used the method of comparison or comparison of information from available sources about satellite navigation systems, their extensions (augmentation), division, their implementation or performance navigation. In the process of summarizing the facts obtained, I also used the method of analysis. The submitted paper consists of three main chapters. In the introduction I deal with a general presentation of the issues addressed in my work, I explained the reasons for choosing the topic. The second chapter discusses materials and methods which were used to write this paper. The third chapter analyzes and solves the parameters of satellite navigation systems. This is developed based on selected input parameters, as well as the way in which the values of these parameters are obtained. Subsequently, a comparison is made using the obtained facts and values. These are inserted into several tables, based on which we can draw a conclusion and the analysis itself. In the fourth, and therefore my last, chapter, I discuss and analyze the very results of my previous research. I will compare the results with the current state of the problem and propose changes for future improvements to satellite navigation systems.

As I already mentioned in my paper, to create an accurate analysis, it is necessary to choose the input parameters based on which we will create the analysis. I chose four basic parameters from the environment of satellite navigation systems, namely: accuracy, integrity, continuity, availability, which we will describe in more detail.

2.1. Accuracy

GNSS position accuracy is defined as the difference between the calculated and actual position. Ground systems such as VOR and instrument landing systems (ILS) have relatively fixed error characteristics. These characteristics can therefore be measured during flight control and subsequently monitored electronically to ensure signal accuracy. However, GNSS errors can change over the hours due to satellite motion and ionospheric influences. Augmentation systems are designed to monitor and compensate for these changes [9].

2.2. Integrity

Integrity is a measure of the confidence that can be placed in the accuracy of information provided throughout the system. Integrity includes the ability of a system to notify the user when the system should not be used for the intended operation. In the case of a conventional device such as ILS, the accuracy of the signal can be monitored at specific points. In contrast, GNSS integrity is based on avionics performing complex calculations to ensure that the error in the calculated position does not exceed the maximum allowed for the current operation [9].

The required level of integrity for each operation is determined with respect to specific vertical guidance approaches, vertical warning limits. Avionics continuously calculates the appropriate protection levels. They are used with ABAS and SBAS. Protection levels are upper confidence limits for position errors; alert limits define the maximum position error allowed for an operation. When any level of protection exceeds the applicable warning limit, the avionics must provide a warning and the flight crew must follow the prescribed procedures [9].

Time-to-alert, or time to alert, is also part of the integrity requirement; it is the maximum time allowed from the beginning of the fault condition to the announcement in the aircraft. Other system integrity requirements are, for example, Error tolerance or Risk probability. Error tolerance or error tolerance expresses to us how much the system can respond to user errors and then correct them. On the other hand, probability risk or probability of risk is the probability that some risk will occur that could affect the integrity of the system [9].

2.3. Continuity

Continuity is the ability of a system to perform its function without unplanned interruptions during an intended operation, expressed as a probability. For example, there should be a high probability that guidance will remain available throughout the instrument approach process. In the case of ABAS, continuity depends on the number of satellites monitored. For GBAS and SBAS, continuity also depends on the redundancy of the components of the expansion system [9].

The continuity requirements are less stringent for airspace on a low-density route and more stringent for areas with high-density and airspace complexity where the failure could affect many aircraft. The requirements are also more stringent for approach operations [9].

If there is a high degree of reliance on GNSS for en-route and terminal navigation, loss of service can be achieved by using alternative means of navigation or by using radar and ATC intervention to ensure that the separation is maintained. This is not possible when ADS-B is the only source of tracking because GNSS provides ADS-B location [9].

For APV and CAT I GNSS-based approaches, a missed approach is considered normal operation because it occurs whenever the aircraft drops to the approach decision height and the flight crew is unable to proceed with visual orientation. The continuity requirement for these operations refers to the average risk of loss of service, normalized to a 15-second exposure time. The specific risk of loss of continuity for a given approach could therefore exceed the average requirements without necessarily affecting the security of the service or access provided. The safety assessment carried out for one system led to the conclusion that, in the circumstances set out in the assessment, continuing to provide the service was safer than withholding it. The anticipated failures for which the pilot message is distributed are not considered in the continuity calculation [9].

2.4. Availability

Service availability is the part of time that the system simultaneously provides the required accuracy and integrity. In fact, integrity always determines availability. Some applications have specific continuity requirements that must be met for the service to be available. The movement of the satellites relative to the coverage area complicates the availability of GNSS, as well as the potential delays associated with returning the faulty satellite. The level of availability in each airspace at a given time should be determined through design, analysis, and modeling rather than measurement [9].

In determining airspace specifications, countries should consider traffic density, available conventional aids, radar surveillance coverage, potential duration and geographical size of outages, as well as flight and ATC procedures [9].

3. RESULTS

In this part of my paper, we will look at the comparison of GPS, Galileo, GLONASS and Bei Dou systems in terms of all pre-selected input parameters.

3.1. Comparison of Accuracy

In this section, we compare the values obtained in terms of accuracy of individual systems. We will consider the average values from the accuracy measurements of all satellite navigation systems, while the GPS system will consider only the most current measurements.

Table 1: Average accuracy values of the investigated systems.

GPS	Galileo	GLONASS	BeiDou
1.2m	0.5m	17.7m	12m

From table no. 1 we can clearly compare the accuracy of individual systems and we can deduce which system lags in which area and what are its shortcomings. GPS and Galileo are the clear leaders in accuracy with average deviations of 1.2 and 0.5 meters. The GLONASS and Bei Dou systems are slightly worse with deviation values of 17.7 and 12m [1][2][3][4][5].

3.2. Comparison of Availability

For a detailed comparison of systems in terms of availability, we insert the values of the systems into the table.

Table 2: Values of availability of investigated systems.

System	GPS	Galileo	GLONASS	BeiDou
Interval	1,00	0.8151 – 0,9996	0,99 – 1,00	0,96 – 1,00

From table no. 2 we can very easily obtain information about the availability of individual satellite navigation systems. The best of the analyzed systems in terms of availability came the GPS system, although as I mentioned above, the measurement of this system took place in the shortest time of all systems. On the contrary, the Galileo system came out worst in this comparison, precisely because of the already mentioned incident of this system, which caused a relatively long-term loss of system availability in the measured area [1][6].

3.3. Comparison of Continuity

Based on the available information, we were able to determine the values of continuity measurements in various satellite navigation systems. The continuity data for the GLONASS and Bei Dou systems are the most relevant for us, as they were performed over a long period of time, while the GPS system, which showed 100% continuity in the tests, was tested in the study only for a short time [1][6].

Table 3: Comparison of continuity values of GLONASS and Bei Dou systems.

System	GLONASS	BeiDou
Interval	0,9958 – 0,9998	0,996 – 0,999

Table no. 3 shows that the GLONASS and Bei Dou systems are almost identical in the long run. Even though the GPS system was tested only for a short time, we can deduce that the long-term value of continuity and the degree of reliability of this system would be almost identical to those of other satellite navigation systems [1][6].

3.4. Comparison of Integrity

When comparing systems in terms of integrity, it is important to be aware of the integrity requirements for each system and whether the system meets them [1][7][8].

Table 4: Integrity requirments for each system.

	Items	GPS	GNLOASS	Galileo	BDS
P_{sat}	Error Tolerance	URE > 4.42 × IAURA	URE > 70 m	URE > 4.17 × URA	URE > 4.17 × URA for B1I; URE > 4.42 × SISA for B1C and B2a
	Time-to-Alert (TTA)	10 s	10 s	Not applicable	60 s for ground monitoring and alarming; 6 s/300 s for satellite and alarming
	Probability	$\leq 10^{-5}$	$\leq 10^{-4}$	$\leq 3 \times 10^{-5}$	$\leq 10^{-5}$
P_{const}	Error Tolerance	URE > 4.42 × IAURA	URE > 70 m	URE > 4.17 × URA	URE > 4.17 × URA for B1I; URE > 4.42 × SISA for B1C and B2a
	Time-to-Alert (TTA)	10 s	10 s	Not applicable	300 s for ground monitoring and alarming; 6 s for satellite monitoring and alarming
	Probability	10^{-8}	10^{-4}	$\leq 2 \times 10^{-5}$	$\leq 6 \times 10^{-5}$

In table no. 4 we can see the integrity requirements for the individual systems GPS, GLONASS, Galileo and Bei Dou. The most important factor when comparing integrity is to determine whether the system has met its own requirements [1][7][8].

Table 5: Meeting the requirments of individual systems.

System	GPS	GPS/GLONASS	BeiDou
Met/Did not met	✓	X	✓

From table no. 5 It follows that the only system that did not meet these system integrity and monitoring requirements is the combined GPS / GLONASS system [1][7][8].

3.5. Suggestion

To improve satellite navigation in all aspects, it would be appropriate in the future to implement a multi-frequency GNSS receiver that is able to calculate position, speed and time using a combination of signals transmitted by different satellite navigation systems, ensuring better accuracy, continuity, availability but also integrity than previously used satellite navigation systems.

3.5.1. *Multi-GNSS*

Until recently, the representative system for satellite navigation was the GPS system operated by the United States, but as we already know, other satellite navigation systems such as Galileo, GLONASS or Bei Dou are or will be implemented. In addition, augmentation systems such as SBAS as a network of geostationary satellite systems WAAS, EGNOS or MSAS are in operation.

a) Advantages of Multi-GNSS

Compared to positioning with a separate GPS system, it achieves higher accuracy, mainly due to the increased number of visible satellites, which also increases the success of positioning. This system receives many more satellite signals and is therefore able to determine the location in places where it has not been possible before. It is also able to withstand interference by frequency bands. In the future, this system would help industries and businesses to provide their products or services, as it is more reliable and accurate than stand-alone satellite navigation systems.

b) Multi-GNSS application options

It is certainly important to note where the multi-GNSS system could be used. This system is widely variable and could be used by many industries, such as the automotive industry, for its navigation and telemetry systems, and could also be used in regular transport for vehicle monitoring. It would also make a significant contribution to geographic information systems used, for example, in computer construction work. He would be able to sign up to save many lives in a disaster prevention management system, for example monitoring of seismic shocks, landslides or monitoring of dams.

3.5.2. Starlink

Another possible alternative is to use the Starlink system for satellite navigation in a similar way to GPS. Starlink is primarily intended for providing internet connection all over the world and especially in places not yet covered by it. Some scientists claim that they have found a way to adapt this system so that it can also be used for satellite navigation. These non-SpaceX researchers were able to triangulate signals from six Starlink satellites to focus on a single location on Earth. They achieved an accuracy of less than 8 meters. These values are very comparable to the accuracy of the GPS system itself. Another attempt to investigate the possible use of the Starlink system was carried out at the University of California, where an antenna was placed that was able to receive signals from Starlink satellites. Based on these signals, they were able to determine the position with an accuracy of 7.7m. It is worth noting that the Starlink system is not yet complete and therefore many more satellites will be in orbit. Thus, it is possible to assume that Starlink determination will become more and more accurate as Starlink itself progresses.

a) Advantages of Starlink

Traditional GPS has been around for over 30 years, so why change it? It is very simple. The GPS system has indeed been here for more than 30 years, which means that it is easy to use in smartphones or the automotive industry, but it is much more susceptible to attacks than the Starlink system. Another advantage is its height. The Starlink satellites are placed in orbit at an altitude of approximately 1,200 km from the Earth's surface and thus much closer than the GPS satellites placed in the mid-Earth orbit, which would allow the Starlink system to make more frequent hardware modifications.

4. CONCLUSION

The aim of my paper was to analyze satellite navigation systems usable in general aviation in terms of selected input parameters: accuracy, integrity, availability, and continuity of individual navigation systems. In my work, the analysis showed the need for continuous improvement of satellite navigation, especially in terms of accuracy, where I was able to demonstrate the enormous progress of the GPS system over the last decade. I have also managed to point out the need for gradual innovation and development of satellite navigation systems and their combinations. It was mainly focused on the analysis of professional literature relevant to the issue of satellite navigation systems. The main purpose of this analysis was to identify and compare satellite navigation systems in terms of selected parameters of integrity, continuity, accuracy, and availability. Emphasis was also placed on the methods used in the measurements of individual authors. These were then compared with the results and served as a tool for designing improvements to satellite navigation systems, which includes the implementation of a multi-GNSS system. It can calculate position, speed and time using a combination of signals transmitted by different satellite navigation systems availability but also integrity as previously used satellite navigation systems. The implementation of a multi-GNSS system would result in huge improvements in many industries, including automotive, construction or road vehicle monitoring. Another possible alternative is to use the Starlink system for satellite navigation in a similar way to GPS. It was created with the intention of providing an Internet connection, but scientists outside the Starlink group used its signals to determine the position with high accuracy, comparable to the GPS system.

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REFERENCES

[1] Pattinson M., Dumville M. (2019) Integrity and continuity analysis from GPS: výskumná správa. Nottingham Scientific Limited, 2019. 22 p.

[2] Matosevic M., Salcis Z., Berber S. (2006) A Comparison of Accuracy Using a GPS and a Low-Cost DGPS: výskumná správa. IEEE Transactions on Instrumentation an measurement, 2006. 7 p.

[3] Yayla G., Van Baelen S., Peeters G., Raheel Afzal M., Catoor T., Singh Y., Slaets P. (2020) Accuracy Benchmark of Galileo and EGNOS for Inland Waterways: výskumná správa. Leuven: a Intelligent Mobile Platforms (IMP) Research Group, Department of Mechanical Engineering, 2020. 10 p.

[4] Eissfeller B., Ameres G., Kropp V., Sanroma D. (2007) Performance of GPS, GLONASS and Galileo: výskumná správa. München: Wichmann Verlag, 2007. 15 p.

[5] Yang Y., Li J., Wang A., Xu J., He H., Guo H., Shen J., Dai X. (2013) Preliminary assessment of the navigation and positioning performance of BeiDou regional navigation satellite system: výskumná správa. Science China, 2014. 9 p.

[6] Lihong F., Rui T., Zengji Z., Rui Z., Xiaochun L., Jinhai L., Xiaodong H., Ju H. (2019) Evaluation of Signal-in-SpaceContinuity and Availability for BeiDouSatellite Considering Failures: výskumná správa. The Royal Institute of Navigation, 2019. 12 p.

[7] Bang E., Milner C., Macabiau C. (2017) Integrity Risk Evaluation for GPS/GLONASS RAIM with Multiple Faults: výskumná správa. Touluse: International Technical Symposium on Navigation and Timing, 2017. 8 p.

[8] Cheng L., Yueling C., Gong Z., Weiguang G., Ying Ch., Jun L., Chonghua L., Haitao Z., Fang L. (2021) Design and Performance Analysis of BDS-3 Integrity Concept: výskumná správa. Remote sensing, 2021. 20 p.

[9] ICAO Doc 9849: 2017: Global Navigation Satellite System (GNSS) Manual

[10] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A., JANOVEC, M. 2020. Komunikačné systémy v letectve. 1. vyd. - V Žiline : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 164 s. ISBN 978-80-554-1737-0.

[11] 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.

[12] NOVÁK, A. 2011. Komunikačné, navigačné a sledovacie zariadenia v letectve. Bratislava : DOLIS, 2015. - 212 s. ISBN 978-80-8181-014-5.

[13] NOVÁK, A., HAVEL, K., JANOVEC,M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

[14] MATAS, M., NOVÁK, A. 2008. Models of processes as components of air passenger flow model. Communications-Scientific letters of the University of Zilina 10 (2), pp. 50-54.

[15] NOVÁK, A., ŠKULTÉTY, F., KANDERA, B., ŁUSIAK, T. 2018. Measuring and testing area navigation procedures with GNSS. MATEC Web of Conferences 236, 01004.

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

[17] NOVÁK, A., PITOR, J. 2011. Flight inspection of instrument landing system. IEEE Forum on Integrated and Sustainable Transportation Systems, pp. 329-332.

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ARTIFICIAL INTELLIGENCE AND ITS USE IN AIR TRANSPORT

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Abstract

In recent years, modern technologies have found large applications in sectors such as engineering, healthcare, information technology, robotics, and so forth. One important field in the use of such modern technologies is the field of air transport, where the main objective of using these technologies is to facilitate work for people, make individual tasks more efficient and faster, or reduce the risks associated with human error. In this paper, we will look at artificial intelligence and its use in aviation. Despite the rapid pace of improvement, artificial intelligence is still finding its way to reach its full potential. The history of artificial intelligence dates back to ancient times when many philosophers wondered whether a machine could think. The answer is found in the second half of the 20th century, when, besides theoretical knowledge, we can also observe the first intelligent machines. There is no clear and single correct definition for artificial intelligence, so the subject of the next section is to define artificial intelligence from different sources. The following section details the difference between deep learning and machine learning, comparing their main differences and applications in aviation. The analysis of the current state of application of artificial intelligence in aviation represents the core part of this paper. The emphasis in the analysis is put mainly on applications in the field of airports, air traffic management and safety. In each of these areas, the benefits of using AI are evaluated based on already established AI-enabled technologies. Finally, by analysing the sources available and those applied in our work with the use of a mathematical model, we assess how important the role artificial intelligence currently plays in air transport.

Keywords

Artificial intelligence, Deep learning, Machine learning, Air transport, Airport, Air traffic management

1. SÚČASNÝ STAV RIEŠENEJ PROBELMATIKY

Umelá inteligencia mení fungovanie dnešného sveta a výrazne ovplyvňuje život obyčajných ľudí, pričom sa jej vývoj a zdokonaľovanie prudko zrýchľuje. Spoločnosť využíva stále väčšie množstvo dát a s rýchlym vývojom vo výpočtovej technike a neustále zdokonaľujúcimi sa algoritmami zohrá v budúcnosti umelá inteligencia hlavnú úlohu vo všetkých priemyselných odvetviach, čím dôjde ku zvýšeniu konkurencieschopnosti, produktivity a v prípadne správneho využitia tejto technológie aj k obrovským ekonomickým a spoločenským výhodám [1].

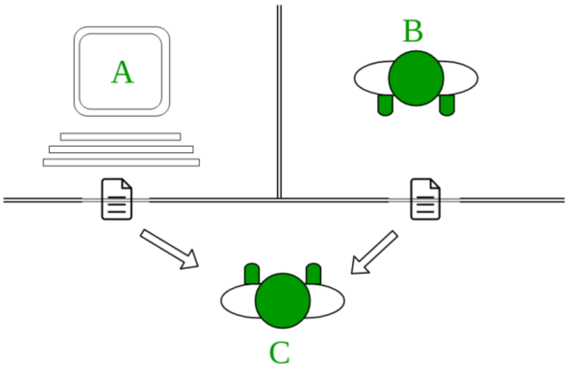
Plný potenciál umelej inteligencie však nie je v súčasnosti ani zďaleka využitý. Hoci existuje mnoho úspešných projektov, v ktorých sa aplikuje, pochopenie toho, ako môže AI vytvárať obchodné a spoločenské hodnoty, je stále len v začiatkoch [1].

1.1. História umelej inteligencie

Mnohé elementárne metodologické problémy umelej inteligencie boli dôležité vo filozofii už v staroveku, stredoveku a ranom novoveku. Filozofi ako Aristoteles, svätý Tomáš Akvinský, René Descartes a mnohí ďalší sa pýtali otázky: „Čo sú kognitívne procesy?“, „Aké nevyhnutné podmienky by mal spĺňať jazyk na to, aby bol adekvátnym nástrojom na precízne a jednoznačné opísanie sveta?“ alebo „Môže byť uvažovanie automatizované?“. Prvé experimenty, ktoré by pomohli zodpovedať otázku „Je možné skonštruovať systém umelej inteligencie?“, nebolo možné vykonať do 20. storočia. To sa zmenilo zostrojením prvých počítačov [2].

1.1.1. Turingov test

Uvedená imitačná hra je v skutočnosti prevádzkovou skúškou umelej inteligencie a môžeme ju opísať nasledujúcim spôsobom. Súčasťou tejto hry sú traja ľudia – muž (A), žena (B) a vyšetrovateľ (C). Vyšetrovateľ sa nachádza v inej miestnosti ako muž a žena, pričom cieľom vyšetrovateľa je určiť, kto zo zvyšných dvoch je muž a kto žena. Pozná ich pod označením X a Y. Na konci hry vyšetrovateľ priradí jednu z dvoch možností – X je muž a Y je žena alebo Y je muž a X je žena. Vyšetrovateľ môže klásť otázky typu: „Povie mi X, prosím, dĺžku svojich vlasov?“. X musí odpovedať na otázku vyšetrovateľa. Predpokladajme, že X je v skutočnosti A. Cieľom hry pre A je pokúsiť sa zmiasť C a pôsobiť tak, aby ho C nesprávne identifikoval. V takomto prípade by mohla odpoveď A znieť takto: „Moje vlasy sú dlhé a najdlhšie pramienky majú až 22 cm.“ Aby vyšetrovateľovi nepomohli vedľajšie faktory, napríklad tón hlasu, odpovede by mali byť napísané na papier, najlepšie však na písacom stroji alebo počítači. Cieľom hry pre hráča B je pomôcť C správne identifikovať osoby. Najlepšou stratégiou pre B je pravdepodobne podávanie pravdivých informácií. Môže si pomôcť tvrdeniami ako: „Ja som žena, nepočúvaj ho!“ Takéto tvrdenia môže podsúvať aj hráč A. Čo sa však stane v prípade, že stroj prevezme úlohu hráča A v tejto hre? Podľa Turinga je umelá inteligencia počítača rovnaká ako inteligencia človeka v prípade, ak vyšetrovateľ nedokáže takúto zmenu rozlíšiť [2] [3].



Obrázok 1: Schéma Turingovho testu.
[https://www.geeksforgeeks.org/turing-test-artificial-intelligence/]

1.1.2. ELIZA

Program simuloval rozhovor medzi pacientom a psychoterapeutom, pričom využíval odpoveď osoby na formovanie svojej odpovede. Interakcia prebiehala medzi počítačovým programom a používateľom, ktorý sedel pri elektrickom písacom stroji, a program reagoval na odpovede používateľa. ELIZA presvedčil viacerých ľudí, že je empatický psychoterapeut so skutočným pochopením. Používatelia tak strávili hodiny diskusiou o svojich osobných problémoch s neživým programom. To priviedlo tvorcu Josepha Weizenbauma k zamysleniu sa nad etikou a dôsledkami pomerne triviálneho programu, ktorý klame naivného používateľa s cieľom odhaliť jeho osobné informácie. Pripúšťal možnosť, že sa v budúcnosti vyvinie program umelej inteligencie, ktorý bude schopný porozumieť reči a prirodzeným jazykom. V takomto prípade by program mohol teoreticky odpočúvať každý dôležitý hovor, čítať e-maily a zhromažďovať súkromné informácie používateľov, prípadne by mohol byť používaný mocnými na potlačenie nesúhlasu a na elimináciu tých, ktorí by ohrozovali ich existenciu. Podsúva sa tak otázka, ako naučiť robota, čo je správne a čo nesprávne. Odpovedať možno tromi zákonmi robotiky, ktoré boli navrhnuté v knihe Ja, Robot. Prvý zákon hovorí o tom, že robot nesmie zraniť človeka ani v stave svojej činnosti, ani v stave nečinnosti. Rovnako sa od robota vyžaduje, aby poslúchal príkazy (za predpokladu, že príkaz nemá spôsobiť ublíženie inej ľudskej bytosti), a napokon musí robot chrániť svoju vlastnú existenciu, pokiaľ jeho ďalšia existencia neublíži človeku [4] [5].

1.1.3. Deep Blue

Ďalšie oživenie umelej inteligencie prichádza už s pokročilejšími algoritmami, ktoré využívajú počítače. Jedným z nich je šachový program Deep Blue od spoločnosti International Business Machines Corporation (IBM), ktorý v roku 1997 dokázal poraziť majstra sveta v šachu Garryho Kasparova. Deep Blue bol údajne schopný spracovať 200 miliónov možných pohybov za sekundu, a tak určiť najlepší pohyb s ohľadom na ďalších 20 ťahov dopredu. Na spracovávanie a vyhodnocovanie ťahov využíval metódu vyhľadávania v strome [5].

1.2. Definovanie umelej inteligencie

V roku 1955 jeden z priekopníkov umelej inteligencie John McCarthy definoval AI tak, že cieľom AI je vyvinúť stroje, ktoré sa správajú, akoby boli inteligentné. Na otestovanie tejto definície bolo použitých pätnásť malých robotických vozidiel pohybujúcich sa v uzavretom priestore konkrétnych rozmerov. Niektoré vozidlá sa pohybovali pomaly, iné sa vyhýbali zrážkam a časť z nich jazdila agresívne. Podľa predošlej definície by bolo možné roboty považovať za inteligentné. Zdanlivo zložité správanie však môže byť vytvorené jednoduchými elektrickými obvodmi. Braitenbergove vozidlá majú dve kolesá, pričom každé z nich je poháňané nezávislým elektromotorom. Rýchlosť, akou sa otáča motor, je ovplyvnená svetelným snímačom, ktorý sa nachádza v prednej časti vozidla. Čím viac svetla dopadne na snímač, tým rýchlejšie sa bude pohybovať. Vyššie uvedená definícia tak nie je dostatočná, pretože hlavným cieľom AI je riešiť zložité problémy [6].

Podľa encyklopédie Britannica možno AI definovať ako schopnosť digitálnych počítačov alebo počítačom riadených robotov riešiť problémy, ktoré za bežných okolností súvisia s vyššími intelektuálnymi schopnosťami človeka. Ako predošlá, tak ani táto definícia nie je ideálna a má svoje nedostatky. Ak je počítač s veľkou pamäťou schopný uložiť dlhý text a následne ho na požiadanie zobraziť, je možné takéto konanie považovať za intelektuálnu schopnosť, keďže memorovanie dlhých textov patrí k intelektuálnym vlastnostiam človeka. Jednou z takýchto schopností môže byť napríklad rýchle násobenie dvoch 20-ciferných čísel. Podľa tejto definície je potom každý počítač systémom AI [6].

Na vyriešenie tejto dilemy možno použiť definíciu od Elaine Rich, ktorá je aktuálna aj desiatky rokov po jej vzniku. Umelá inteligencia je výskum toho, ako prinútiť a naučiť počítače robiť také veci, v ktorých si počínajú ľudia v súčasnosti lepšie. Ide o stručné a výstižné charakterizovanie toho, o čo sa usilujú mnohí výskumníci v oblasti AI za posledných 50 rokov. Medzi silné stránky digitálnych počítačov, v ktorých jednoznačne prekonávajú ľudí, patrí vykonávanie viacerých a zložitých výpočtov v krátkom čase. V mnohých iných oblastiach však ľudia ďaleko prevyšujú schopnosti strojov. Napríklad osoba, ktorá príde do neznámej miestnosti, rozpozná okolie vo veľmi krátkom čase a v prípade nutnosti sa dokáže pohotovo rozhodovať a konať. Podľa zmienenej definície je jednou z úloh AI naučiť sa zvládať tieto situácie [6].

Z pohľadu leteckej dopravy sa nám naskytujú hneď tri definície. EASA zvolila širokospektrálnu definíciu: AI je akákoľvek technológia, ktorá napodobňuje výkon človeka. IATA, naopak, vo svojej štúdii označuje AI ako počítačové programy, ktoré vykazujú ľudskú inteligenciu, napríklad ľudské uvažovanie, učenie sa a riešenie problémov. Môžeme sa s ňou stretnúť v digitálnej (Apple Siri, Google Now), ale aj telesnej forme (roboti). EUROCONTROL použil ako východiskovú komplexnú definíciu systému AI, ktorá bola vypracovaná skupinou High-Level Expert Group on Artificial Intelligence (AI HLEG). Umelá inteligencia (AI) je označenie pre systémy, ktoré dávajú najavo svoje inteligentné správanie analyzovaním a vykonávaním (do určitej miery aj autonómnych) akcií na dosiahnutie konkrétnych cieľov. Hardvérové a softvérové systémy AI sú navrhnuté ľuďmi a pôsobia vo fyzickej alebo digitálnej dimenzii tak, že vnímajú svoje prostredie cez získavanie a interpretovanie štruktúrovaných alebo neštruktúrovaných údajov, ktoré následne spracovávajú na vykonanie najlepšieho kroku, nevyhnutného na splnenie daného cieľa. Systémy AI môžu takisto prispôsobiť svoje správanie na základe analýzy prostredia, ktoré bolo ovplyvnené ich predchádzajúcimi činnosťami [7] [1] [8].

1.3. *Delenie umelej inteligencie*

Umelá inteligencia sa bežne delí do dvoch tried podľa svojich schopností.

- Slabá AI (tiež úzka AI): ide o stroje, ktoré simulujú inteligenciu. Sú zvyčajne navrhnuté na špecifickú úlohu, a preto ich nie je možné použiť mimo tejto oblasti z dôvodu vlastných limitácií. Často sa využívajú na automatizovanie náročných a opakujúcich sa úloh.
- Silná AI (tiež všeobecná AI): hlavným rozdielom oproti slabej AI je ten, že stroje majú skutočnú inteligenciu. Takéto stroje sa vedia prispôsobiť rôznym úlohám, ktoré vykonávajú plne autonómne a rovnako efektívne alebo ešte efektívnejšie ako človek [9].

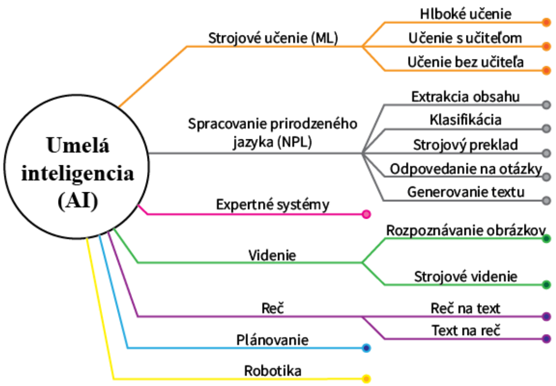


Figure 2: Možnosti využitia umelej inteligencie. [https://www.iata.org/contentassets/2d997082f3c84c7cba001f506edd2c2e/ai-white-paper.pdf]

1.3.1. Strojové učenie

Strojové učenie (ML) označuje schopnosť algoritmov učiť sa. Vo vzťahu k umelej inteligencii ide o jej podmnožinu, ktorá zahŕňa algoritmy. Algoritmy strojového učenia vyžadujú počiatočnú, takzvanú tréningovú fázu. V nej sú parametre daného modelu optimalizované na základe poskytnutých dát. Tréningové algoritmy sú zamerané na minimalizovanie chýb pri splnení istých požiadaviek alebo obmedzení. V tejto fáze sa môže vyskytnúť overfitting – dochádza k nemu v prípade, že sa štatistický model naučí a zapamätá si údaje zhodné s tréningovými údajmi, čím sa negatívne ovplyvní výkon modelu na nových dátach. Pri strojovom učení nás vo všeobecnosti budú zaujímať tri hlavné metódy učenia [9] [10].

- **Učenie bez učiteľa:** Súbor údajov, ktorý sme použili počas fázy trénovania, neobsahuje výstupné hodnoty.
- **Učenie s učiteľom:** Na rozdiel od učenia sa bez učiteľa je modelu počas tréningu poskytnutý súbor údajov, ktorý v sebe zahŕňa nielen vstupy, ale aj výstupy.
- **Učenie pomocou spätnej väzby**: V takomto prípade sa v trénovacej fáze počas každej iterácie vykoná po vyhodnotení aktuálnej situácie náhodná akcia, ktorá buď je, alebo nie je ocenená na základe úspechu dosiahnutého v predchádzajúcich predpokladoch a cieľoch.

1.3.2. Hlboké učenie

Hlboké učenie (DL) je podmnožinou strojového učenia a je založené prevažne na umelých neurónových sieťach. Podobne ako náš ľudský mozog aj hlboké učenie využíva výpočtové bunky, teda neuróny, ktoré sa navzájom ovplyvňujú pri vykonávaní jednoduchých operácií. Hlboké neurónové siete pozostávajú z viacerých skrytých vrstiev a sú navzájom poprepájané pomocou uzlov. Každý vrstva nadväzuje na predchádzajúcu, pričom sa usiluje o spresnenie a optimalizáciu predpovede [11].

Nástup DL umožňuje riešiť doposiaľ neriešiteľné problémy s presnosťou presahujúcou človeka. Rozpoznávanie obrazu a hlasu sa stalo typickým príkladom využitia hlbokého učenia. Pri identifikácii prichádza obrázok vo forme poľa s hodnotami pixelov a prvá vrstva na základe naučených znakov vyhodnocuje prítomnosť alebo neprítomnosť okrajov na konkrétnych miestach daného obrázka. Druhá vrstva môže detegovať vzory pomocou pozorovania usporiadania okrajov. Úlohou tretej vrstvy je zhromažďovať vzory do takých kombinácií, ktoré sa zhodujú s predmetmi podobnými tomu identifikovanému. Kľúčovým aspektom celého procesu – a teda aj hlbokého učenia – je to, že jednotlivé vrstvy nie sú navrhnuté ľudskými inžiniermi, ale učia sa samy prostredníctvom dát, ktoré využívajú [12].

1.4. *Uplatnenie AI v oblasti leteckej dopravy*

Náš reálny svet, v ktorom žijeme, využíva čoraz viac zložitých dát. Aj s pomocou počítačom podporovaných analýz ľudia identifikujú a spracovávajú takéto dáta ťažko. Práve pre schopnosť identifikovať údaje a ich vzorce sa javí umelá inteligencia ako mimoriadne vhodná pre letecký sektor, ktorý je stále viac závislý od elektronických dátových tokov medzi pozemnými a vzdušnými systémami.

1.4.1. EHang

Koncept technologického dizajnu autonómnych vozidiel EHang, ktorý je lepší v porovnaní s lietadlami riadenými posádkou, sa riadi tromi myšlienkami. Prvou je spustenie maximálneho množstva záložných systémov na zaistenie bezpečnosti, druhá hovorí o využití autonómnych pilotov a posledná o centralizovanom riadení centra riadenia takýchto vozidiel [13].

Pri plne autonómnom lete by sa mohli eliminovať zlyhania alebo chyby spôsobené človekom. Cestujúci by tak mali možnosť cestovať a užívať si cestu bez akýchkoľvek starostí. Za výhodu autonómnych vozidiel sa považuje aj to, že nie je potrebné veľké letisko ani pristávacia dráha. EHang využíva 4G a 5G bezdrôtový a vysokorýchlostný prenosový kanál na komunikáciu s centrálou riadenia a vedenia. Vďaka takémuto prenosu je umožnené diaľkové ovládanie lietadla a zdieľanie letových údajov v reálnom čase. Koncept sa zaoberá aj prípadným dopadom na životné prostredie. Využitie elektrickej energie výrazne zníži environmentálne škody spôsobené emisiami. Nabitie lietadla trvá dve hodiny a nabíjacie zariadenia môžu komunikovať so systémom riadenia batérií v reálnom čase [13].

Obrázok 3: Autonómne vozidlá spoločnosti EHang. [https://www.moodiedavittreport.com/ehang-partners-aerotree-to-co-develop-urban-air-mobility-business-in-malaysia]

1.4.2. Stanley Robotics

Letisko v Lyone po úspešnej skúšobnej prevádzke rozširuje svoju službu automatizovaného parkovania. V spolupráci so spoločnosťou Stanley Robotics pracuje letisko na zväčšení svojich parkovacích kapacít. Službu má prevádzkovať sedem autonómnych robotov, ktoré pracujú súčasne. Na odstavenie motorového vozidla môžu cestujúci využiť 28 kabín, ktoré sú k dispozícii 24 hodín denne. Hlavným cieľom tejto spolupráce je zvýšiť spokojnosť zákazníkov a znížiť dopad letiskových služieb na životné prostredie. O účinnosti týchto služieb svedčí aj fakt, že toto letisko bolo v roku 2019 Medzinárodnou radou letísk (ACI) vyhlásené za najlepšie európske letisko v kategórii od 10 do 25 miliónov cestujúcich a na základe automatizovaného parkovania získalo certifikát uhlíkovej neutrality [14].

V praxi pomáha robotický parkovací systém cestujúcim nájsť si parkovacie miesto alebo ľahko vyhľadať svoje vozidlo. Ak si cestujúci rezervuje parkovacie miesto prostredníctvom služby, ktorú ponúka letisko v Lyone, odovzdá svoje vozidlo do jednej z kabín. Pri presune do terminálu s pomocou autobusu sa cestujúci už viac o parkovanie nezaujíma. Tu prichádza úloha robota, ktorý vozidlo zaparkuje na strážených parkovisku. Pri návrate cestujúceho sa robot postará, aby si zákazník našiel svoje vozidlo v jednej z dostupných kabín. Využívanie robotického parkovacieho systému je šetrnejšie k životnému prostrediu, pretože vytvára o 50 % viac miest na rovnakej ploche a zároveň znižuje emisie oxidu uhličitého tým, že cestujúci nemusia blúdiť po veľkej ploche a hľadať voľné parkovacie miesto [14].

Figure 4: Robotický parkovací system od spoločnosti Stanley Robotics. [https://stanley-robotics.com/static/media/uploads/illustration%20block/bloc-3.jpg]

1.4.3. IRTOS 2.0.

IRTOS 2.0. predstavuje druhú generáciu digitálnej veže od spoločnosti Indra. V porovnaní s prvou generáciou je vylepšená o niekoľko pokročilých aplikácii počítačového videnia, ktoré sú zobrazené pomocou rozšírenej reality na panoramatickej obrazovke. Všetky kontrolné a detekčné procesy sú vykonávané autonómne, pričom sa v prípade potreby spustia alarmy a dôjde k upozorneniu riadiacich letovej prevádzky. Letecký priemysel je veľmi citlivý na mieru falošných poplachov, ktoré by mohli odlákať pozornosť od tých relevantných. Hlavným cieľom tohto projektu je dosiahnuť mieru presnosti nad 90 % [15].

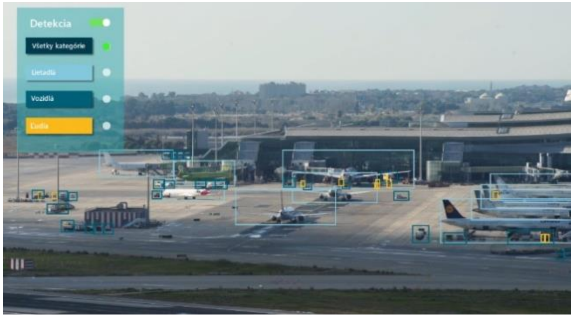


Figure 5: Detekcia objektov v závislosti od konfigurácie. [Autor podľa: https://www.youtube.com/watch?v=nNK9S1urHHQ]

2. METODIKA A METODOLÓGIA

Pri analyzovaní súčasného stavu sme rozdelili využitie umelej inteligencie na viacero oblastí tak, aby sme pokryli všetky sektory dopravy, v ktorých môžeme nájsť jej uplatnenie. Na overenie a porovnanie zistení, ktoré v jednotlivých kapitolách uvádzame, sme sa rozhodli vykonať širšiu analýzu využitia AI. Za zdroj údajov sme si zvolili letecké časopisy opisujúce využitie umelej inteligencie jednoduchým a nie podrobným spôsobom, ktorý pomôže verejnosti danej téme a problematike lepšie porozumieť.

Cieľom je prostredníctvom výskumu analyzovať trend využitia umelej inteligencie, rozdeliť jej uplatnenie v rôznych sektoroch a poskytnúť na základe porovnania údajov odporúčania na aplikáciu umelej inteligencie v budúcnosti.

Na základe teoretických vedomostí, ktoré sme pri písaní získali, sme si stanovili dve hypotézy.

H1 V dôsledku pandémie COVID-19 dochádza k vyššiemu využitiu umelej inteligencie medzi leteckými spoločnosťami a na letiskách.

H2 AI je v súčasnosti aplikovaná len na palube lietadla v systémoch nevyhnutných pre bezpečný let.

2.1. Postup skúmania problematiky

Postup skúmania problematiky bol navrhnutý a prispôsobený tak, aby sme dosiahli stanovené ciele práce. Najdôležitejší bol výber zdrojov, z ktorých sme čerpali údaje. Leteckých internetových časopisov je mnoho, preto bolo potrebné na základe relevantných kritérií vybrať dva najvhodnejšie. Pri výbere sme dbali na to, aby časopis disponoval prepracovaným vyhľadávaním a triedením jednotlivých článkov do takzvaných „značiek“ a kategórií, ktoré sú mimoriadne dôležité pri vytváraní vstupných parametrov potrebných na vytriedenie relevantných článkov. Druhým kľúčovým parametrom na výber časopisu bol časový horizont jeho vydávania. Keďže chceme v práci hodnotiť trend využitia AI, je nevyhnutné, aby letecký časopis archivoval články minimálne od roku 2018.

Postup analýzy článkov sa skladal z nasledujúcich krokov:

- stanovenie metódy výskumu – pri analýze sme využili kvalitatívnu a kvantitatívnu metódu s využitím štatistickej analýzy;
- preštudovanie jednotlivých článkov – vybrali sme tie články, ktoré sú pre náš výskum relevantné;
- zber údajov, analýza a vytvorenie štatistík, interpretácia údajov – údaje sme zaznamenali do tabuliek, na základe ktorých sme neskôr vytvorili grafy;
- porovnanie súčasného stavu so zisteniami, potvrdenie alebo vyvrátenie hypotéz s využitím t-testu, vyvodenie záverov.

3. ANALÝZA VYUŽITIA AI V LETECKEJ DOPRAVE

Na základe predstavených kritérií analýzy sme zúžili výber leteckých časopisov na dva. Prvý z nich sa nazýva Aviation Today. Obsah článkov tohto časopisu je rôznorodý. Nájdeme v ňom aktuálne novinky nielen z civilného, ale aj vojenského letectva. Okrem toho sa v ňom publikujú články z oblastí ako všeobecné letectvo, regulácia, avionika, manažment letovej prevádzky a futuristické koncepty. Druhý časopis sa nazýva Future Travel Experience. Podobne ako v prvom časopise aj tu nájdeme rozmanitý výber článkov. Články sú zamerané predovšetkým na inovácie v oblasti leteckej dopravy.

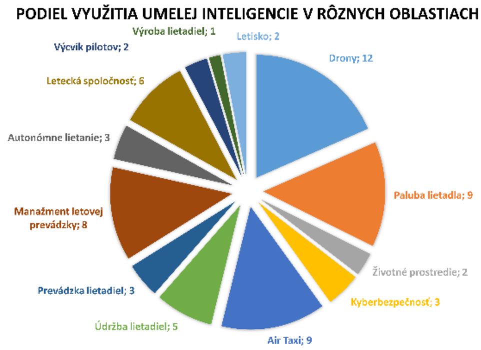
3.1. Definovanie vstupných parametrov

Vstupné parametre našej analýzy boli zvolené prostredníctvom kľúčových slov a značiek. S cieľom vybrať najrelevantnejšie články z prvého časopisu sme vybrali také kľúčové slová, ktoré sa často vyskytovali pri opise súčasného stavu a úzko súviseli s témou. Ako filter článkov sme použili nasledujúce kľúčové slová: „AI“, „Artificial intelligence“, „Deep learning“. Dospeli sme k 238 výsledkom. Následne bolo potrebné články preštudovať a vybrať tie, ktoré priamo súvisia s využitím AI v leteckej doprave. Z uvedených 238 článkov nám vo výsledku zostalo 65. Na analýzu druhého časopisu Future Travel Experience sme využili tag s názvom „Artificial intelligence“, ktorý bol dostatočný na stanovenie početnosti využitia AI v leteckých spoločnostiach a na letiskách. Po preštudovaní celkovo 55 článkov sme analýze podrobili 46 článkov.

Na postrehnutie a zhodnotenie trendu využitia umelej inteligencie sme ako ďalší parameter zvolili dátum publikácie. Smerodajný bol pre nás rok, keďže analyzujeme početnosť článkov v časovom intervale 2017 – 2022.

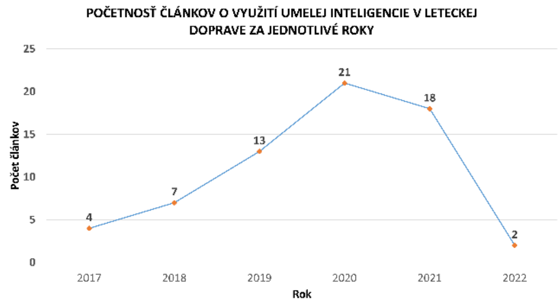
3.2. Analýza zdrojov, overenie matematickým modelom

Ako už bolo uvedené, analýza zdrojov sa opiera o dva internetové letecké časopisy. V časopise Aviation Today zaznamenávame dva základné parametre. Prvým parametrom je sektor, v ktorom sa umelá inteligencia využíva. Ten slúži na to, aby sme vedeli štatisticky určiť, v ktorom sektore prevláda väčší a v ktorom menší záujem o implementovanie AI. Druhým parametrom je rok. Vďaka početnosti výskytu článkov v konkrétnom roku vieme určiť trend vývoja AI v období, ktoré sme si zvolili.



GraF 1: Podiel využitia AI v rôznych oblastiach.

Najväčší počet článkov bol venovaný oblasti dronov (12). Na druhom mieste skončila aplikácia na palube lietadla (9) spoločne s konceptom Air Taxi (9). Tretie miesto patrí manažmentu letovej prevádzky (8), za ním nasleduje využitie AI v leteckej spoločnosti (6) a na údržbu lietadla (5). Rovnaký podiel má oblasť autonómneho lietania (3), kyberbezpečnosti (3) a prevádzky lietadiel (3). Posledné priečky patria letiskám (2), životnému prostrediu (2), výcviku pilotov (2) a výrobe lietadiel (1).



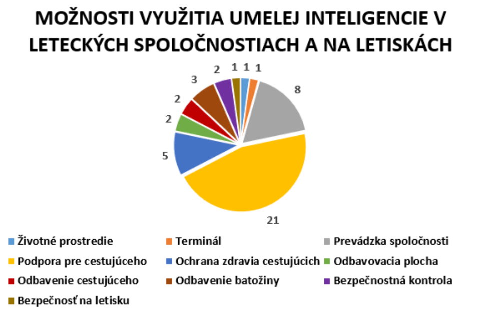
GraF 2: Početnosť článkov o AI za jednotlivé roky

V roku 2017 boli na základe Graf 2 publikované 4 články. O rok neskôr dochádza k takmer dvojnásobnému nárastu počtu článkov. Približne rovnaký nárast nastáva aj v roku 2019. Najvyššiu početnosť sme zaznamenali v roku 2020 a len o dva články menej v roku 2021. Do februára roku 2022 boli publikované 2 články.

Internetový časopis Future Travel Experience sme využili na analýzu podielu využitia umelej inteligencie na letiskách a v leteckých spoločnostiach. Hlavný dôvod, prečo sme sa rozhodli analyzovať tieto dva segmenty, je ten, že sú najviac ovplyvnené pandémiou COVID-19. Pri analýze nás zaujímali celkovo dva parametre. Prvý parameter sa vzťahoval na oblasť využitia AI – letecké spoločnosti a letiská. Druhý parameter súvisel s konkrétnym využitím AI.

GraF 3: Početnosť článkov o využití AI medzi leteckými spoločnosťami a letiskami

V 25 článkoch z celkového počtu 44 analyzovaných článkov (57 %) sa hovorilo o využití umelej inteligencie v leteckých spoločnostiach. Zvyšných 19 článkov (43 %) sa venovalo využitiu AI v prostredí letísk.



Graf 4: Možnosti využitia AI v leteckých spoločnostiach a na letiskách.

Z Graf 4 možno odčítať, že umelá inteligencia sa najvýdatnejšie využíva v súvislosti s podporou pre cestujúceho (21), potom nasleduje prevádzka spoločnosti (8) a ochrana zdravia cestujúcich (5). Menšiu mieru využitia pozorujeme v kategóriách ako odbavenie cestujúceho (2) a batožiny (3) a bezpečnostné kontroly (2). Najmenšie zastúpenie je v oblastiach bezpečnosti letiska (1), terminálu (1), životného prostredia (1) a odbavovacej plochy (1).

Súčasný výskum AI v letectve smeruje k vzniku nových inteligentných systémov, ktoré by asistovali človeku. Vo vzťahu k cestujúcim ide napríklad o systémy rozpoznávania nebezpečných predmetov, automatizáciu odbavenia batožiny, čistenie prostredia letiska a pod. Hoci aktuálne nemožno hovoriť o úplnej autonómii týchto systémov, mnohé z nich sú schopné nahradiť určité činnosti človeka. V spolupráci s ľuďmi sa dosahuje vyššia efektívnosť a presnosť vykonanej úlohy. Súčasný stav a vývoj AI možno opísať ako medzikrok k dosiahnutiu plnej autonómie, či už v prostredí letísk, leteckých spoločností, alebo aj mestskej vzdušnej prepravy, ktorá sa v poslednom čase tiež stáva populárnou.

4. DISKUSIA

Vďaka rastúcemu potenciálu umelej inteligencie sa v posledných rokoch vytvára obrovský priestor na využitie inteligentných systémov. S nástupom digitalizácie dát sa myšlienka bezpečnejšieho, ekonomickejšieho a lepšieho prostredia v leteckej doprave viac a viac zdokonaľuje. Aplikácie AI, ktoré nám pred pár rokmi pripadali ako sci-fi, sa dnes stávajú realitou a neodlúčiteľnou súčasťou leteckej infraštruktúry.

Hypotéza H1 tvrdila, že v dôsledku vypuknutia pandémie COVID-19 dochádza k väčšiemu využitiu umelej inteligencie a k výraznému záujmu o túto problematiku v leteckých spoločnostiach aj na letiskách. Vychádzali sme z toho, že počas pandémie COVID-19 došlo k prísnym protipandemickým opatreniam, ktoré výrazne zvýšili zaťaženie personálu a museli ich dodržiavať nielen letiská, ale aj leteckí dopravcovia.

Tabuľka 1: Využitie AI v leteckých spoločnostiach a na letiskách.

Sektor využitia	Počet článkov	Aritmetický priemer na jeden rok	Smerodajná odchýlka	Hodnota štatistickej významnosti
Pred pandémiou COVID-19 (2017, 2018, 2019)				
Letecké spoločnosti	21	7,00	5,29	
Letiská	7	2,33	2,081	
Počas pandémie COVID-19 (2020, 2021, 2022)				
Letecké spoločnosti	4	1,33	1,53	0,25
Letiská	12	4,00	1,73	0,34
Spolu	44	7,33	3,72	

Na základe analýzy sme zistili rozdiel vo využívaní AI pred a počas pandémie COVID-19 v leteckých spoločnostiach a na letiskách. Otázkou však je, do akej miery je tento rozdiel signifikantný a aký má vplyv na pravdivosť hypotézy H1. Uskutočnili sme teda t-test a jeho výsledky preukázali, že výsledky kvalitatívnej a kvantitatívnej analýzy nemožno interpretovať jednoznačne. Hodnota štatistickej významnosti pre obdobie pred pandémiou a počas pandémie predstavuje v prípade leteckých spoločností 0,25 a v prípade letísk 0,34. Obe hodnoty sa nachádzajú nad 0,05, preto sa na základe týchto hodnôt hypotéza H1 nepotvrdila – nevedeli sme priamo dokázať, že pandémia COVID-19 zvýšila výskyt AI vo vybraných sektoroch.

To, či je AI je v súčasnosti aplikovaná len na palube lietadla v systémoch nevyhnutných pre bezpečný let, bolo obsahom hypotézy H2. Na jej potvrdenie alebo vyvrátenie sme opäť použili výsledky dvoch výskumov.

Tabuľka 2: Rozdeleniepočetnosti článkov v sektore paluba lietadla a drony.

Oblasť využitia	Počet článkov	Aritmetický priemer na jeden mesiac	Smerodajná odchýlka	Hodnota štatistickej významnosti
Paluba lietadla	9	0,75	0,62	0,62
Drony	12	1,00	1,28	
Spolu	21	1,75	1,45	

Analýzou početnosti vybraných článkov o využití umelej inteligencie na palube lietadla a v dronoch sme získali hodnotu štatistickej významnosti 0,62. Hypotéza H2 sa nepotvrdila, keďže medzi využitím AI na palube lietadla a v dronoch nie je významný štatistický rozdiel.

5. ZÁVER

V prvej časti sme sa zaoberali vývojom umelej inteligencie. Je zaujímavé pozorovať, ako sa človek s ľudskou inteligenciou zaoberal myšlienkami na vytvorenie inteligentných strojov už dávno pred vznikom prvých počítačov a neskôr dokázal tieto myšlienky pretvoriť do reálnych aplikácií.

Druhá časť sa zaoberala definíciami umelej inteligencie. Keďže nie je možné AI samu osebe nahmatať a v mnohých prípadoch je skrytá za zložitými procesmi s dátami, ktoré bežne nevnímame, je náročné predstaviť si, čo vlastne AI znamená. Prostredníctvom viacerých definícií sme sa usilovali ponúknuť všeobecnú a ľahko pochopiteľnú definíciu. V tejto časti práce sme charakterizovali aj strojové a hlboké učenie.

V tretej časti sme sa zaoberali sektormi, v ktorých môže nájsť uplatnenie umelá inteligencia. Na rýchle napredovanie technológií a výpočtových výkonov pohotovo reagujú firmy, ktoré sa venujú výrobe rôznych inteligentných systémov, autonómnych vozidiel a robotov. Opisom konkrétnych a praktických príkladov využitia AI v týchto segmentoch sme zistili, že umelá inteligencia môže byť nápomocná v akomkoľvek sektore. Zaujímavým zistením v tejto časti bolo, že v porovnaní s minulosťou sa umelá inteligencia spoločne s algoritmami zdokonaľuje podstatne rýchlejšie a dosahuje väčšiu spoľahlivosť a presnosť. Analýzou súčasného stavu sme tiež zistili, ako veľmi ovplyvňuje AI procesy v leteckej doprave a aké dôležité je ju aplikovať, ak majú byť zabezpečené požadované štandardy nielen z hľadiska bezpečnosti, ale aj ekologickosti a životného prostredia.

Štvrtá časť bola venovaná analýze článkov z časopisov. Tá bola nevyhnutná na potvrdenie alebo vyvrátenie našich hypotéz. Po zadefinovaní vstupných parametrov sme si vybrali dva časopisy – Aviation Today a Future Travel Experience. Zaznamenanie kľúčových údajov do tabuliek nám umožnilo vykonať štatistickú analýzu. Analýzou sme sa dopracovali k viacerým zisteniam. Letecké spoločnosti a letiská si uvedomujú, že pokrok umelej inteligencie nemožno zastaviť a je potrebné využiť jej plný potenciál v oblastiach, ktoré pozitívnym spôsobom ovplyvnia sektor leteckej dopravy. Vzhľadom na stúpajúci trend využívania AI, ktorý nezastavili ani nepriaznivé okolností súvisiace s pandémiou, a na popularitu, aká sa jej dostáva od verejnosti, je len otázkou času, kedy sa umelá inteligencia stane plnohodnotnou podporou pre ľudí a kedy ľudských pracovníkov úplne nahradí v niektorých sektoroch leteckej dopravy.

POĎAKOVANIE

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REFERENCIE

[1] EUROCONTROL. 2020. *The FLY AI Report* [online]. 2020. Available from: https://www.eurocontrol.int/publication/fly-ai-report (Accessed 2022-01-15)

[2] FLASIŃSKI, M. 2016. *History of artificial intelligence*. In *Introduction to artificial intelligence* . [s.l.]: Springer, 2016. p. 3–13. ISBN 978-3-319-40022-8.

[3] TURING, A.M. 1950. *I.—COMPUTING MACHINERY AND INTELLIGENCE*. In *Mind* [online]. 1950. Vol. LIX, no. 236, p. 433–460. Available from: https://doi.org/10.1093/mind/LIX.236.433.

[4] HAENLEIN, M. - KAPLAN, A. 2019. A brief history of artificial intelligence: On the past, present, and future of artificial intelligence. In California management review . 2019. Vol. 61, no. 4, p. 5–14.

[5] O'REGAN, G. 2018. Eliza Program. [s.l.]: Springer, 2018. 119–122 p. ISBN 978-3-030-02619-6.K. Elissa, "Title of paper if known," unpublished.

[6] ERTEL, W. 2018. *Introduction to artificial intelligence*. [s.l.]: Springer, 2018. ISBN 3319584871.

[7] IATA. 2018. *AI in Aviation - Exploring the fundamentals, threats and opportunities of artificial intelligence (AI) in the aviation industry* [online]. 2018. Available from:

[8] https://www.iata.org/contentassets/2d997082f3c84c7cba001f506edd2c2e/ai-white-paper.pdf (Accessed 2022-02-03)

[9] EASA. 2020. *A human-centric approach to AI in aviation* [online]. 2020. Available from: https://www.easa.europa.eu/document-library/general-publications/easa-artificial-intelligence-roadmap-10#group-easa-downloads.

[10] PÉREZ-CAMPUZANO, D. a kol. 2021. *Artificial Intelligence potential within airlines: a review on how AI can enhance strategic decision-making in times of COVID-19*. 2021. p. 53–72.

[11] BROWNLEE, J. 2019. *Overfitting and Underfitting With Machine Learning Algorithms* [online]. 2019. Available from: https://machinelearningmastery.com/overfitting-and-underfitting-with-machine-learning-algorithms/ (Accessed 2022-02-01)

[12] IBM CLOUD EDUCATION. 2020. *Deep Learning* [online]. 2020. Available from: https://www.ibm.com/cloud/learn/deep-learning (Accessed 2022-03-07)

[13] O'MAHONY, N. a kol. 2020. *Deep Learning vs. Traditional Computer Vision BT - Advances in Computer Vision*. Ed. Kohei Arai a Supriya Kapoor. Cham: Springer International Publishing, 2020. 128–144 s. ISBN 978-3-030-17795-9.

[14] EHANG. *EHang AAV: The Era of Urban Air Mobility is Coming* [online]. Available from: https://www.ehang.com/ehangaav (Accessed 2022-03-14)

[15] FUTURE TRAVEL EXPERIENCE. 2020. *Lyon Airport to expand robotic parking service with additional spaces* [online]. 2020. Available from:

[16] https://www.futuretravelexperience.com/2020/01/lyon-airport-to-expand-robotic-parking-service-with-additional-spaces/ (Accessed 2022-04-13)

[17] 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.

[18] NOVÁK, A. 2011. Komunikačné, navigačné a sledovacie zariadenia v letectve. Bratislava : DOLIS, 2015. - 212 s. ISBN 978-80-8181-014-5.

[19] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A., JANOVEC, M. 2020. Komunikačné systémy v letectve. 1. vyd. - V Žiline : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 164 s. ISBN 978-80-554-1737-0.

[20] NOVÁK, A., HAVEL, K., JANOVEC,M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

[21] MATAS, M., NOVÁK, A. 2008. Models of processes as components of air passenger flow model. Communications-Scientific letters of the University of Zilina 10 (2), pp. 50-54.

[22] NOVÁK, A., ŠKULTÉTY, F., KANDERA, B., ŁUSIAK, T. 2018. Measuring and testing area navigation procedures with GNSS. MATEC Web of Conferences 236, 01004.

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

[24] NOVÁK, A., PITOR, J. 2011. Flight inspection of instrument landing system. IEEE Forum on Integrated and Sustainable Transportation Systems, pp. 329-332.

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ANALYSIS OF THE AIR NAVIGATION SERVICE CHARGING SYSTEM IN THE USA AND CANADA

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Abstract

This paper deals with analysis of the air navigation service charging system in the USA and Canada. General information about air navigation service providers is explained here. In the paper are described FAA ATO´s and NAV CANADA´s history, organizational structure, financing and air navigation service charges. And there are practical calculations of charges collected in the USA and Canada.

Keywords

USA, CANADA, Air navigation services, Air navigation service providers, Air navigation charges, FAA, NAV Canada

1. INTRODUCTION

Air navigation service providers (ANSPs) are infrastructural enterprises. As stated by IATA (2022) ANSPs ensure safe and efficient movement of the aircraft within airspace under their control. Each state has its own ANSP that provides air navigation services (ANS) in their airspace. The ownership of these infrastructural enterprises may be in public ownership, where they are organized as part of the state apparatus such as the Air Traffic Services of the Slovak Republic. Some ANSPs are partially privatized but at present it is rather an exception such as British NATS or the Swiss Skyguide.

Main product of ANSPs is providing ANS. Providing ANS is comprehensive set of activities and services that are an essential aspect of maintaining and maximizing the flow and safety of air transport.

The Chicago Convention from 1944 also known as the Convention on international Civil Aviation set out the basic principles of international air transport. And it also affected the charging of air navigation services.

ICAO in its document ICAO's Policies and Charges for Airports and Air Navigation Services (Doc 9082/9) issued recommendations to the States that should ensure that ANS charging works on the basis of these basic principles stated in this document.

2. PROVIDING AIR NAVIGATION SERVICES IN THE USA

Air Traffic Organization (ATO)

In the USA air navigation services are provided by the Federal Aviation Administration (FAA). Specifically the Air Traffic Organization (ATO) which is a part of the FAA's organizational structure. Organizational structure consist of five operational segments. They are responsible for airports, provision of air navigation services, air safety, space activities and hazardous materials (Figure 1).

Figure 1: Organizational structure of the FAA. Author by: (FAA 2022a).

The ATO provides ANS to users of the airspace of the USA. The airspace size is 29,4 milion square miles. It is more than 17% of the world's airspace. Airspace of the USA includes all of the USA and big part of Pacific and Atlantic Oceans and also includes the Gulf of Mexico. The ATO operates more than 50 000 commercial, private and military flights that pass through US aisprace daily. This is provided by ATO staff of more than 35 000 and includes air traffic controllers, technicians, engineers and support staff (FAA 2022b).

History of the ATO

Since 1958, the FAA has been responsible for ensuring the safe operation of the world's busiest and most complicated air transport system. The FAA oversees all aspects of civil aviation in the USA, including the operation of the air traffic control system and safety regulation. The FAA underwent several reorganizations, the main one in terms of providing air navigation services was in 2000. At that time, President Clinton ordered the establishment of the ATO, which began operations in 2004 (Enotrans 2016).

Organizational structure of the ATO

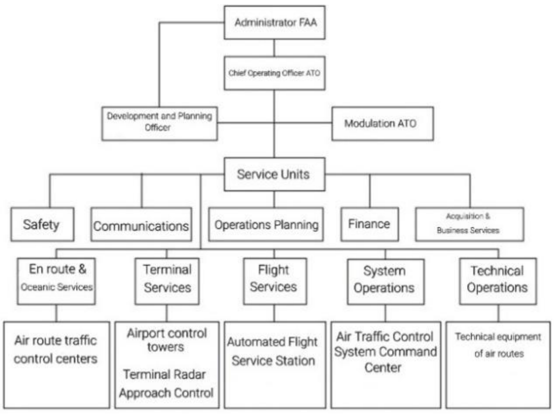

Figure 2: Organization structure of the FAA ATO. Author by: Tomová, Marerna, Lokaj (2017).

The FAA ATO's organizational structure (Figure 2) has five main organizational units:

- Flight Services – provided by an Automated Air Services Station,
- Terminal Services – provided by Airport control towers and Terminal Radar Approach Control,
- En route & Oceanic Services – provided by Air route traffic control centers,
- System Operations – provided by Air Traffic Control System Command Centre,
- Technical Operations – provided by a Technical equipment of air routes.

There are five other units in the highest part of the organizational structure :

- Safety,
- Communications,
- Operations Planning,
- Finance,
- Acquisition & Business Services.

3. CHARGES FOR THE PROVISION OF AIR NAVIGATION SERVICES IN THE USA

In the USA the FAA does not charge fees for the use of federal navigational facilities ot telecommunications services. This definiton is given in the FAA's Aeronautical Information Publication (AIP) (FAA, 2022c). Thus, how the funding system of the FAA ATO works, and where it generates its resources, needs to be discussed in more detailed overview of the FAA overall funding.

According to the FAA (2022d), the FAA is funded from two sources:

- General budget,
- Airport and Airway Trust Fund (AATF).

Airport and Airway Trust Fund (AATF)

The Airport and Airway Revenue Act of 1970 created AATF to provide funding for the aviation system of the USA. This fund is indepedent of the general fund. Revenues to the AATF come from excise taxes on passengers, cargo and fuel collected by air transport. The AATF provides funding to improve airports and air routes in the USA. FAA is mostly funded by AATF, in 2021 it was 95% from the whole budget of the FAA.

To collect aviation excise taxes and to spend finances from the AATF the FAA needs an authorization and it must be reauthorized periodically. The last Reauthorization Act was enacted on October 5, 2018 (FAA, 2020).

Financial resources of the AATF

AATF receives revenue mainly from the various excise taxes paid by the USA airspace users. Excise taxes come from plane tickets, certain domestic flights (between the USA and Alaska/Hawaii or between Alaska an Hawaii), international arrivals and departures, purchases of aviation fuel and much more. Summary of the excise taxes is given in following table.

Table 1: Structure of excise taxes, resources for AATF. Author by FAA (2022e).

Aviation taxes	Comment	Tax Rate
	Passengers	
Domestic Passenger – Ticket tax	Ad valorem tax	7,5% of ticket price
Domestic flight		$ 4,30 per passenger
Passenger Ticket Tax for Rural Airports	Flights that begin/end at a rural airport	7,5% of ticket price
International Arrival & Departure Tax		$ 18,90
Flights between continental U.S. and Alaska or Hawaii		$ 9,50 international facilities tax + applicable domestic tax rate
Frequent Flyer Tax	Ad valorem assessed on mileage awards	7,5% of value of miles
	Freight/Mail	
Domestic Cargo/Mail		6,25% of amount paid for the transportation of property by air
	Aviation Fuel	
General Aviation Fuel Tax		Aviation gasoline: $0,193/gallon Jet fuel: $0,218/gallon

Commercial Fuel Tax		$ 0,043/gallon

Charges for flights through US controlled airspace

Direct user fees are charged only for flights through airspace of the USA. Airspace of the USA is divided into oceanic and enroute airspace (Figure 4).

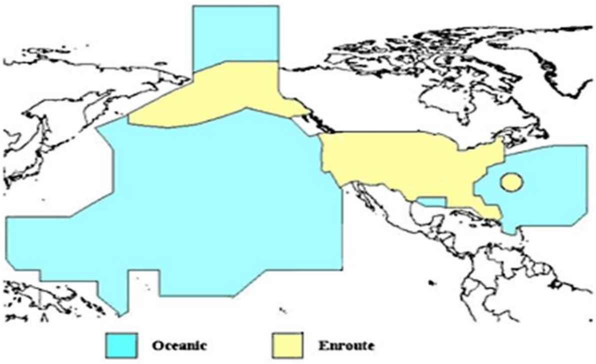

Figure 3: Airspace of the USA divided into Oceanic and Enroute. FAA(2022e)

Table 2: Overflight charge rates in the USA. Author byFAA (2022f).

Effective Date	Enroute rate	Oceanic rate
January 1, 2019	$ 61,75	$ 26,51

These rates are expressed per 100 nautical miles, taking into account the distance of the great circle from the point of entry to the point of exit from airspace of the USA.

Calculation of the enroute and oceanic charges

Formula for calculation of the enroute charge:

$$Enroute\ charge = Enroute\ rate\ x\ \frac{Enroute\ flown\ distance}{100}$$

Formula for calculation of the oceanic charge:

$$Oceanic\ charge = Oceanic\ rate\ x\ \frac{Oceanic\ flown\ distance}{100}$$

Formula for calculation of overall charge:

$$Overall\ charge = ER\ x\ \frac{EFD}{100} + OR\ x\ \frac{OFD}{100}$$

- Overall charge – charged per aircraft between inbound and outbound point of the airspace of the USA,
- ER – Enroute rate,
- EFD – Enroute flown distance,
- OR – Oceanic rate,
- OFD – Oceanic flown distance.

4. CHARGES FOR THE PROVISION OF THE AIR NAVIGATION SERVICES IN CANADA

Air navigation service provider in Canada is NAV Canada. NAV Canada provides air navigation services for the users of airspace under Canadian control. Airspace of Canada is more than 18 million square kilometers big and includes North Atlantic airspace controlled by NAV Canada.

Nav Canada is geographical monopoly and is one of few private entities in the world that is fully responsible for the provision of the ANS. It has more than 4000 employees (NAV Canada 2022a).

According to Tomova and Havel (2005) NAV Canada is non-profit organization providing ANS. In such a company the profit generated by the provider's activity can only be used for the development of the provider itself.

History of NAV Canada

History of the NAV Canada began on November 1, 1996. On that date the air navigation services were purchased from the Canadian Department of Transportation for CAD 1,5 bilion. John Crichton founding chairman and CEO of NAV Canada from 1997 to 2015 wanted to make significant development in the company. He asked for help from employees with their experiences form segment in order to make NAV Canada world's most respected ANSP. In the following years the vision of the company's founder became a reality and NAV Canada began to achieve success (NAV Canada 2021b).

Organizational structure of the NAV Canada

NAV Canada has no shareholders. The company is managed by a board of directors with 15 members. These members represents 4 stakeholder groups that established NAV Canada – the Canadian government, commercial air carriers, the commercial and general aviation sector and the employee unions. This combination ensures that all points of view are represented at the table and all groups has the same rights. A committee with 20 aviation experts is also used to give recommendations to key issues.

Table 3: Number of voted members by stakeholders. Author by NAV Canada (2021a).

Stakeholder	Number of members
Canadian government	3
Commercial air carriers	4
The commercial and general aviation sector	1
Employee unions	2

So the first 10 members of the Board of Directors are selected as stated in table. Next these 10 members elects next four members who cannot have any ties to these groups. And these

14 members elects President and Chief Executive Officer, who become the 15th member of the Board of Directors.

Board members cannot be active employees or members of airlines, unions or governments. And atleast two-thirds of the board members including President must be Canadian citizens.

FINANCING NAV Canada

Nav Canada receives its revenues in the form of direct fees paid by aircraft operators for the provision of ANS.

According to NAV Canada (2020), the charging system is divided into three main categories for terminal and enroute services:

- Charges for propeller aircraft (including helicopters) weighing three metric tonnes or less,
- Daily charges for propeller aircraft over three metric tonnes and small jet aircraft,
- Movement-based charges for propeller aircraft over three metric tonnes and jet aircraft.

In additions, there are movement-based charges for oceanic services.

Charges for propeller aircraft (including helicopters) weighing three metric tonnes or less

Table 4: Quarterly charges for foreign-registered propeller aircraft (including helicopters). Author by NAV Canada (2020).

MTOW (metric tonnes)	Base Rates Effective March 1, 2022
0,617 to 2,0	$ 87,69
Over 2,0 to 3,0	$ 292,88

Table 5: Quarterly charges for foreign-registered propeller aircraft (including helicopters). Source: Author by NAV Canada (2020).

MTOW (metric tonnes)	Base Rates Effective March 1, 2022
0,617 to 2,0	$ 21,92
Over 2,0 to 3,0	$ 73,22

Table 6: Daily charges on certain international airports. Author by NAV Canada (2020).

Base rate Effective March 1, 2022	Annual maximum
$ 12,91	120 cherges per year per aircraft

Daily charges for propeller aircraft (including helicopters) over three metric tonnes and small jet aircraft

Table 7: Daily charges for propeller aircraft (including helicopters). Author by NAV Canada (2020).

MTOW (metric tonnes)	Base Rates Effective September 1, 2020
Over 3.0 to 5.0	$ 54,19
Over 5.0 to 6.2	$ 108,40
Over 6,2 to 8,6	$ 429,72
Over 8,6 to 12,3	$ 997,52
Over 12,3 to 15,0	$ 1486,59
Over 15,0 to 18,0	$ 1785,97
Over 18,0 to 21,4	$ 2407,98
Over 21,4	$ 3124,17
Maximum Daily Charge for Helicopters	$ 108,40

Table 8: Daily charges for small jet aircraft. Author by NAV Canada (2020).

MTOW (metric tonnes)	Base Rates Effective September 1, 2020
0,617 to 3,0	$ 205,19
Over 3,0 to 6,2	$ 264,55
Over 6,2 to 7,5	$ 429,72

Movement based charges for propeller aircraft over three metric tonnes and jet aircraft

Enroute Charges

Enroute charges are applied to air navigation services provided in an airspace controlled by Canada, with exception of the Gander Ocean Area. Divided Canadian airspace is shown on the figure below.

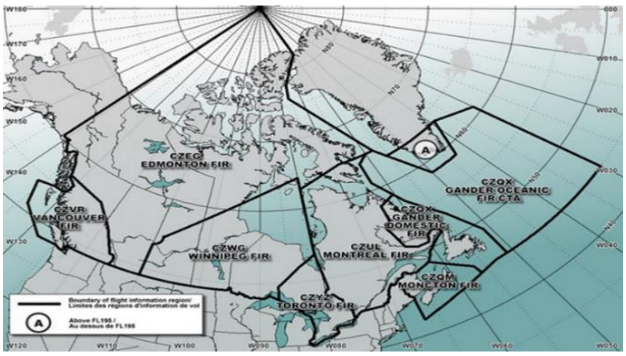

Figure 4: Divided Canadian controlled airspace. Canada (2022).

The enroute charge applies to overflights and flights that land or take-off in Canada. In the case of landing or take-off in Canada the charges apply to:

- Flights between two Canadian airports , where at least one is located at or below 60° North latitude, and at least one of which is aerodrome where NAV Canada applies the Terminal Service charge,
- To flights between two Canadian airports that are located north of 60° North latitude, and at least one of which is an airport where NAV Canada applies the Terminal Service charge,
- To international flights.

The charge takes into account the distance flown and, less than proportionately, the aircraft weight. The charge is applied on a per flight basis and is equal to the product of unit rate (R), the weight factor (W) and the distance (D). The calculation of terminal charge is described below:

$$charge = R\ x\ W\ x\ D$$

- The unit rate (R) is \$ 0,03802 (Effective September 1, 2020)
- The weight factor is obtained: √MTOW
- The distance (D) is equal to the distance of the great circle in Canadian airspace, excluding Gander Ocean airspace, in the case of overflights and international flights landing or taking off in Canada

The distance (D) may be adjusted by 35 km or 65km (deducted) if the airport is listed in the following tables. If an aircraft takes off and lands at the airport, where the distance is adjusted, this value shall be deducted on departure and arrival.

Aerodrome	Facility			Reduction	
	Tower	FSS	FIC	65 km	35 km
Abbotsford	✓			✓	
Boundary Bay	✓			✓	
Brandon		✓			✓
Calgary Int'l	✓			✓	
Calgary/Springbank	✓			✓	
Campbell River		✓		✓	
Castlegar		✓			✓
Charlottetown		✓			✓
Chicoutimi/Saint-Honoré	✓			✓	
Churchill		✓			✓
Cranbrook		✓			✓
Deer Lake		✓			✓
Edmonton Int'l	✓		✓	✓	
Edmonton/Villeneuve	✓				✓
Fort McMurray	✓				✓
Fort Nelson		✓			✓
Fort St. John		✓			✓
Fredericton	✓				✓
Gander (IFSS)	✓	✓			✓
Gatineau		✓		✓	
Grande Prairie		✓			✓
Halifax	✓			✓	
Hamilton	✓				✓
High Level		✓			✓
Iles-de-la-Madeleine		✓			✓
Inuvik		✓			✓
Iqaluit		✓			✓
Kamloops		✓	✓		✓
Kelowna	✓				✓
Kenora		✓			✓
Kingston		✓			✓
Kitchener/Waterloo	✓				✓
Kuujjuaq		✓			✓
La Grande Rivière		✓			✓
La Ronge		✓			✓
Langley	✓			✓	
Lethbridge		✓			✓
Lloydminster		✓			✓
London	✓		✓		✓
Medicine Hat		✓			✓
Moncton	✓				✓
Mont-Joli		✓			✓
Montréal/Dorval	✓			✓	
Montréal/Mirabel	✓	✓		✓	
Montréal/Saint-Hubert	✓			✓	
Nanaimo		✓		✓	
Norman Wells		✓			✓

Aerodrome	Facility			Reduction	
	Tower	FSS	FIC	65 km	35 km
North Bay		✓			✓
Oshawa	✓				✓
Ottawa	✓			✓	
Peace River		✓			✓
Penticton		✓			✓
Pitt Meadows	✓			✓	
Port Hardy		✓			✓
Prince Albert		✓			✓
Prince George	✓				✓
Québec	✓		✓	✓	
Rankin Inlet		✓			✓
Red Deer	✓				✓
Regina	✓	✓		✓	
Rouyn		✓			✓
Saint John		✓			✓
Saint-Jean	✓			✓	
Saskatoon	✓	✓		✓	
Sault Ste. Marie	✓				✓
Sept-Îles		✓			✓
Sioux Lookout		✓			✓
Smithers		✓			✓
St. Catharines		✓			✓
St. John's	✓				✓
Sudbury		✓			✓
Terrace		✓			✓
Thompson		✓			✓
Thunder Bay	✓	✓		✓	
Timmins		✓			✓
Toronto Island City Centre	✓			✓	
Toronto LBPIA	✓			✓	
Val-d'Or		✓			✓
Vancouver Harbour	✓			✓	
Vancouver Int'l*	✓			✓	
Victoria	✓			✓	
Victoria Harbour		✓		✓	
Wabush		✓			✓
Whitecourt		✓			✓
Whitehorse	✓		✓		✓
Williams Lake		✓			✓
Windsor	✓			✓	
Winnipeg	✓		✓	✓	
Winnipeg/St. Andrews	✓			✓	
Yellowknife	✓	✓			✓

Figure 5: List of airports in Canada with distance adjustment. NAV Canada (2020).

Terminal Charges

The terminal charges takes into account, less than proportionately, the aircraft weight. The charge is applied on departures only on a per flight basis and is equal to the product of the unit rate (R) and the weight factor (W). The calculation of terminal charge is described below:

$$charge = R\ x\ W$$

- The unit rate (R) is \$ 31,86 (Effective September 1, 2020),
- The weight factor (W) is obtained: $(MTOW)^{0,8.}$

Oceanic Charges

Oceanic charges are divided into two types:

- Charge for providing ANS in North Atlantic (NAT) – charge for providing ANS in the Gander Ocean area,
- International Communications Service Charge (Int'l Comm) – applies to air-to-ground radio communications provided to an aircraft during an international flight other than between Canada and USA.

Oceanic charges are based on a flat fee for one flight.

Table 9: Oceanic charges. Source: Author by NAV Canada (2020).

	Base Rates **Effective September 1, 2020**
NAT	\$ 230,22
Int'l Comm	
Position reporting using voice	\$ 74,93
Position reporting using data link	\$ 28,19

5. DIRECT COMPARSION OF AIR NAVIGATION SERVICE CHARGING SYSTEMS IN THE USA AND CANADA

Table 10: Basic characteristics ANSP in the USA and Canada. Author.

	USA	**Canada**
ANSP	ATO	NAV Canada
Ownership	Public	Public
Organizational structure	Part of the state apparatus	Non profit organization
Year of origin	2004	1996
Regulator	FAA	Transport Canada

Financing	Excise taxes and appropriations	Direct charges for providing ANS

There are differences in ownership but also in funding between ANSPs in the USA and Canada. FAA is publicly owned entity and directly depends on budgets and excise taxes, as well as government decisions. In contrast, NAV Canada is non-profit entity and its funding depends on direct fees from Canadian airspace users for providing ANS. NAV Canada can take financial decisions separately from its government. But must use the profits generated by the ANSP only for its own development and is therefore reinvested within undertaking.

The air navigation charging systems in the USA and Canda have significant differences so charges in the USA and Canada are directly compared on practical examples below.

6. PRACTICAL EXAMPLES OF CALCULATIONS

Charge for overflight of Canadian controlled airspace

The Boeing 747-400 flies from Seattle (KSEA) to London (EGLL). MTOW is 395 metric tonnes and distance flown is 3787 kilometers.

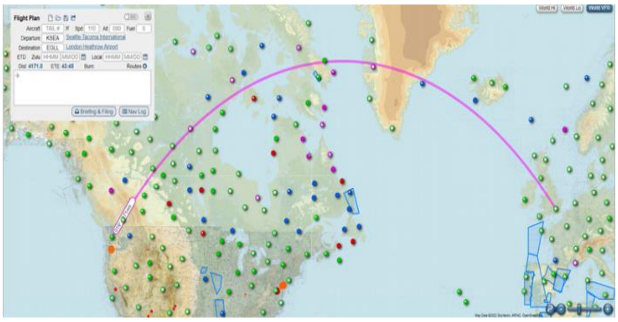

Figure 6: Illustration of the flight from KSEA to EGLL. Skyvector (2022[a]).

Calculation:

The first step is to calculate the oceanic charges. Aircraft position reporting is provided by a data link, where the rate is $ 28,19 per flight. The oceanic charge is:

$$Oceanic\ charge = \$\ \mathbf{28,19}$$

For calculation of enroute charge is used formula:

$$Enroute\ charge = R\ x\ W\ x\ D$$

The weight factor (W) = √MTOW=√395=19,87

The unit rate (R) = $ 0,03802

$$Enroute\ charge = 0{,}03802\ x\ 19{,}87\ x\ 3787$$

$$Enroute\ charge = \$\ \mathbf{2860,92}$$

As the terminal charge does not apply to this flight, amount ANS provided (KSEA-EGLL) was calculated as:

$$Total\ charge = Oceanic\ charge + Enroute\ charge$$

$$Total\ charge = 28{,}19 + 2860{,}92$$

$$Total\ charge = \$\mathbf{2889,11}$$

Charge for overflight of controlled airspace by the USA

In the case of the USA, formula for calculating the amount of charges for flying through US airspace is completely different. Oceanic charges are collected otherwise, therefore the length of the oceanic flown distance will be adjusted to reflect the oceanic charge in Canada ($ 28,19). And enroute flown distance will be the same as when flying through the airspace of Canada (3787 kilometers).

Table 11: Example for calculation overflight fees in airspace controlled by the USA. Author.

Enroute flown distance	2353,1385536928 nautical miles (3787 km)
Oceanic flown distance	106,35 nautical miles ($28,19)
Enroute rate	$ 61,75
Oceanic rate	$ 26,51

In direct comparison of the charges in airspace of the USA and Canada, where the same distances were used and the same oceanic charge, there is a significant difference in the amount of charges. It is due to different formulas used for calculations in these countries. So even if the length of the flights and oceanic charge are the same, the values of the Overall charges are very different.

Charge for a domestic flight in the USA

The formulas cannot be used to calculate the domestic charge in the USA, as the FAA does not directly charge for air navigation services. But it is possible to calculate the amount of excise taxes that will be collected for certain flight.

Flight from San Francisco (KSFO) to San Diego (KSAN) with Boeing 737-400. Distance flown is 624 kilometers. Number of passengers is 145. Price for the plane ticket was uniform $50. And the aircraft used 1100 gallons of fuel.

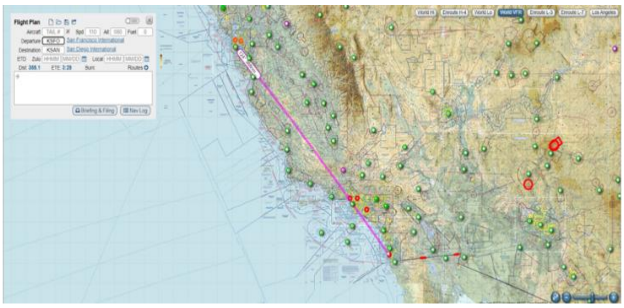

Figure 7: Illustration of flight from KSFO to KSAN. Skyvector (2022[b]).

By the Figure 3 we can make a calculations of:

Domestic passenger ticket tax

If the price of the ticket was $50 then 7,5% of one ticket is $3,75. The number of tickets was 145, so the total value is **$543,75**.

Domestic flight tax

Unit rate is $4,30 per passenger, on board there was 145 passengers. Total value is **$ 623,50**.

Commercial fuel tax

Unit rate for commercial fuel tax is $0,043/gallon. During the flight was used 1100 gallons of fuel. Total value is **$47,30**.

Total value of all taxes collected on this flight is **$1214,55.** That amount will be credited to AATF.

Charge for a domestic flight in the Canada

For better comparison with the charge for domestic flight in the USA a shorter domestic flight in Canada was picked.

Flight from Calgary (CYYC) to Vancouver (CYVR) where the distance flown is 598 kilometers. And the aircraft is Boeing 737-400 with MTOW of 70 metric tonnes.

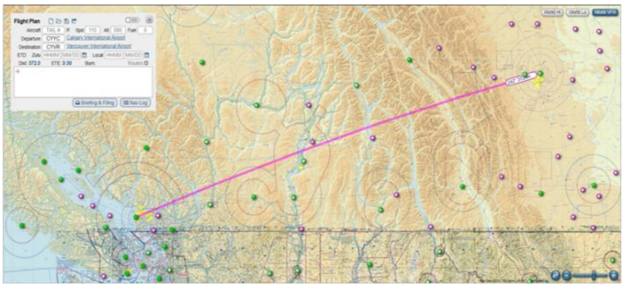

Figure 8: Illustration of flight from CYYC to CYVR. Source: Skyvector (2022[c]).

Oceanic charge is not applicable on this flight.

Calculation of enroute charge is:

$$Enroute\ charge = R\ x\ W\ x\ D$$

The weight factor (W) $\sqrt{MTOW} = \sqrt{70} = 8{,}36660$

The unit rate (R) = $ 0,03802

$$Enroute\ charge = 0{,}03802\ x\ 8{,}36660\ x\ (598 - 65 - 65)$$

$$Enroute\ charge = \$\ 148{,}87$$

Terminal charge calculation (Calgary and Vancouver):

The weight factor (W)= $MTOW^{0,8} = 29{,}92805$

The unit rate (R) = $ 31,86

Terminal charge=31,86 x 29,92805

Terminal charge=$ 953,51

Total charge for ANS (CYYC – CYVR) is $ 1102,38.

SUMMARY OF CALCULATED VALUES FOR DOMESTIC FLIGHTS IN THE USA AND CANDA

Table 13: Overview of calculated values for domestic flight in the USA. Author.

Domestic passenger ticket tax	$ 543,75
Domestic flight tax	$ 623,50
Commercial fuel tax	$47,30
Total tax	**$ 1214,55**

Due to lack of direct navigation charges in the USA, the amounts of excise taxes for flight between KSFO and KSAN were calculated from the determined values. The total amount of excise taxes collected from this flight was $1241,55 and this amount is credited to the AATF.

Table 14: Overview of calculated values for domestic flight in Canada. Author.

Enroute charge	$ 148,87
Terminal charge	$ 953,51
Total charge	**$ 1102,38**

In Canada, the provision of air navigation services on domestic flights is subject to direct user charges. According to formulas, the enroute charge and terminal charge were calculated and total value of charge is $1102,38.

7. CONCLUSION

The paper was aimed to find out how air navigation service charging systems work in the USA and Canada, and then compare them with an analysis, and highlight differences. Significant differences were found in ownership and funding between ANSPs in the USA and Canada.

The FAA is part of the state apparatus and depends on excise taxes and budgetary resources, and government decisions. Charges for providing ANS are not divided into terminal and enroute. Direct user fees are charged only for the flights through US controlled airspace. The FAA is mainly funded by the AATF, and AATF is generated by revenue from excise taxes.

NAV Canada as a non-profit entity is not depended on financing from budgetary resources. Its revenues consist of direct user charges to users of Canadian-controlled airspace for providing ANS. However, NAV Canada, as a non-profit entity must use the profits generated by itself only for its own development.

In the practical examples of calculations were compared overflights through the airspace of the USA and Canada, where significantly different values were calculated. Then there were compared also domestic flights in the USA and Canada. Domestic flights had very similar entry values but since the FAA ATO does not charge direct user charges on domestic flights, the comparison was more demanding, but the resulting charges were similar, although the calculations methods were completely different.

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References

Canada, 2022. Available on the internet: https://www.canada.ca/content/dam/eccc/migration/main/manair/E090AC01-C2AF-4A93-B852-9BFF0CA808F2/figd1.jpg

Endotrans, 2016. A History of Air Traffic Control Provision in the United States. Available on the internet: https://www.enotrans.org/article/history-air-traffic-control-provision-united-states/

FAA, 2020. AATF Fact Sheet. Available on the internet: https://www.faa.gov/sites/faa.gov/files/about/budget/aatf/AATF_Fact_Sheet.pdf

FAA, 2022[a]. Key Officials. Available on the internet: https://www.faa.gov/about/key_officials

FAA, 2022[b]. Air Traffic Organization. Available on the internet: https://www.faa.gov/about/office_org/headquarters_offices/ato

FAA, 2022[c]. AIP Publication Part 1 Section 4.2. Available on the internet: https://www.faa.gov/air_traffic/publications/atpubs/aip_html/part1_gen_section_4.2.html

FAA, 2022[d]. Airport and Airway Trust Fund. Available on the internet: https://www.faa.gov/about/budget/aatf

FAA, 2022[e]. Excise Tax Rate Structure. Available on the internet: https://www.faa.gov/sites/faa.gov/files/about/budget/aatf/Excise_Tax_Rate_Structure.pdf

FAA, 2022[f]. Overflight Fees. Available on the internet: https://www.faa.gov/about/office_org/headquarters_offices/afn/offices/finance/overflight_fees

IATA, 2022. Air Navigation Service Providers. Available on the internet: https://www.sita.aero/solutions/industries/air-navigation-service-providers/

NAV Canada, 2020. Customer Guide to Charges. Available on the internet: https://www.navcanada.ca/en/customer-guide-to-charges-sep-2020-en.pdf

NAV Canada, 2021[a]. Governance. Available on the internet: https://www.navcanada.ca/en/annual-report-2021.pdf

NAV Canada, 2021[b]. NAV Canada Celebrates a Quarter Century of Safety Service and Innovation. Available on the internet: https://www.navcanada.ca/en/news/blog/nav-canada-celebrates-a-quarter-century-of-safety-service-and-innovation-.aspx

NAV Canada, 2022[a]. About Us. Available on the internet: https://www.navcanada.ca/en/corporate/about-us.aspx

Skyvector, 2022[a]. Departure : KSEA, Destination: EGLL. Available on the internet: https://skyvector.com/

Skyvector, 2022[b]. Departure: KSFO, Destinaton: KSAN. Available on the internet: https://skyvector.com/

Skyvector, 2022[c]. Departure: CYYC, Destination: CYVR. Available on the internet: https://skyvector.com/

Tomová, A., Havel, K., 2015. Ekonomika poskytovateľov leteckých navigačných služieb, 2015. EDIS – Vydavateľské centrum Žilinskej univerzity, Žilina.

Tomová, A., Materna, M., Lokaj, P., 2017. Dimenzie a varianty štrukturálnej reformy vzdušného priestoru: Komparácia prístupov v severnej Amerike a Európe.

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.

Novák, A., Novík Sedláčková, A. 2010. Medzinárodnoprávna úprava civilného letectva. Žilinská univerzita, 2010. - 125 s. ISBN 978-80-554-0300-7.

Badánik, B., Červinka, M. 2015. Marketing leteckých spoločností a letísk. 1. vyd. Bratislava : DOLIS, 2015. 152 s. ISBN 978-80-8181-024-4.

Novák Sedláčková A., Novák, A. 2010. Simulation at the Bratislava airport after application of directive 2009/12/EC on airport charges. Transport and Telecommunication 11 (2), pp. 50-59.

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

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TURBULENCE AS A DANGEROUS WEATHER PHENOMENON

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Abstract

The aim of the theme is to examine and clarify the turbulent flow on a larger scale, especially for better flight preparation in the field of turbulence. The work explains the air flow, the formation of turbulent flow and its division into important species. It is solved how the Förchtgott classification is divided according to the type of flow on the leeward side of the mountain obstacle. At the end, it contains information on the written topic. The information is found to be that turbulence is a dangerous weather phenomenon to be taken into account, especially by the pilot so as the turbulence information has been clarified.

Keywords

Air Transport, Turbulences, Wake Turbulence, Turbulence Measurement, Cumulonimbus, Clear Air Turbulence, Jet Stream

1. INTRODUCTION

In a scientific article, I address the causes of turbulence in terms of aviation dangers. Turbulence in the aviation area is characterized by a forced change in aircraft altitude due to a given condition and situation in the atmosphere [1]. It falls into the category of dangerous weather events, which can have serious, possibly fatal consequences.

Turbulent flow is a well-known meteorological phenomenon, often a threat for some. At present, it is possible to accurately predict this phenomenon by measuring and determining its conditions of occurrence.

Meteorological information is very necessary for flight planning and precise study, because especially the weather can cause unpleasant situations. This topic inspired me in terms of a certain impact on aviation and interest in meteorology, specifically turbulence. The term impact on aviation means overall meteorology and its specifics and impact on flight. By developing this topic, it is possible to gain more new knowledge about what turbulence is, how it arises and other interesting properties.

2. PHYSICAL SUBSTANCE OF TURBULENCE

2.1. AIRFLOW

The air flow is caused by differences in atmospheric pressure, which are offset by the flow from the higher air pressure area to the lower air pressure area.

It is a complex process made up of macroscopic gas molecules that flow in a certain direction and with each other.

they can change their position, direction. The main airflow distributions include laminar and turbulent flow.

The boundary layer, whether laminar or turbulent, can be identified by its velocity profile.

2.2. Laminar flow

Laminar flow refers to a steady flow of gas at a lower velocity. It shows jets that are still, parallel to each other, and the gas layers are shifted one after the other. The laminar flow is smooth, and the velocity is constant at each flow point. Since a low velocity act at laminar flow, this means that vortices causing turbulent flow cannot be formed.

2.3. Turbulent flow

Laminar flow can only take place at a certain speed. When the speed is exceeded, swirling or agitating air and unstable flow begin. We call such a flow turbulent. It is undergoing unpredictable changes. The velocity at irregular flow is not constant at every point of the flow.

2.4. Reynolds number

The Reynolds number is a quantity used in hydromechanics and aerodynamics. It is called Re and is given as a dimensionless quantity by which the laminar and turbulent flow is determined. It is expressed by the value Re = 2320. The critical Reynolds number expresses the transition between laminar and turbulent flow, that is, if the value is less than 2320, laminar flow takes place and at a value greater than 2320, turbulent flow already occurs. It is one of the main control parameters in all viscous flows [4].

3. TURBULENCE AND ITS TYPES

The agitation of air as air particles move in the atmosphere is the movement of matter to which a flying aircraft responds depending on its speed and mass. Turbulence is caused by frequent changes in wind speed. It can be observed in the ground layer by means of wind gusts [5]. There are 3 types of turbulence.

3.1. Thermal turbulence

For the formation of thermal turbulence, a condition is given, which is an unstable stratification of the air. This means that the instability of the stratification, which occurs during sunny weather, is needed when the earth's surface heats up the fastest and has the highest temperature. It is usually the result of uneven heating of the earth's surface or a moving cold stream of air above the warm earth's surface.

In daytime, thermal turbulence reaches its maximum in the afternoon. The weaker intensity of this turbulence occurs before sunset, it is weak at night, but still during the night it is possible to observe a stronger occurrence of turbulence, especially in storm clouds.

In terms of seasons, thermal turbulence most often occurs in the spring and summer months [1].

3.2. Mechanical turbulence

Obviously, the flow of air near the Earth's surface will flow through various obstacles, such as cliffs, mountains, buildings, structures. In this case, the arranged horizontal flow is interrupted and turns into an irregular complicated flow of currents.

The difference between thermal and mechanical turbulence is that mechanical turbulence needs a stable pruning to occur. In general, it arises as a result of the friction of the air on the earth's surface, therefore the obstacle, as well as the flow itself over the mountain obstacle [1].

3.2.1. Turbulence due to friction on the earths's surface

This kind of turbulence occurs over the relatively flat surface of the Earth, due to the fact that individual vortices are created behind buildings, obstacles, or even forests. It is associated with thermal turbulence and occurs at a speed of 7 to 10 m / s.

3.2.2. Turbulence due to flow over the mountains

- *Clouds*

The main role is represented by vertical air movements. The most well-known phenomena include Ac, rotor clouds and rib-shaped clouds. The orographic clouds also include the so-called pearl clouds. Pearlescent clouds are also referred to as stratospheric clouds, so they appear at higher altitudes. They have been observed, for example, in Norway, Scotland, Alaska and Greenland.

- Field research

The results obtained from observations from different mountain areas agree to some extent. The wave flow manifests itself as a vertical oscillation around a dynamically steady state, with the mountain obstacle being the source of the commotion and the gravitational force causing these oscillations. Gravitational waves occur in all mountains of the world [1].

3.2.3. Förchtgott classification

The flow of air over mountain obstacles is divided into windward and leeward sides. On the windward side there are outgoing movements of the air and on the leeward side there are descending movements. According to Förchtgott, the leeward air flow is divided into four types: Laminar, Vortex, Wave, Rotor [1].

3.2.4. Dynamic turbulence

Dynamic turbulence is divided into two categories from different perspectives and its manifestations. For turbulence in the lower layers and for turbulence in the upper layers of the atmosphere. It does not depend on obstacles, terrain, or storm clouds. It occurs in parts of the troposphere and stratosphere [1].

3.2.5. Turbulence of the lower tropospheres

The dynamic turbulence of the lower layers of the troposphere is related to wind shear. Thus, significant changes in wind direction and speed in a short period of time prevail. The flow of layers on top of each other leads to turbulence because they cause changes in vertical movements. This type of dynamic turbulence takes place up to a height of 4 km. Temperature inversion is usually associated with wind shear or cloud change. These include stratus clouds, which turn into stratocumulus, and the species altostratus changes into altocumulus.

3.2.6. Turbulence of the higher tropospheres

The dynamic turbulence of the upper layers is otherwise called CAT. It is the turbulence of the clear sky created in the upper troposphere or lower stratosphere that is connected or associated with the nozzle flow. This turbulence reaches a height of 5.5 km and occurs in a clear cloudless area of the air during strong wind gusts, as well as in clouds Ci, Cc, Cs. The waves that flow through a jet stream are called dynamically stable. Waves that act against the jet stream are called dynamically unstable.

3.3. Measurement and intensity of turbulence

Measurement of turbulence values is provided by an accelerometer. Accelerometers are special devices that work on the basis of inertia, therefore they use the principle of inertia of a fixed body. More precisely, the device records changes in the position of the body relative to the aircraft. It is indicated in "g" units. Aircraft overload means the ratio of lift in turbulent air impact to the aircraft to the ratio of lift in horizontal flight [1].

Table 1: Manifestations of conditions from the intensity of turbulence. [1]

Intensity	Acceleration in g	Manifestations of conditions
Weak	do 0,20	Smaller and light tilts of the aircraft
Moderate	0,21 – 0,50	Stronger impacts, to some people it causes nausea
Strong	0,51 – 1,00	Steep tilts, aircraft ambushes, flight mode disrupted, need to buckle up
Very strong	more than 1,00	Major plane ambushes occur, plane damage risks

4. EFFECT OF TURBULENCE ON FLIGHT

Turbulence acts on the aircraft by disrupting its aerodynamic properties. Disruption of aerodynamic properties causes poorer maneuverability of the aircraft, changes in height and tilt of the aircraft, or destruction and wear under increased stress. The tilt of the aircraft to one side is the reason why turbulent air movements pass through one side of the wing and an imbalance is created that tilts the aircraft to one side.

Aircraft overload is characterized by force and accidental acceleration, which is caused by turbulence on the aircraft structure.

4.1. Air accidents due to turbulence

From the pilot's point of view, a flight in the area of turbulence is usually considered to be a disturbance to the comfort of the crew and passengers, not entirely a problem or a disturbance to the safety of the aircraft. The aircraft itself is designed to withstand a large amount of load, strain, and positive and negative overload. In the event of strong turbulence, we can observe a more frequent oscillation of the wings, because the wings are structurally flexible. The wings can bend up to 10 degrees, so it is not possible to "break" them under natural conditions. From the point of view of the design of the transport aircraft, turbulence is not dangerous. Where the danger of turbulence can be demonstrated, it is the crew or passengers.

From the technical side of the aircraft, such as the fuselage, structural nodes of the fuselage, wings, pins are several times more stressed on tension, pressure, torsion, bending. For smaller sport aircraft, the cover may twist on certain parts of the aircraft. In the case of incorrect technical capability, for example, a pin mounted in a wing suspension can manifest itself after loose turbulence by loosening and weakening of the pin wall. This leads to consequences such as shear damage and consequently to complete destruction of the wing support part.

4.2. Turbulence areas

The occurrence of turbulence in the atmosphere is its natural characteristic. Areas with a stronger manifestation of turbulence fill a larger area evenly, therefore uniformly. Other times, under other conditions, the given turbulence manifestation occupies the zones separately. The occurrence of turbulence most often manifests itself from the ground level to a height of 3 kilometers. As we proceed above, between the 3rd and 6th kilometer, the turbulence of the atmosphere decreases. However, the 8th and 10th kilometer represent levels that are relatively more turbulent than those in the lower troposphere [1].

4.2.1. Turbulence in the clouds

The change in the height of the aircraft due to the turbulent phenomenon most often occurs in the clouds. The development of clouds is related to the outgoing movements of the air and thus the formation of condensation is connected. This means that if the output vertical movements meet together with the descending movements of the air, they represent the basic condition for the formation of turbulence.

Cb type clouds have the greatest credit for the development of turbulence in the cloud area, in which the maximum impacts of turbulence are manifested in the middle part of the cloud. Forced changes in aircraft altitude tend to be strong, reaching a drop or increase in altitude that exceeds hundreds of meters from the aircraft's original altitude. This is because their vertical currents reach speeds of around 40 m / s [1].

4.2.2. Turbulence in the area of fronts

The queues are divided into cold, warm, and occlusive queues. They are different in that behind the cold front, the air mass flows faster and with a higher air density, so it behaves differently than a warm front.

The rise of warm air along the sloping frontal interface and the subsequent friction between two different air masses creates turbulence in the frontal zone. Hot airflow properties such as humidity and instability are the result of significant turbulence and can be extremely strong if storms occur. Turbulences are mostly associated with cold fronts, but sometimes they can be present in the warm front [14] [5].

4.2.3. Turbulence in jet stream

The jet stream areas are connected in particular to the cyclonal side of the frontal zone. Occurrence of turbulence on the anticyclonic side tends to be very small.

In the upper layers of the troposphere, turbulence development is indicated by wind speed. The higher the wind speed, the more likely it is to occur. Jet stream is caused by changes in wind speed and horizontal changes in wind direction. It is also related to wind shear, as turbulence in the jet stream area is especially created at the edge of the flow zone.

Jet stream can also be observed by the clouds that specify it. They have different shapes, often parallel prominent bands according to the passing jet stream. The intensity of the turbulence can be determined from the appearance of the cloud. If the shapes of the clouds suddenly change, it is a strong turbulence. If the shape is mostly stable, it is sufficient to expect only weaker turbulence [1].

4.2.4. Turbulence in a storm

Storm activity is a meteorological phenomenon in which more intense turbulence is manifested. Strong turbulence from the storm area causes sharp tilts, aircraft overloads and significant changes in altitude. The basic condition in the area of the storm is to avoid the storm cloud during takeoff and landing. It is not possible to fly against a Cb cloud, where dangerous turbulence occurs with strong vertical impacts [16].

4.2.5. Wake turbulence

The wake turbulence means the turbulence that is caused by the flying aircraft when passing through the air. Airplanes are formed on the wings of the wings and so-called jetwash, which indicates fast-moving gases coming out of the engine. As a result, the areas behind the plane become too turbulent, but their duration is short. For vortices, the duration of turbulence is a little longer, it can be about three minutes, because the vortices at the ends of the wings are more stable. The wake turbulence creates a disturbed area of air [18].

4.2.6. Areas of turbulence in Slovakia

From our own experience in areas in Slovakia, it is the most common occurrence with orographic turbulence over mountains such as Pohronský Inovec or Zobor. Above these hills, turbulence of stronger intensity was captured, either on either side of the hill, depending on the wind. Similarly, with thermal turbulence, there is experience over cities and fields, but always to a lesser extent.

The information obtained from other pilots is similar because they had the most common experience with turbulence over the mountains, hills and during the summer months with thermal turbulence over various areas. It contains an unpleasant experience of entering the rotor behind the Veľká Javorina mountains towards the Czech Republic. Another strong turbulent flow in the Lietava, Rajec and areas of Tatras.

The most common occurrence is in the High Tatras, more precisely from the Poprad-Tatry Airport, information is obtained where the southwest wind prevails. In this case, you can see how the air flow slowly moves towards the mountains, and then the turbulence is only very mild. The purely southern wind causes an air flow at Poprad-Tatry Airport, which goes with the terrain, therefore on the windward side, and creates good conditions for a flight similar to zero turbulence. This situation would change on the leeward side. When the north wind blows, the Poprad-Tatry Airport is located on the leeward side, where the turbulence is very strong.

Experience has shown that the best turbulence generation is close to the mountains, ideally on the leeward side. It does not have to be just the High and Low Tatras, but also other smaller mountains. For example, when the wind blows from the south side and the plane is located on the north side of the hill, therefore behind it, it is obvious that strong turbulence will cause. If it is located at the height of the top of the hill, slightly above it or below the level of the mountain range, but on the leeward side, then the turbulence is considerable.

5. DISCUSSION

If severe turbulence is observed or predicted, the Aeronautical Meteorological Service issues a SIGMET alert. The turbulence forecast and its criteria vary by type. Thermal turbulence and its prediction are related to the development and prediction of convective clouds. The developmental stage of the Cu cloud is characterized by weakness, while Cu and Cb clouds are characterized by mild to strong turbulence.

The prediction of mechanical turbulence is given in the presence of stably layered air layers at a wind speed of at least 10 m / s. The turbulence that causes the wave flow is expected especially when the direction of flow is perpendicular to the ridge of the mountain barrier [5] [1].

Wind shear is related to dynamic turbulence, so wind shear maps are mainly used to predict it. The basic tool is the use of on-board detectors, which are based on the horizontal change in air temperature, which is essentially related to the area of nozzle flow. However, horizontal changes tend to be small, as their usual on-board indicators do not show, and therefore more precise apparatus has been devised. With these more precise instruments, the indication is usually already when the temperature changes by tenths of a degree [1].

6. CONCLUSION

Turbulence is characterized in aviation as a weather phenomenon that can dangerously affect the track, passenger comfort and, last but not least, flight safety, without the intervention and influence of the pilot. Based on the mentioned air accidents and experience, turbulence really manifests itself as a problem that can endanger the flight. This is a dangerous weather phenomenon occurring over different areas and with which every pilot has some experience.

The aim of the bachelor's thesis, from which the scientific article follows, is to describe and find out more detailed information about the turbulence and its dangerous impact on air transport, and at the same time to understand its meaning in practice. It is important to know the substance of turbulence, because when planning a flight, it is necessary to deal with various meteorological phenomena, including turbulence.

The work provides important information on how and on what basis turbulence is determined, where it can occur and the adverse and dangerous effects of turbulence have been identified. Turbulence is a dangerous weather phenomenon that can cause some uncertainty for the pilot himself. It is especially dangerous in terms of flight near a mountain obstacle. If the pilot is very close to the mountain range and flies into a strong turbulent zone, this can cause a sudden drop in flight altitude to very close to the surface of the mountain obstacle, at worst directly into it, which would result in an accident. The aforementioned air incidents or experiences show that the turbulence itself needs to be taken care of, but there is no need to show signs of fear from the passengers' point of view.

If the flight is performed by a transport aircraft or a sport aircraft, this difference is determined only by how the passenger's turbulence is felt during the flight. There is a small probability of an accident causing turbulence, but this risk is never ruled out. Other factors have an impact. Therefore, it is necessary to properly respond to external influences and keep the aircraft under control when flying through a turbulent area. Pilots on longer routes at higher flight levels are able to prepare for flight using aeronautical meteorological maps, making the flight safer. I also documented the correct presentation of the issue on the examples, which I discussed in more detail in the discussion.

REFERENCES

[1] RNDr. Ing. Nedelka, M. CSc. 1979. Letecká meteorológia II. Bratislava : Vydavateľstvo technickej a ekonomickej literatúry ALFA,1979. 326 s. ISBN 63-751-79

[2] Mechanika kvapalín a plynov: kapitola 7.1. Laminárne a turbulentné prúdenie [online]. Dostupné na internete: http://physedu.science.upjs.sk/kvapaliny/lamturprud.htm (citované 2022-02-15)

[3] MIT News Office: Understanding how fluids heat or cool surfaces. [online]. Dostupné na internete: https://news.mit.edu/2020/how-fluids-heat-cool-surfaces-0428 (citované 2022-02-15)

[4] Encyklopédia poznania: Reynoldsovo číslo [online]. Dostupné na internete: https://encyklopediapoznania.sk/clanok/7415/reynoldsovo-cislo-reynoldsovo-kriterium-re-kriticke-reynoldsovo-cislo-prudenie-v-potrubi (citované 2022-02-15)

[5] RNDr. Dvořák, P. 2019. Učebnica pilota 2019. Příbram : Vydavateľstvo leteckej literatúry

[6] Svět krídel, 2019. 439 s. ISBN - 978-80-7573-049-7

[7] ResearchGate: Mechanical turbulence [online]. Dostupné na internete: https://www.researchgate.net/figure/Mechanical-turbulence_fig15_312270470 (citované 2022-02-15)

[8] Slide ToDoc: Nebezpečie horských oblastí [online]. Dostupné na internete: https://slidetodoc.com/m-ii5-nebezpeie-horskch-oblast-orografick-vplyvy-na/ (citované 2022-02-15)

[9] The World of Aviation: Etihad flight hits severe turbulence [online]. Dostupné na internete: https://theworldofaviationblog.wordpress.com/2016/05/04/31-injured-after-an-etihad-flight-hits-severe-turbulence/ (citované 2022-02-16)

[10] SKYbrary: B788, Amritsar India, 2018 [online]. Dostupné na internete: https://skybrary.aero/accidents-and-incidents/b788-vicinity-amritsar-india-2018 (citované 2022-02-16)

[11] Wikipedie: Let American Airlines 587 [online]. Dostupné na internete: https://cs.wikipedia.org/wiki/Let_American_Airlines_587 (citované 2022-02-16) YouTube: Did a Poorly Trained Pilot Cause Flight 587's Crash? [online]. Dostupné na internete: ttps://www.youtube.com/watch?v=nPHtof6tHKE (citované 2022-02-16)

[12] SKYbrary: A346, northern Turkey, 2019 [online]. Dostupné na internete: https://skybrary.aero/accidents-and-incidents/a346-en-route-northern-turkey-2019 (citované 2022-02-19)

[13] General civil aviation authority:Air Accident Investigation Sector [online]. Dostupné na internete: [2020-SRP02-2020 on Turbulence.pdf (gcaa.gov.ae) (citované 2022-04-11)

[14] Meteopress: Oklúzny front [online]. Dostupné na internete: https://stary.meteopress.sk/2010/09/okluzny-front-a-to-je-co/ (citované 2022-02-19)

[15] Weather.gov: Turbulence [online]. Dostupné na internete: https://www.weather.gov/source/zhu/ZHU_Training_Page/turbulence_stuff/turbulence/turbulence.htm (citované 2022-02-19)

[16] FIALA, Ľ. 2018. VLIV BOUŘKOVÉ ELEKTŘINY NA LETECKOU DOPRAVU: bakalárska práca. Brno: VUT, 2018. 51 s.

[17] SlidePlayer: Cumulonimbus [online]. Dostupné na internete: https://slideplayer.com/slide/9116590/ (citované 2022-04-11)

[18] Wikipedia: Wake turbulence [online]. Dostupné na internete: https://en.wikipedia.org/wiki/Wake_turbulence (citované 2022-03-05)

[19] FLIGHT LITERACY: Wake turbulence [online]. Dostupné na internete: https://www.flightliteracy.com/wake-turbulence/ (citované 2022-03-06)

[20] Google maps: Letisko Poprad [online]. Dostupné na internete: https://www.google.com/maps/place/Letisko+Poprad-Tatry/@49.0695669,20.240724,3052m/data=!3m1!1e3!4m5!3m4!1s0x473e3ac065b25aed:0xa4a122d02a6cd9!8m2!3d49.0689216!4d20.248479 (citované 2022-04-11)

[21] Skystef.be: Aviation weather [online]. Dostupné na internete: https://www.turbulenceforecast.com/maps/europe-alt-12.png (citované 2022-03-14 a 2022-04-11)

[22] CFI notebook.net : Prognostic chart symbols [online]. Dostupné na internete: https://www.cfinotebook.net/notebook/weather-and-atmosphere/prognostic-charts (citované 2022-03-14)

[23] SHMÚ: Prízemné tlakové pole [online]. Dostupné na internete: https://www.shmu.sk/sk/?page=980 (citované 2022-03-14 a 2022-04-11)

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

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

[26] 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.

[27] KAZDA, A., CAVES, R.E. 2007. Airport Design and Operation. Bingley: Emerald Group Publishing Limited, 2007. 538 s. ISBN 978-0-08-045104-6.

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POSSIBILITIES OF REDUCING ENVIRONMENTAL IMPACTS OF AIRCRAFT ON MOVEMENT AREAS AND APRONS

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Abstract

This aim of the paper is based on a theoretical analysis of possibilities of reducing fuel consumption, emissions and noise during aircraft take-off, taxi and turn-over procedure. In the very beginning, author defines the basic terms of airport infrastructure and defines types of taxiways based on their constructional solution and physical characteristic. Taxiways are not given to the aircrafts as efficient as possible on many airports. To point out the possibility of reducing fuel consumption and emissions production from different taxiway route, author decided to analyse taxiway and runway infrastructure of Vienna-Schwechat Airport (IATA: VIE) and made runway analysis of Airbus A320-200. Another option how to reduce mentioned attributes and increase the quality of environment is single engine taxi (SET) procedure. Author analysed advantages and disadvantages of SET and established possible communication between aircraft crew and air traffic control officer. Push-back tractors produce not negligible amount of pollutants too. The solution is to operate zero emission push-back tractors powered by electric engine or implement innovative system WheelTug into the nose landing gear. These solutions bring many advantages for surrounding environment and reduce airport noise too. Last not but least, author describes advantages and possibilities of use of Fixed Electrical Ground Power instead of APU or GPU during turn-over procedure.

Keywords

Emission reduction, Environment, Turn-over, Push-back, Taxiing, Derate

1. INTRODUCTION

Nowadays, there is a significant pressure from governments and society to reduce the environmental impact of aviation. The fastest possible step to reduce the adverse environmental impact of aviation on the surrounding environment, given current technologies, is to eliminate fuel consumption by reducing the environmental impact of aircraft on movement areas and airport stands. This will significantly reduce production of emissions. Emissions reduction can be achieved not only through the appropriate method and route of taxiing, but also through the use of modern emission-free technologies during turn-over or push-back procedures.

2. NOISE AND EMISSIONS DURING TAXIING

2.1. Noise polution and environment

Noise can be understood as an unwanted, disturbing or harmful sound (sound is a vibration) that propagates as an acoustic wave, through a transmission medium such as a gas, liquid or solid. With the increasing intensity of air traffic, which is associated with the growing rate of urbanization in recent decades, there is also an increasing noise pollution in airport areas, which adversely affects the quality of life and health of exposed residents, but also the occurrence of the surrounding fauna. Long-term exposure of noise can cause sleep disorders, has negative effects on the cardiovascular and metabolic system, and also causes cognitive disorders in children. Noise pollution at airports can be reduced by using half of the power units during taxiing, or by implementing electric engines into airport ground handling vehicles during turn-over and push-back procedures [1].

2.2. Emissions and environment

Emissions produced by aviation account for only 3.77 percent of all emissions in the European Union (in 2017). On the other hand, they have risen by almost 130% in the last twenty years, which is the most significant growth in the entire transport sector. The most abundant compound generated by the combustion of aviation fuel, which has a negative effect on the atmosphere, is carbon dioxide. The decay time of this gas in the atmosphere is about 100 years. Due to its low concentration in the atmosphere, carbon dioxide does not pose a direct risk to human health, but it can cause dizziness, headache, confusion or ringing in the ears [2].

3. FUEL CONSUMPTION DURING TAXIING

The easier way how to calculate fuel consumption during taxiing is to use the procedure set by ICAO. This procedure assumes that average thrust during taxiing is 7% of maximum take-off thrust of the power units. Therefore, this method defines the fuel burn index as the fuel flow at a thrust of 7% of each power unit. Another method of determining fuel consumption during taxiing is to examine the influence of individual factors and divide the taxiing trajectory into individual phases (e.g., constant speed taxiing, stopping, turning, etc.) and assuming a certain power unit setting for each phase and finally interpolating or extrapolating ICAO fuel combustion indices for individual thrust settings. The sum of the fuel consumption during each individual phase gives the final amount of fuel consumed during taxiing. However, the fuel consumption itself and thus the amount of emissions produced are influenced by other determinants, which impact is unpredictable [3].

3.1. Influence of the most important determinants on fuel consumption during taxiing

Reducing engine thrust during stopping reduces fuel consumption if stopping takes longer time. However, for the aircraft to start moving (taxiing) again, the thrust must be increased again, which is accompanied by a sharp increase of fuel consumption. On the other hand, if the pilot stops the aircraft with the brakes only, without reducing the thrust of the engines, the fuel flow remains high during entire stopping and can lead to a significantly higher amount of total fuel consumed [3].

Fuel consumption and the amount of produced emissions also depend on current visibility. While aircraft taxiing speed generally decreases under reduced visibility conditions, taxiing time over the same distance increases. Therefore, increasing fuel consumption and amount of emissions. Taxiing under reduced visibility increases fuel consumption by 1.5672 times compared to consumption during taxiing under non-significant weather conditions [3].

Whether the aircraft taxiing for take-off (taxi-out) or taxiing to the stand after landing (taxi-in) has also a significant effect on fuel consumption. Globally, it takes almost 52% less time for an aircraft to provide taxi-in than taxi-out. This is mainly due to the push-back procedure and the priority of landing aircraft over take-offs [3].

3.2. Aircraft Communications, Addressing and Reporting System

Aircraft Communication, Addressing and Reporting System (ACARS) is a digital data link system for transmitting messages between aircraft and ground stations. The system automatically delivers a lot of information to the operator during taxiing and the flight, fuel consumption not excluding. Based on the subsequent evaluation of data packets, it would be possible to implement the effectiveness of the established procedures for reducing environmental impacts - we prefer to consider the parameters of consumption during the taxiing, which is the main purpose of this thesis [4].

4. PROPOSAL FOR TAXIING BY SHORTER TRAJECTORY

4.1. Analysis of taxiway and runway system at Vienna-Schwechat Airport (VIE)

To analyze the movements at taxiway and runway system has been selected Vienna-Schwechat Airport. VIE Airport has 159 stands (159 options, but some stands overlap, and therefore the maximum aircraft capacity is 98), 30 taxiways, 18 taxi lines and 4 runways (RWY 11-29 and RWY 16-34). The runway 11-29 has a declared length of TORA of 3500m, and the runway 16-34 has a declared length of TORA of 3600m [5].

4.2. Analysis of Airbus A320-200

The Airbus A320-200 was chosen as the representative for the proposal for the shortened taxiing distance, as it is one of the most frequented type of aircraft operated at VIE airport.

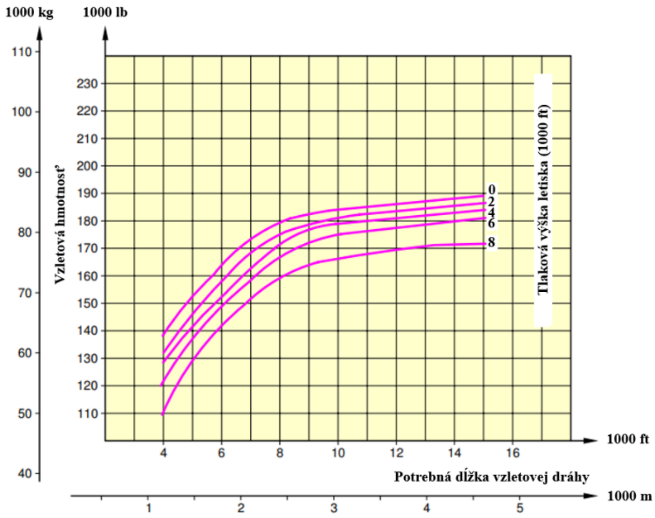

Figure 1: Dependence of the required runway length on the take-off weight under ISA conditions for A320-200 with CFM56-5B power units. [Airbus. 1985. rev. 2020. Aircraft characteristics – airport and maintenance planning, page 146]

If we consider the ISA conditions (Temperature 15°C, Pressure (QNH) 1013.25hPa, Air density 1.225kg/m3), no wind, dry runway, air conditioning - ON and Heating - OFF and wing mechanization set to position 1+F (flaps set to 8.5 ° and slots to 17 °), the required runway length for the Airbus A320-200 at 600ft (VIE altitude) with CFM56-5B power units and weight 70 tons is approximately 1600 meters [6].

4.3. Proposal for taxiing by shorter trajectory from stand F13 to RWY 34

Traditional air carriers often use the entire runway 34 for take-offs. But for take-off under the conditions stated above, the sufficient runway length is 1600m. So, it is not ecological nor economical to use the entire runway length, as it can be entered by multiple taxiways. When determining the possibility of reducing fuel consumption due to the use of a more suitable taxiing trajectory, the average thrust setting of the power units is 7% of their maximum take-off power. When setting a given thrust, the fuel consumption per each power unit is 0.12 kg/s. In the subsequent analysis of the possibility of shortening the trajectory and taxiing time, an average taxiing speed of 15 kts is considered [7].

Fuel consumption during conventional taxiing (Aircraft using all power units) in kilograms, denoted as FB_{Eng}, is given by:

$$FB_{Eng} = t \cdot FF_{idle} \cdot N \quad (1)$$

Where

- FB_{Eng} is amount of fuel consumed by the power units (kg);
- t is time (s);

- FF_{idle} is fuel flow at idle (kg/s);
- N is number of running power units [8].

Assume that the aircraft is parked on stand F13. If the aircraft entered RWY 34 via taxiway B10, TORA would be 2336 meters and TODA would be 2396 meters, which are sufficient distances to execute a safe take-off. Taxiing from stand F13 to RWY 34 and enter RWY via taxiway B10 would save approximately 771 meters of taxiing compared to using the entire length of RWY 34, which at an average taxiing speed of 15 kts represents a time of approximately 100 seconds. This would save 23.98 kg of fuel.

Due to the current take-off weight and weather conditions, the crew of the aircraft could use an even earlier entrance to RWY 34, for example taxiway B8, while TORA and TODA would be 1949 meters long and 2009 meters long. The aircraft save approximately 1396 meters of taxiing compared to using the entire length of RWY 34, which would be approximately 181 seconds at an average taxiing speed of 15 kts. This would save 43.42 kg of fuel.

4.4. Proposal for taxiing by shorter trajectory from stand F13 to RWYs 11, 16 and 19

RWYs 11, 16 and 29 can also be entered via several taxiways. The attached table shows the impact of the use of different entry taxiways on runways in order to shorten the taxiing distance (m), shorten the taxiing time (s) and reduce the amount of fuel consumed (kg). In the analysis, during taxiing both CFM56-5B power units are used on the A320-200 aircraft with an average thrust of 7% of the maximum take-off thrust. Consumption of one power unit for a given configuration is 0.12 kg/s and the average taxiing speed is 15 kts [7].

Table 1: Shortened taxiing trajectories from stand F13. [Authors]

F13							
RWY	TWY	TORA	TODA	ASDA	Skrátená vzdialenosť (m)	Skrátený čas (s)	Ušetrené palivo (kg)
					v porovnaní s využitím vstupnej rolovacej dráhy pri prahu RWY		
11	A11	3390	3450	3390	133	17	4,14
	A10	3001	3061	3001	487	63	15,15
	A9	2458	2518	2458	772	100	24,01
	A7	1930	1990	1930	1231	160	38,29
29	A2	3404	3464	3404	92	12	2,86
	A3	3158	3218	3158	333	43	10,36
	A4	2639	2699	2639	495	64	15,40
	A6	2116	2176	2116	452	59	14,06
16	B2	3470	3530	3470	232	30	7,22
	B4	2482	2542	2482	41	5	1,28
	B5	2219	2279	2219	-	-	-
	B7	1806	1866	1806	-	-	-
34	B11	3448	3508	3448	111	14	3,45
	B10	2336	2396	2336	771	100	23,98
	B8	1949	2009	1949	1396	181	43,42

Due to the position of the stand F13 when using the taxiways B5 and B7, a larger amount of fuel will be consumed during the taxiing than using the entire length of the runway. However, from the point of view of performing the flight as an entirety, the aircraft will additionally pass this distance during takeoff. Thus, in the final analysis, it can be stated that from the point of view of the entire flight, the traveled or flown distance will not be saved. If the aircraft enters the runway via taxiway B5 or B7, the power units operate at a higher thrust for a shorter time. This means that even if the taxiing itself takes a longer time and there is more fuel consumed during the taxiing, more fuel should be saved at the take-off phase.

4.5. Possibilities of using Rapit Exit Taxyway afer landing

As well as before take-off also after landing, it is possible to select a more or less efficient taxiway for runway vacation. However, in this case, it is not possible to determine unambiguously via which taxiway the aircraft should vacate the runway due to the possibility of shortening the distance and time of taxiing. It is because landing, braking and coasting are affected by a large number of determinants. For example, meteorological conditions, point of touchdown, crew skills, runway contamination or traction reverser application, aerodynamic brakes and landing gear application force.

5. ANALYSIS OF USING HALF OF THE AMOUNT OF POWER UNITS TO REDUE NOISE AND ECOLOGICAL IMPACTS DURING TAXIING ON MOEMENTS AREAS

The main potential benefits of using half of the amount of power units are lower fuel consumption and lower emissions such as carbon emissions, nitrogen oxides (NOx) and unburned hydrocarbons (HC). [9].

The fuel consumed by the APU must also be taken into calculation of total fuel consumption of the aircraft during the SET procedure (SET procedure is a procedure used by twin-engine aircrafts while taxing with only one active engine). It is essential that the APU is active unless all power units of the aircraft is started-up. APU fuel consumption is significantly lower than one of the power units, but this consumption must also be taken into calculation. Consideration is given by:

$$FB = FB_{Eng} + FB_{APU} \quad (2)$$

Where

- FB total amount of consumed fuel (kg)
- FB_{APU} fuel consumed by APU (kg);
- FB_{Eng} fuel consumed by Power unit [8].

5.1. Comparison of conventional taxiing wih SET

For comparison, a model example of taxiing from stand B85 to RWY 34 with entry to the runway via taxiway B10 is performed. The taxied distance is 4332 meters. At a taxiing speed of 15 kts, the aircraft will ride this distance in time of 561 seconds. The push-back time (4 minutes) and the estimated waiting time (2 minutes) must be added to this time. Calculations of fuel consumption during conventional taxiing and taxiing using the SET procedure have shown that the demonstrated taxiing should save 52.78 kg of fuel, which represents approximately 23.87% savings. The calculations also take into account the start-up and warm-up time of the second power unit to operating temperature (ESUT) of 5 minutes.

The savings at the model example did not reach 50%, despite the fact that the aircraft uses SET procedure. The reasons are as follows. If we consider a twin-engine aircraft that uses the SET procedure, to ensure sufficient electricity for the needs of the aircraft on-board system and to ensure the functionality of all hydraulic and ventilation systems (air conditioning), it is necessary to keep the APU in operation, which has its significant consumption [8]. At VIE, using the SET method for taxiing from the stand to the runway could result in an average fuel saving of

18.69%. As the taxiing distance increases, the percentage fuel savings increase.

5.2. *Disadvantages of SET*

Problems arising during executing a SET procedure are related to excessive exhaust gas flow - Jet Blast. If not all engines are used for taxiing, the remaining engines must generate more thrust in order for the aircraft to move, which causes the danger associated with the force of the air impact generated behind the jet engine. Another problem with twin-engine aircraft during the SET procedure is that asymmetric thrust occurs. Such an asymmetry makes it difficult to turn the aircraft to the side of the running engine [10].

6. POSSIBILITIES OF USING TOWING TRUCK FOR TAXIING

Theoretically, it would be possible to use an electric towing truck to move the aircraft from the stand to the runway holding point. However, we rejected such an aircraft movement process due to the disproportionate safety risk associated with the movement of trucks on taxiways and the high workload of pilots, who would have to verify the functionality of all systems associated with the operation of power units in a short period of time.

7. TAKE-OFF DRATE PROCEDURE

The take-off derate procedure electronically reduces the rated thrust of the engine by one or more specified values, or by a selected percentage of the maximum take-off thrust [11]. Individual operational, meteorological and mass flight data are entered into the flight management system, FMS (Flight Management System), which calculates the speeds V1, VR and V2, and the setting of the thrust of the engines during take-off. In both Airbus and Boeing aircraft, the pilot chooses the derate setting indirectly from a selection of assumed temperatures calculated by FMS. These temperatures correspond to the thrust settings needed to achieve a safe take-off for different take-off weights. In response to the expected increase in temperature, the FMS will reduce the fuel flow to the engine and consequently reduce the thrust generated by the engine [12].

Turbine speed, internal temperature and internal pressure are among the others the most important engine parameters that affect its life. Operating the engine at lower thrust or at reduced thrust reduces the size of these parameters, thereby increasing engine life [12].

The use of reduced thrust during take-off reduces fuel consumption, emissions NOx and BC by 1,0 – 23,2 %, 10,7 – 47,7 % a 49,0 – 71,7 % depending on the aircraft-engine combination compared with 100% setting of power unit thrust (so-called nominal engine thrust). If reduced procedure is not used, total ground fuel consumption is expected to increase, as well as emissions of NOx a BC by 3,3 %, 31,9 %, respectively 71,3 % [13].

8. PUSH-BACK PROCEDURE

Push-back procedure means pushing the aircraft out of the stand using external force, most often in the form of a specialized ground vehicle, called a "push-back tractor" or "tug", in order to get the plane to the taxi lane or taxiway [14].

8.1. *Electric push-back*

A significant source of pollutants in aviation industry is also those produced by conventional push-back vehicles using diesel engines. Such push-back methods are responsible for 9.5% of nitrogen oxide (NOx) and PM emissions produced by the airport's ground handling vehicles. The approximate fuel consumption of a conventional push-back vehicle with an internal combustion engine at an engine torque of 300 Nm and an engine speed of 2000 rpm is 16 l/h [15].

In order for air transport to be able to maintain its sustainable development and competitiveness, especially with regard to high-speed rail transport, it is necessary to reduce emissions, preferably to zero. One of the parts of aviation where it is possible to reduce emissions due to today's technology is the push-back process.

While diesel engines produce a significant amount of noise, electric motors are very quiet. This contributes to improving the working environment and passenger comfort.

8.1.1. *Electric push-back at Munich Airport*

In 2021, Munich Airport began renewing its push-back tractor fleet. Conventional push-back vehicles powered by diesel engines are gradually being replaced by »PHOENIX« E vehicles from the Goldhofer workshop. The vehicle uses a modular battery expansion system, which means that the basic battery has a capacity of 66 kWh, while its capacity can be expanded by other battery modules up to a capacity of 165 kWh. If the vehicle uses 165 kWh batteries, it can perform up to 15 push-backs on a single charge. Charging the vehicle´s battery from 20% capacity to 80% capacity takes about 30 minutes thanks to using fast charging technology. Thanks to the use of fast charging technology, vehicle can be recharged in a short time, so they can be efficiently charged outside rush-hours, when a lower number of push-back vehicles is sufficient for the needs of the operation. [16].

The type of charging connector is selectable according to operator´s preferences and according to the existing electrical infrastructure at the airport, which contributes to saving the operator considerable costs [16].

8.2. *WheelTug System*

The idea of WheelTug system is to use high-performance electric motors installed into the front undercarriage leg. The system allows not only the movement of the aircraft backwards but also forwards. WheelTug replaces conventional push-back vehicles needed to push an aircraft out of the stand [17].

8.2.1. *WheelTug system composition*

The basis of the WheelTug system are two asynchronous electric motors integrated into the front undercarriage leg, and thus become part of it. Electric motors are relatively small, but they can still develop a large torque moment, thus ensuring the required traction. The required electrical energy for WheelTug is taken from the auxiliary power unit - APU. Inverters are another important part of the system. The main task of the inverters is to adapt the electrical energy from the APU to that which is needed to drive the electric motors. The inverters also serve as a control unit for the electric motors, protecting the electric motors from damage at high speeds or skidding. Such protection is provided by power regulation and subsequent disconnection of the stator and rotor parts, based on a signal from a load sensor located on the chassis. The last physical part of the system is the control panel installed in the cockpit of the aircraft. The control panel allows the crew to activate the system and select the desired operating mode [17].

In addition to the physical components, the WheelTug system also contains software on which the correct functioning of the entire system depends. In addition to managing the individual components of the system, the software collects data on its use, and thanks to this, the entire WheelTug system can be constantly improved and optimized [17].

8.2.2. *Time and economical aspect of using the WheelTug system*

In terms of time, the primary advantage is that the aircraft requesting push-back does not have to wait for a ground service vehicle. Thanks to the WheelTug system, the aircraft can perform its own push-back and is not necessary to unnecessarily wait at the stand. Also, the number of steps performed during the push-back is reduced [18].

8.2.3. *Noise aspect of using the WheelTug system*

The only significant source of noise is APU activity. However, the noise level produced by the APU is significantly lower than the amount of noise produced by the main power units. If the aerodrome operating time is limited during night, as soon as the Night Curfew ceases to apply, the aircraft can be ready at the runway area and start starting-up the power units. The aircraft can perform push-back and start taxiing during the night noise limit, as the use of the WheelTug system does not exceed the night noise limits [17].

8.3. Mototok – Spacer

It is a small electric vehicle powered by two electrically controlled electric motors. Electric motors are driven by accumulators, while traction accumulators with positive armor plates of the PzS and PzB type or AGM accumulators with LifeGrid technology are used. The batteries provide the device with a voltage of 80 V and their nominal capacity is 300 Ah, which is enough for 30 to 50 push-backs, depends on the weight of the aircraft and the traveled distance. Subsequently, the batteries must be recharged. The charging time is 3 hours. A charging time of 3 hours is sufficient to be able to recharge the Spacer outside of Rush Hours [19].

As this is an electric-powered vehicle, fuel consumption is zero and therefore the vehicle produces zero emissions and is carbon free. It also provides a lower noise compared to conventional push-back vehicles, as it does not have an internal combustion or petrol engine. Other undeniable advantages include its small size and the possibility of service by one staff member only [19].

9. POSSIBILITIES OF REDUCING EMISSIONS PRODUCED DURING TURN-OVER PROCEDURE

The turn-over procedure is a procedure at the airport stand from the moment of stop of the aircraft at the stand to the push-back procedure. The turn-over procedure most often consists of disembarking and embarking passengers, unloading and loading luggage and cargo, refueling, cleaning the interior of the aircraft, replenishing the catering and powering the aircraft with electricity [20].

9.1. Ground Power Unit – GPU

One of the most widely used methods of supplying electricity to the aircraft's on-board power grid during the turn-over procedure is to use a GPU.

The GPU can be understood as an electricity generator, which is most often powered by a diesel engine. To ensure GPU compatibility with different types of aircraft, it is essential that the GPU be able to provide both DC and AC power. The GPU provides 28 VDC as standard for general aviation aircraft, turboprop aircraft and smaller jets, or 115 V AC with 400 Hz for large commercial airliners [21].

9.1.1. *Comparison of APU and GPU fuel consumption*

The average fuel consumption of a medium-haul airliner APU is 0.032 kg per second and a long-haul airliner is 0.073 kg per second, which is 115 to 263 kg of fuel per hour. The average consumption of a conventional diesel GPU is from 25 to 35 kg of fuel per hour. Due to the significantly lower fuel consumption, the GPU is used to ensure the supply of the required electricity for the aircraft during the turn-over procedure. However, using of GPU accounts for up to 42% of emissions produced during the turn-over procedure. The APU is used only exceptionally, in cases when the GPU is not available at the airport [22].

9.2. One GPU for two aircrafts

One of the possibilities how to reduce fuel consumption and emissions is to use a special GPU that can provide electricity for two aircraft at the same time. Such a GPU is, for example, the ITW GSE 4400 Diesel GPU. This GPU is capable of supplying 28.5V DC or 115V AC and 400Hz or both at the same time [23].

If two aircraft are to be powered from one GPU, they must stand on the stands next to each other, which is a complication in terms of allocating stands to the aircraft. The ideal allocation of stands would be such that a pair of aircraft with similar time-in and time-out stands next to each other, i.e., the times between which the aircraft stands on the stand.

9.3. eGPU – Electric GPU

eGPU can be understood as a kind of portable accumulator that is charged on one place from a fixed electrical network and then provides its energy to aircraft during turn-over procedure. The representative of such a GPU is the ITW GSE 7400 eGPU [22].

While airport staff, crew and passengers benefit from zero emissions and low noise near the aircraft, the eGPU has a short return on investment due to lower electricity prices and lower maintenance costs, as eGPUs do not have any moving parts that are subject to considerable wear and tear [22].

The use of eGPU compared to a conventional GPU with daily operation of 5.5 hours, for a period of 1 year achieves an overall reduction of CO_2 emissions by 90% and NOx emissions by 95% [22].

eGPU ITW GSE 7400 is powered by Nissan Leaf batteries with a capacity of 40 kWh for the 28 VDC and 90 kVA 400 Hz versions, and a capacity of 62 kWh for the 140/180 kVA 400 Hz version. Battery life depends on the type of aircraft to which the electricity is provided and on the air carrier itself. For example, some carriers execute shorter but more energy-intensive turn-over procedures, while others execute longer but less energy-intensive turn-over procedures. In a rough estimate, the manufacturer states that the batteries last 6 to 10 hours in a version providing 90 kVA and 400 Hz alternating current with a battery capacity of 40 kWh [22].

9.4. FEGP – Fixed Electrical Ground Power

FEGP is an ecological ground-based energy system that allows aircraft to connect directly to a fixed electrical power source when stopped at a stand equipped with such a system. The FEGP system is directly connected to a conventional electrical network that supplies 50 Hz AC, but 400 Hz is required to power the aircraft. For this reason, the system has three rotary converters, each of which is switched on or off depending on the demand at the stands [24].

The electricity itself can be supplied via the cable system either via the airbridge, via cable winding devices that can be wound as required, using an "alligator cable carrier", or via a system of holes built in the terminal apron area´s ground (PIT). PIT system is being used more and more often, because it enables to use a FEGP even on remote stands [24].

Building a system of holes in the terminal apron area´s ground is the costliest operation, due to the need for underground power cables, but it provides the highest level of safety and access to such a system can be provided even at remote sites [24].

9.5. Pre-conditioned Air System

A PCA system is often built together with the FEGP system. It is a system of pre-conditioned air adapted for cooling, ventilation and heating of aircraft cabin during the turn-over procedure [25].

There is an AHU (Air Handling Unit) at the stand. AHU is an air handling unit, i.e., a compressor-air conditioning unit that filters, compresses, cools or heats ambient air. Such air is then blown into the aircraft cabin via an insulated duct [25].

Due to the external supply of pre-conditioned air, the aircraft does not have to have the APU running. PCA systems are significantly quieter during operation and reduce fuel consumption and related CO2 emissions [25].

10. CONCLUSION

Based on the performed analyzes and analyzes of the possibility of taxiing trajectories, taxiing method and take-off derate procedure, it can be stated that to reduce fuel consumption and produced emissions, steps such as shortening the distance traveled by taxiing, use a more suitable taxiing trajectory, execute SET procedure, use of the take-off derate procedure.

In most cases, the use of an earlier (more suitable) taxiway to enter the runway is justified. The aircraft does not have to cross the route in addition, thus saving fuel and reducing emissions. However, depending on the relative position of the stand and the runway, there may be a case where the use of a taxiway that provides a shorter TORA may not lead to a reduction of the produced emissions. Based on the analysis of the VIE airport (three stands selected (B85, F13 and F26)) and the A320-200 aircraft with CFM56-5B power units, it can be stated that using a more suitable taxiway can save 16.41 kg of fuel on average, with a median value of 14.06 kg of fuel.

Analysis of the same input elements by SET procedure, has shown that such taxiing at VIE airport leads to an average fuel saving of 18.69%, with a median of 18.95%. In addition to the reduced amount of fuel consumed, there is also a reduction in emissions and noise at airport movement areas. However, the crew is exposed to a higher workload during this type of taxiing and must take into consideration the thrust asymmetry and the higher Jet Blast.

It is also necessary to introduce modern emission-free systems such as Phoenix E or Spacer for the push-back procedure. However, airport operators will have to carry out feasibility studies, as the implementation of such electrical systems will require the construction of charging stations and electrical infrastructure. In addition, it is necessary to consider their charging time and possibly the increased number of vehicles compared to conventional vehicles. On the contrary, the WheelTug system does not bring the described problem, so from the point of view of the airport operator, its implementation is more advantageous. However, the operation of the APU is necessary for its functionality, so it is not an emission-free push-back principle.

The GPU produces up to 42% of the total emissions produced during the turn-over procedure, so its replacement is necessary. The FEGP system, which is clearly the most environmentally friendly system, seems to be the most appropriate. Its construction requires high investment costs, especially for its construction on remote stands. The use of individual systems and procedures will ensure, in particular, the improvement of the environment around airports and the reduction of noise pollution. Last but not least, the carriers themselves can also benefit from such methods, in the form of saved financial costs for fuel and in the form of saved time.

REFERENCES

[1] E. Peris, „Európska environmentálna agentúra," 02. 04 2020. [Online]. Available: https://www.eea.europa.eu/sk/articles/zatazenie-hlukom-predstavuje-vazny-problem. [Cit. 03. 02. 2022].

[2] Európsky Parlament, „Europarl.Europa," Spravodajstvo - Európsky Parlament, 05. 12. 2019. [Online]. Dostupné: https://www.europarl.europa.eu/news/sk/headlines/society/20191129STO67756/emisie-z-leteckej-a-lodnej-dopravy-fakty-a-cisla-infografika. [Cit. 03. 02. 2022].

[3] Ming Zhang et al., Assessment Method of Fuel Consumption and Emissions of Aircraft during Taxiing on Airport Surface under Given Meteorological Conditions, Nanjing: College of Civil Aviation, Nanjing University of Aeronautics and Astronautics, 2019.

[4] „SKYbrary," [Online]. Available: https://skybrary.aero/articles/aircraft-communications-addressing-and-reporting-system. [Cit. 08. 02. 2022].

[5] AIP Austria, LOWW AD 2.24-1-2, Austrocontrol, 2020.

[6] „CFM Aero Engines," [Online]. Available: https://www.cfmaeroengines.com/engines/cfm56/. [Cit. 01. 31. 2022].

[7] Emanuel Fleuti, Silvio Maraini, „Flughafen Zuerich," Zurich Airport, [Online]. Available: https://www.flughafen-zuerich.ch/-/jssmedia/airport/portal/dokumente/das-unternehmen/politics-and-responsibility/environmental-protection/technische-berichte/2017_taxi_study_zurichairport.pdf?. [Cit. 02. 02. 2022].

[8] A. T. Escapa, Estimation of energy consumption and emissions in aircraft operation and potential for savings: Master of Science Thesis, Lisbon: Técnico Lisboa, 2015.

[9] George S. Koudis et al., „Royal Aeronautical Society," rev. The impact of single engine taxiing on aircraft fuel consumption and pollutant emissions, London, 2018.

[10] Dirk Bresser, Simon Prent, „Schipol," [Online]. Available: https://www.schiphol.nl/en/innovation/blog/single-engine-taxiing/. [Cit. 09. 02. 2022].

[11] „SKYbrary," [Online]. Available: https://skybrary.aero/articles/reduced-thrust-takeoff. [Cit. 11. 02. 2022].

[12] Andy Mihalchik, Max Moutoussamy, „Boeing Performance and Flight Operations Engineering Conference," rev. Reduced Thrust Takeoff – Proven Benefit, Lowering Engine Maintenance Cost, 2010.

[13] George S. Koudis et al., „ScienceDirect," Elsevier, 05 2017. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1361920916302401. [Cit. 31. 01. 2022].

[14] „SKYBrary," [Online]. Available: https://skybrary.aero/articles/pushback. [Cit. 21 02 2022].

[15] „Munich-Airport," 28. 01 2021. [Online]. Available: https://www.munich-airport.com/press-all-electric-aircraft-pushback-tug-in-operation-10524189. [Cit. 21. 02. 2022].

[16] „Goldhofer," [Online]. Available: https://www.goldhofer.com/fileadmin//downloads/airport_technology/E-MOBILITY_EN-met_A4.pdf. [Cit. 21. 02. 2022].

[17] T. Kulifaj, Případová studie vlivu využití systému wheeltug na Letišti Praha: Diplomová práce, Praha: České vysoké učení technické v Praze, 2016.

[18] „WheelTug," [Online]. Available: https://www.wheeltug.com/. [Cit. 21. 02. 2022].

[19] K. Eckert, Opertion Manual SPACER 8600 MA, Krefeld: Mototok International GmbH, 2013.

[20] Airbus, Aircraft Characteristics – Airport and Maintenance Planning - A320, Blagnac: Airbus, 2020.

[21] Aviation Learnings Team, „Aviation Leranings," 29. 05 2020. [Online]. Available: https://aviationlearnings.com/aircraft-ground-power-unit/. [Cit. 07. 03. 2022].

[22] „ITW GSE," [Online]. Available: https://itwgse.com/products/power/itw-gse-7400-egpu/. [Cit. 09. 03. 2022].

[23] „ITW GSE," [Online]. Available: https://itwgse.com/products/power/itw-gse-4400-diesel-gpu/. [Cit. 09. 03. 2022].

[24] Emanuel Fleuti, Christian Ruf, Aircraft Ground Energy Systems at Zurich Airport, Zurich: Zurich Airport, 2018.

[25] „Munich-Airport," [Online]. Available: https://www.munich-airport.com/a-fresh-breeze-thanks-to-pca-1229006. [Cit. 21. 03. 2022].

[26] KAZDA, A. 1995. Letiská design a prevádzka. Žilina: Edičné stredisko VŠDS 1995. 377 s. ISBN 80-7100-240-2

[27] KAZDA, A., CAVES, R.E. 2007. Airport Design and Operation. Bingley: Emerald Group Publishing Limited, 2007. 538 s. ISBN 978-0-08-045104-6.

[28] 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.

[29] 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.

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

[31] NOVÁK, A., HAVEL, K., JANOVEC,M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

[32] NOVÁK, A., ŠKULTÉTY, F., KANDERA, B., ŁUSIAK, T. 2018. Measuring and testing area navigation procedures with GNSS. MATEC Web of Conferences 236, 01004

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

[34] ŠKULTÉTY, F., JAROŠOVÁ, M., ROSTÁŠ, J. 2022. Dangerous weather phenomena and their effect on en-route flight delays in Europe. Transportation Research Procedia, 2022, 59, pp. 174–182. ISSN 23521457.

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IMPACT OF CLOUDS ON THE AVIATION

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Abstract

The aim of the paper is to study concepts and types of cloud coverage and clouds itself. It also brings the different types of clouds and its effect on aviation closer to the reader. In the first part paper focuses on general concepts. Then it describes types of clouds and talks about them in detail. Next theme are radars and maps used in aviation to worn and tell us about the cloud coverage as its possible threats. In the last part, the paper shows us some maps and tells us about possible threats caused by clouds or vice versa its positive effects on the flights.

Keywords

Clouds, Cloud coverage, Meteorological reports, Cloud base.

1. INTRODUCTION

In this paper we study basic concepts as clouds and cloud coverage. We also devide clouds into diferent groups and we allocate types of clouds that belongs to the groups. We mostly focused on types of clouds which are the most important in aviation, weather for pilots and meteorologists. Then we talked about negative effect that accompany cloud coverage. Next topic to discuss are satelites, radars that we use to detect clouds. Maps and reports are used to plan the flight, from the deprature to landing, with minimum meteorological threts during the flight. During this teoretical part we collect informations. This informations are later used in more practical part of the paper. In the practical part of the paper we collect maps and we talk about clouds and the threts that can accompany them. In this part we use maps that are accessible on the Internet.

2. CLOUDS AND CLOUD COVERAGE

Clouds are visible sets of small particles of water or ice in the atmosphere. But they can also contain parts of dust or smoke. Fog is also considered a type of cloud. I tis cloud touching the Earth's surface. Clouds differ by the height which they are located, shape, by their composition, etc. [1,2].

There is several reasons why the air that contains water vapour begins to go up to the sky. This is mostly conected to the air temperature. Air with the higher temperature is extruded by cooler air. Wind output can also take place along atmospheric frontal surfaces but also along terrain obstacles. With rising height atmospherich pressure decreases and temperature of the air is also decreasing. In this height, when temperature and preassure are lower, water particles are frozing and becoming ice [1,2].

The part of the sky that is covered in clouds is called cloud coverage. It is one of the most important meteorological elements, not only for aviation but also for our Earth. Informations about clouds are provided by Air Weather Service and then they are forwarded to air traffic control and pilots. To identify clouds and cloud coverage we use satellite images and our own eyes [1,2].

In aviation is important to know how many eights of sky is covered by clouds. With cloud coverage reduces visibility. That impacts VFR flights the most. On the other hand IFR flights aren't so limited. IFR flights are instrument flights so visibility is not a problem, but aircraft needs to be equpped with instruments for flying in the clouds. In higher hights with temperatures below zero, aircraft must have defrosting equippment due to possible icing. Biggest problem with cloud coverage is during landing and take – off. When the visibility is low flight can be canceled or delayed. With landing there is a bigger problem, becouse when ther is very low visibility aircraft can't land at a designated airport but it must find alternate airport. With cloud coverage there is several negative effect, not just on flight, but also for crew, there are higher operating costs [1,6,10].

Table 1: Cloud coverage.

Meaning	Sky cover	Abbreviation
Clear or Few	≤1/8	SKC or FEW
Few	2/8	FEW
Scattered	3/8 – 4/8	SCT
Broken	5/8 – 7/8	BKN
Overcast	8/8	OVC

3. CLASSIFICATION

Clouds are divided into different groups. Clouds are classified according to their height above and appearance from the ground, how they form, types of clouds [4].

Cloud classification according to the mechanism of their formation:

- Convective clouds,
- Frontal clouds,
- Turbulent clouds,
- Orografical clouds,
- Ect

Cloud classification according to their heigh appearance from the ground:

- Low clouds – 0 ft to 6 500 ft,
- Middle clouds – 6 500 ft to 23 000 ft,
- High clouds – 16 500 ft to 45 000 ft,
- Clouds with vertical development – clouds which belong to more floors.

We also classify clouds according different types, which belong to each floor. We know clouds as Cirrus, Stratocumulus, Nimbostratus, etc. [1,4].

3.1. Low clouds

Low clouds are the most important clouds for aviation. Low clouds have most negative effect on flights. They can affect take – off, landing and flight itself. Best conditions for the creation of low clouds is in warm sectors of cyclone. Width of this clouds can be up to 400 km and its length can be up to 2 000 km [5].

In this group of clouds we include clouds as Sc – Stratocumulus, St – Stratus, Ns – Nimbostratus [1].

Low cloud base should be in the height of dew point. In reality i tis different. Low clouds base is higher than dew point. Cloud base has multiple layers [5].

Low visibility during landing can be biggest problem during flight. Landing visibility can be divided into oblique visibility and horizontal visibility. As it was told earlier, cloud coverage doesn't affect only landing, but also flight itself and take – off. Thanks to advanced technology we don't need to have good visibility to fly. Pilots can also fly safe thanks to instruments on the board. That helps pilots to monitor inclination and height of the aircraft during flight. Low clouds can also influence cargo flights, construction helicopters, when the cloud base is near the construction area [5].

3.2. Middle clouds

Middle clouds consists of both water droplets and ice crystals. They are forming vertically instead horizontally, that is why they look like heaps. Width of this clouds can be between 200 m to 700 m [4].

In this group of clouds we include clouds as Ac – Altocumulus, As – Altostratus [1].

3.3. High clouds

High clouds are made up of ice crystals. This category of clouds can be higher than tropopause, but mostly they have base 1 km to 2 km under the base of tropopause. High clouds arise in warm fronts. Sun, moon, stars can be visible through the high clouds [4,6].

In this group of clouds we include clouds as Ci – Cirrus, Cc – Cirrocumulus, Cs – Cirrostratus [1].

3.4. Convective clouds

Convection clouds belong to the group of clouds with vertical development. Flowing air with vertical air currents as a result of warming is called convection. This convection usually take place in summer, during the day when the sun is shining. Best conditions for formation of convectional clouds is in atmospheric fronts. Convectional clouds can reach up to the level of tropopause, as a result of strong warming. Convectional currents are makers of copious clouds called Cumulus. They can also make storm cloud called Cumulonimbus [4,5].

We can await low visibility and turbulence around clouds as Cumulus. Icing shouldn't be the problem around them because they are result of warm fronts. But there are exceptions between seasons, when clouds can reach up to the heights with minus temperatures. And there is also exception in more developed clouds, as Cumulus congestus, where we can have problems with strong icing during flight, turbulences and low visibility. Worst conditions are in cloud called Cumulonimbus. Cumulonimbus is storm cloud where the visibility can be only up to 20 m. Vertical development of Cumulonimbus may cause overloading of the aircraft, change in angle of attack, tilt of the aircraft, frontal air repulsion. There is also a chance of being struck by lightning and strong icing. Flying in this clouds is prohibited [5].

3.5. Wave clouds

This clouds, like other clouds, they arise under certain conditions. They are formed from air inversions. Wave clouds consist of ice crystals, water droplets or as combination of both. They are usually formed in temperatures below zero. In very low temperatures wave clouds are considered unstable. This means that we can await rain, snow or ice. In this clouds we can normally have problems with icing or lower visibility or some different phenomena relevant to aviation [5].

Among wave clouds we can find low clouds as Stratocumulus and Stratus, middle clouds as Altocumulus and high clouds as Cirrus and some Cirrocumulus clouds. As it was said earlier, in aviation are low clouds the most important. They are St and Sc from this category. Flight in this conditions is quite hard if we plan VFR flight [5].

3.6. Copious clouds

They are usually formed on warm atmospheric fronts. We can find here clouds from every single category. From low clouds we have St, Sc and Ns, middle cloud are As and high clouds are Cs. They are vertically long, up to 2 km. On the other hand we also have small copious clouds which are formed in Anticyclones under the inversions. They have horizontal length up to 100 km [5,9].

3.7. Frontal clouds

Atmospheric front is the area separating air masses. We know three main atmospheric fronts: warm front, cold front and occluded front. Every front has it own clouds. Frontal clouds can make flight very difficult. Clouds which are in this group are horizontally and vertically very large. We can await here turbulence, fogs, icing or maybe storms. They are 1 500 km to 2 500 km long. Impact of aviation are similar to groups earlier, we can await turbulence, icing, rain, low visibility and in summer we can await also storms [4,5].

Warm front clouds are formed under and above the frontal area. With warm air are clouds above frontal area formed and vice versa with cold air are clouds under frontal area formed. Clouds under the frontal area are produced by turbulent air mixing. In this group we include clouds as St a Fs. Clouds above the frontal area are clouds vertically very large. In this group clouds as As, Ns, Ci and Cs are included [5,6].

Cold fronts are divided into two groups. Cold front type one and cold front type two. Cold front type one has mostly clouds above frontal area. Impacts are similar to warm front clouds. Only difference is in temperature and in icing. In summer moths we can count on the occurance of storms. Clouds which belong to this group are storm clouds Cb. Cold front type two is characteristic by faster movements of air. In this type we know clouds as Ci, Cc, As and Ac. This type is associated with colder months of the year. This clouds produce zones of rain. This zones have width up to several tens of thousands of km and length up to several thousands km.

Occluded front formed by catching up warm front by cold one. We know Occluded warm front and occluded cold front. It is for the best for flight to avoid this types of clouds, especially in summer. The reason is emergence of storm clouds Cb [6].

4. RADARS, MAPS, REPORTS

Weather reports are one of the key ingredients for flight planning. It is important to report rain, icing, turbulence, etc. With rain reports we can say if the visibility is going to be positive, in the icing on the ground or on the aircrafts won't be strong, To forecast such phenomena we use reports as METAR, SPECI, etc. For METAR making we use maps and photos from satellites and radars. On the other hand we can use our own eyes to observe clouds [10].

4.1. Meteorological cosmic systems – Satellites

Satellites were designed in the early twenties by Arthur C. Clark. In 1945 he wanted to put satellites on the geostationary path of the Earth. First European satellite were used in 1977 and it was Meteostat-1. Now we use Meteostat-MSG. To analyse weather we need only one photography. One photography can provide so many useful information for meteorologist so he can make a report. With satellites we can classify clouds into other different groups: clouds of small size, clouds od subsynoptic size, clouds of synoptic size and cloud of planetary size [9, 10].

4.2. Radars, radar images of cloud coverage

Without satellites we can't imagine life in modern meteorology and this also applies to radars. During Word War 2 were more practical use for radars found. They started to use radars to track aircrafts. But it wasn't that easy as they wanted, because there were smudges all around the images. It was found out later that this smudges were clouds. That is why now we use radars to identify clouds and weather. They gave us clear image of zones of rain, zones of clouds and so on. Radar images are freely available on the internet. In Slovakia we can find them on the SHMÚ website [10].

On the airports it is important that weather reports are up-to-date. Meteorological maps are very important for flight planning. Reports are published every 30 min or 60 min, it is up to the airport. We also know reports as TAF, SIGMET, GAMET, AIRMET and more [10].

4.3. Meteorological maps

Meteorological maps are mandatory equipment for pilots and meteorologist. They easily and aptly displays every crucial information about weather during flight. Meteorological maps are also important for flight planning. Some maps are specially adapted by meteorologists to facilitate planning. For pilot and meteorologist are important surface pressure maps same as heightmap [10].

4.4. SYNOP

By observations at the Earth's surface and aerological observations of various mountains or levels are a synoptic maps made. On this map is easy to mark information from large areas as Europe and whole Atlantic. This map contains current information about weather in UTC. It contains compared information from more weather stations. Information are sent to this stations in numeric form and then they are transformed into the map using symbols. This symbols are used worldwide for easy reading. There are two types of synoptic maps – first one is analyzed and the second is unanalyzed. Unanalyzed map contains only symbols of weather. On the other hand analyzed map contains also symbols of weather, atmospheric fronts, surface pressure fields, etc [10].

4.5. Significant weather

SW maps are maps that shows us important changes or information about weather. This maps are designated for airliners. It describes weather on flight level FL100 and FL450. They show us important meteorological phenomena which can have impact on our flight. Such as JetStream, turbulence, icing, storms, occurrence of Cb clouds, zones with vulcanic ash, and so on. In the past there were also atmospheric fronts shown, but is was many information in one place. They are published four times a day: 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC. Maps are freely available on the internet. The current SW map is mandatory aircraft equipment [10].

4.6. METAR and SPECI

METAR is a report about current weather. METAR is published by Air Weather Service every 30 min or every 60 min. It is written in codes according to the standards of ICAO. In this reports are informations about airport, time and date, speed of the wind, temperature, dew point, cloud coverage, meteorological phenomenons and so on. We can find informations about visibility on the position 5 or 6. Code CAVOK or 9999 means that visibility is more than 10 km, but on the other hand code as 0800 means that visibility is only 800 m. Between informations about clouds and visibility are often informations about meteorological phenomenons as rain RA, sand SA, Storm TS, etc. Before the abbreviation is + as strong intensity or – as minimum intensity used. Next group are codes used to identify cloud coverage in eights, as it was written earlier. We can find here abbreviation as SKC, FEW, SCT, BKN, OVS, then height of cloud base in ft and type od clouds. If the wind values, cloud coverage values, or else, suddenly changes, a SPECI report is published. SPECI is published immediately after worsening weather conditions, but it is published after 10 min after improving weather conditions [10].

4.7. SIGMET

SIGMT is report drowing attention to a certain meteorological phenomena. I tis one of the most important reports in aviation. It is published exclusively by met office. Name of this report is from the phrase „Significant Meteorological Phenomenon“. SIGMENT is send to the flying aircrafts, because it contains informations which are important now. But we can also use it during the flight planning. Report is send by VOLMET. And i tis written similar to METAR or every single meteorological report. But in this report is possible to use whole words. SIGMET is actual only for 4 hours, but it can be published to less than 4 hours. Exception is SIGMET for vulcanic ash, it is published for 6 hours [10].

We divide SIGMETs into three categories:

- SW SIGMET – significant weather SIGMET,
- WV SIGMET – vulcanic ash SIGMET,
- TC SIGMET – Tropical cyclones SIGMET [10].

Every SIGMET report has introduction as place of phenomena, met office, expiration time. Next part is meteorological, which describes concrete phenomenon, for example SEV TURB – Severe turbulence, OBSC TS – Obscured thunderstorm, and more. Next is time when the phenomenon was spotted and place where it was spotted, height maybe displacement of the phenomenon and the last one is intensity. Intensity is written if the phenomenon is intensifying – INTSF, No change – NC or if it is weakening – WKN. In reports is mostly marked intensifying of phenomenon [10].

5. OBSERVATION

In this part of paper we are going to use informations what we get earlier in the theoretical part. We are going to read maps and try to report weather and it impact of flight.

5.1. SYNOP

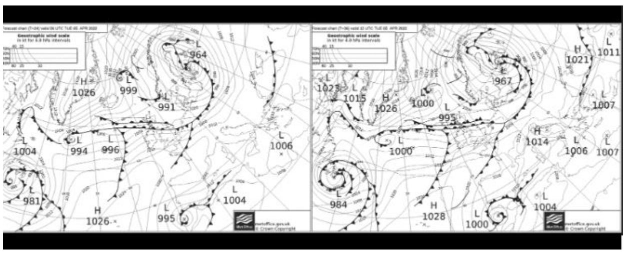

Figure 1: Weather & Aviation Page - Weather Forecast Europe UKMO mslp and thickness (skystef.be).

MSL pressure map, main sea level pressure map, is calculated by ISA (1 013,2 hPa) and atmospheric fronts. We can describe possible incoming frontal clouds and then characterize its possible impact on flight.

On the left map we can see that it was published on the April the 5th at 0600 UTC. Cyclones dominate above the Europe. Informations on the maps are analyzed. We can see atmospheric fronts – above the west Europe and Benelux we can see cold and also warm atmospheric front.

The right map is also published on the April 5th but at 1200 UTC. On this map we can see that in six hours are some changes around South Europe. Now we observe that there is mostly anticyclone around this part. For atmospheric fronts it is almost the same. Occluded fronts are visible. But in the southwest we can see the warm front.

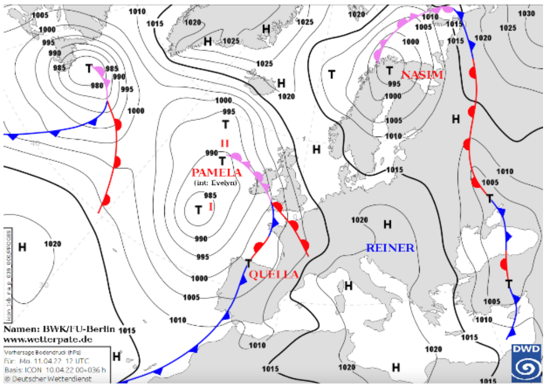

Figure 2: Weather & Aviation Page - Weather Forecast Europe DWD mslp (skystef.be).

Next used map is map of surface pressure and with atmospheric fronts. It is possible to see that the middle Europe is located in zone of anticyclone and west Europe is lightly in the zone of cyclone. In the southwest we can see cold atmospheric front, in the west we see warm atmospheric front and above the Great Britain is occluded front.

5.1.1. <u>Warm front</u>

With warm fronts are clouds like St, Fs, As, Ns, Ci and Cs formed. Conditions for flight in warm fronts depend on the flight level [5,10].

Ci – Cirrus is on the level of 10 km. It consists of ice crystals, because of the minus temperatures on his hight level. There is no icing associated with this type of cloud, but as a result of bumping and melting ice crystals on an aircraft there is possibility of icing [8].

Cs – Cirrostratus also consists of ice crystals and is formed 10 km above ground. If sky is fully covered with this clouds, then we can await tropical temperatures. Only large cargo airplanes fly through this clouds and there is not so many negative impact on flight. Just aggravated visibility [7,9].

As – Altostratus is a cloud at a height of 2 km to 5 km above the Earth's surface. They are grey and they usually cover whole sky.

Rainfall is usual with this type of clouds and with it there is also low visibility and possibility of icing [7,8].

Ns – Nimbostratus is rain style cloud. They can be made by ice crystals or water droplets or as combination of both. There are many negative impact on flight associated with Nimbostratus. One of them is icing, then rain, snow. Sometimes flight in this conditions is impossible [7,8].

St – Stratus not so different from fog. Sometimes drizzle may fall out of these clouds. There is also low visibility in this clouds [7].

5.1.2. Cold front

In this type of front are clouds like Cb, Ci, Cc, As, Ac, Sc and Cu formed.

Cc – Cirrocumulus is very rare. It looks like little sheeps on the sky and is made from ice crystals. There are no negative impacts on flight associated with clouds like Cirrocumulus [7,8].

Ac – Altocumulus is a cloud at a height 2 km to 4 km above the ground surface. Altocumulus is made from water droplets or as a mix of water and ice. Precipitation from these clouds falls, but they do not reach the Earth's surface, as they gradually evaporate during the fall [8].

Sc – Stratocumulus looks like duvet. Rainfall may fall out of Sc clouds [7].

Cu – Cumulus looks like hills or towers. They are formed during the day only. They are made from water droplets primary, but on his tips we can find ice crystals too. Rain tend to fall out of Cumulus. They are phase before the storm clouds. They can have large proportions, but they can be small too [7].

5.1.3. Occluded front

Cb – Cumulonimbus is only cloud formed with occluded fronts. Cb is storm cloud and it don't belong to any level of troposphere. He can be from 2,5 km to 15 km high. Cloud base is 2,5 km above the ground and it's going bigger with raining. Rain turns into hail. Cb are already ranked as dangerous in aviation on their own, that's why we can't fly through this type of clouds. In these clouds, vertical speeds cause very strong turbulence, which can even damage the plane. Furthermore, due to the cooling of the wind in the clouds, strong icing on the plane may occur [7,8].

5.2. Significant Weather charts

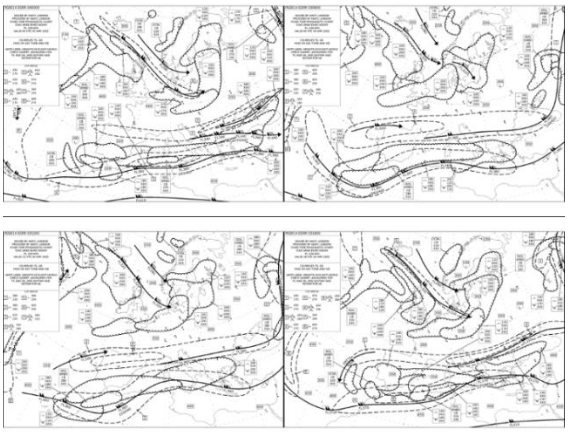

Figure 3: Weather & Aviation Page - Aviation Weather (skystef.be).

Significant weather maps are published four times a day. First map, upper left, is published at 0000 UTC. On the left are inormations about the map, used symbols for meteorological phenomenon, that we can await during the flight.

First map is published on April 5th at 0000 UTC. On this map, we can observe the occurrence of cumulonimbus storm clouds over the whole of northern Europe and also over the southern part of Europe. Next information that we can see, is information about turbulence around the clouds and JetStream is also visible.

On the second map, also from April the 5th, but at 0600 UTC are no significant changes. Clouds are still over the northern part of Europe. On the other hand, over the southern Europe clouds reduced.

On the third map from April the 5th, at 1200 UTC, we can't see any significant changes. But on the south side there is turbulence and icing only on the eastern and western parts of the clouds. On the north side are turbulences mainly on the north – east parts of the clouds.

On the last, forth map, published at 1800 UTC there is almost no cloud coverage above the southern part on the Europe. Cloud cover over the northern part of Europe is still shifting slightly towards the middle of the Europe. In these clouds we still see weak turbulence and mild icing, almost on the entire area.

According to the maps of the significant weather on April the 5th 2022, we can say that the best track for flying over Europe in terms of cloud cover is through its center. Cloud cover appears throughout the day in the south as well as in the north. Throughout the day there is no flyover through the cloud cover completely without negative impacts.

6. CONCLUSION

By observing the meteorological maps available on the Internet, we have brought to our attention the phenomena associated with cloud cover, which can significantly affect our flight. Using maps, we've zoomed in on the types of clouds that may occur above those territories. For observation, we used maps of significant weather, commonly available on the Internet. This maps give us closer informations about already given phenomena that may affect our flight at certain hours. Next, we used synoptic maps that show us pressure fields on the sea level and on the Earth's surface, and incoming atmospheric fronts associated with pressure fields. According to the incoming atmospheric fronts, we have better defined the clouds that might be above the territories and what adverse conditions they might cause for our flight.

REFERENCES

[1] SEKAL, ONDŘEJ. Škola pilotú [online]. Základy letecké meteorologie. Aktualizácia 2013-11-01. Available on the internet: < https://docplayer.cz/17354442-Zaklady-letecke-meteorologie.html>

[2] MUNZAR, Jan. Malý průvodce meteorologií. Praha: Mladá fronta, 1989. Malé encyklopedie (Mladá fronta).

[3] Meteorologický slovník výkladový terminologický: s cizojazyčnými názvy hesel ve slovenštině, angličtině, němčině, francouzštině a ruštině. Praha: Academia, 1993. ISBN 80-85368-45-5.

[4] SCHMIDT, M. Meteorológia pre každého. Bratislava: Alfa, 1980. Edícia teoretickej literatúry (Alfa).

[5] NEDELKA, M. Letecká meteorológia II. Bratislava: Alfa, 1979.

[6] Let za ztížených poveternostných podmínek. Praha: Naše vojsko,1963.

[7] KELLER, Ladislav. Učebnice pilota 2011: pro žáky a piloty všech druhů letounů a sportovních létajících zařízení, provozujících létání jako svou zájmovou činnost. Cheb: Svět křídel, 2011. ISBN 978-80-86808-90-1.

[8] Učebnice pilota 2019: pro žáky a piloty všech druhů letounů a sportovních létajících zařízení, provozujících létání jako svou zájmovou činnost. Cheb: Svět křídel, 2019. ISBN 978-80-7573-049-7

[9] ZVEREV, Aleksej Semenovič. Synoptická meteorologia: celoštátna vysokoškolská učebnica pre matem.-fyz. a prírodoved. fakulty vysokých škôl. Bratislava: Alfa, 1986. Edícia matematicko-fyzikálnej literatúry.

[10] DVOŘÁK, Petr. Letecká meteorologie: učebnice meteorologie pro piloty kvalifikace UL, GLD, PPL, CPL, ATPL a všechny ostatní, kteří potřebují odborné znalosti letecké meteorologie. Cheb: Svět křídel, 2010. ISBN 978-80-86808-85-7.

[11] NOVÁK, A. 2011. Komunikačné, navigačné a sledovacie zariadenia v letectve. Bratislava : DOLIS, 2015. - 212 s. ISBN 978-80-8181-014-5.

[12] NOVÁK, A., NOVÁK SEDLÁČKOVÁ, A., JANOVEC, M. 2020. Komunikačné systémy v letectve. 1. vyd. - V Žiline : Žilinská univerzita v Žiline, EDIS-vydavateľské centrum ŽU, 2020. 164 s.

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

[14] KAZDA, A., CAVES, R.E. 2007. Airport Design and Operation. Bingley: Emerald Group Publishing Limited, 2007. 538 s. ISBN 978-0-08-045104-6.

[15] ŠKULTÉTY, F., JAROŠOVÁ, M., ROSTÁŠ, J. 2022. Dangerous weather phenomena and their effect on en-route flight delays in Europe. Transportation Research Procedia, 2022, 59, pp. 174–182. ISSN 23521457.

[16] NOVÁK, A., HAVEL, K., JANOVEC,M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

[17] NOVÁK, A., PITOR, J. 2011. Flight inspection of instrument landing system. IEEE Forum on Integrated and Sustainable Transportation Systems, pp. 329-332.

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

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CONVERSION OF PASSENGER AIRCRAFT TO CARGO VERSIONS

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Abstract

In this presented paper on the topic of conversion of passenger aircrafts to cargo versions, the use of this transformation in the modern history of aviation is analyzed and the current situation is analyzed. For a better introduction to the issue, the introductory part defines the fundamental terms and explains the conversion itself and its various stages. The paper also discusses the companies that provide services for the actual conversion of passenger aircraft and the location where this process takes place. The paper is further supplemented by individual types of aircraft, which are divided according to global manufacturers such as the American Boeing and its European competitor Airbus. The main goal of this paper is to bring closer and clarify this process, which has gained momentum in recent years and has great potential for the future. This paper is very significant in case of COVID-19 pandemic and its huge influence on general aviation when there is enormous demand of conversion passenger aircrafts to cargo versions. The most common causes of conversion, advantages and disadvantages are also included. The conversion process itself is described in more detail and the paper focuses on the various technical phases of the aircraft conversion itself.

Keywords

Conversion of aircraft, Transport, Freighter, Company, Boeing, Airbus

1. INTRODUCTION

Since its inception, air transport has been a permanent part of everyday life, in the form of the transport of passengers and their luggage, otherwise it can provide the transport of various goods of everyday needs. Freight transport accounts for a significant share of the aviation market and accounts for a significant proportion of the flights that take place during the day at world airports.

For companies that have specialized mainly in freight transport since its inception, the option was to purchase a new cargo aircraft or convert a passenger transport aircraft that would meet all requirements and provide technical parameters as a full-fledged original cargo version. The use of aircraft for purposes other than those originally manufactured and specialized dates back to the war period, where mainly military aircraft later performed tasks in civil aviation for the transport of passengers or goods. The conversion or process of conversion of the aircraft from the original destination, in this case freight, to freight has long been associated with aviation associated with its application has found many carriers who have used this option to extend the life of their aircraft or the entire fleet.

The last period of 2 years has significantly increased the intensity of cargo flights and has benefited more from companies that have focused exclusively or largely on cargo flights. While passenger companies had no one to transport, as travel between countries was banned due to the measures, this was a significant burden for freight companies. For many passenger airlines, focusing on freight was the only way to avoid losses during the COVID-19 pandemic, and their origins included the transfer of medical supplies, respirators, drapes and gloves. Companies with their transport versions could only use the lower cargo area of aircraft, which is often called belly cargo hold. In this way, however, the flights were not financially advantageous and the maximum payload of the aircraft was in many cases less than half. For this reason, too, the first steps consisted of storing the goods directly in the unmodified cabin in the passenger seats, where everything was secured with drawstrings, or still secured with safety nets if the goods were released. This solution was not financially sustainable in the long run, so they decided to dismantle the seats, resulting in lightening while maximizing space exclusively for the goods. As a result, it was again possible to load the aircraft more to make the flight itself even more financially profitable.

However, the situation did not improve and the vision of freight transport drew even more attention to the possibility of conversion and forced companies to use this solution to modify their current aircraft, or most of their fleets.

2. METHODOLOGY AND SELECTION

The main goal is to describe and present the individual phases of the process of conversion of passenger transport aircraft to cargo versions. Specify the technical steps during the conversion. For easier introduction to the issue, the individual basics of the issue will be described and listed as basic concepts to better clarify the topic.

The main method we will use will be the analysis, as the given topic will be divided into individual parts as a whole, which we will discuss in more detail and explain in more depth.

We will primarily deal with the current state, but we will also look at the history, as long as it will be necessary and necessary in the individual parts for the smooth continuity of the whole issue.

Subsequently, the individual types of aircraft and companies that provide the possibility of conversion will be listed and we will describe them in more detail. Next, the reasons and causes of the conversion, which most often occur in individual operators, are discussed.

3. CURRENT SITUATION OF THE ISSUE HISTORY AND THE BEGINNING OF CONVERSION IN AVIATION

Air transport saw a significant increase in the post-war period, when it slowly but surely integrated into the daily lives of the citizens of almost every country in the world. During these times, the number of built aircraft, which no longer had a way to be used in their original purpose, also increased significantly. If they were not to be decommissioned, they had to find an alternative role that would extend their life, especially from an economic point of view [5].

As it was no longer necessary to carry soldiers, weapons, bombs, ammunition and other military equipment, the civil aviation offered options such as transporting passengers or goods. As air tickets were an extremely expensive item for the average citizen, the vision after the transport of goods was more attractive. It should also be noted that the conversion of former military aircraft to freight was a relatively easier route, as providing sufficient equipment and comfort for passengers was a much more extensive modification, which of course took longer and cost more [5].

Over time, aircraft manufacturers began to produce new aircraft, in this case primarily aimed at transporting passengers and cargo. Meanwhile, freight traffic began to grow and gain strength, with a sufficient number of aircraft and demand coverage itself to be ensured thanks to a combination of newly manufactured and converted aircraft [5].

Among the first aircraft to be converted for freight were piston models such as the DC-3 / C-47 or DC-4 / C-54, which were produced in large numbers and were the most proven aircraft at the time. pilots. From the piston to the turboprop, where we can mention representatives such as Convair 580, Vickers Viscount, Lockheed L-188 Electra or Fokker F27 Friendship [5].

The current era in the late 1960s brought aircraft such as the Boeing 707 or Douglas DC-8. These were four-engine narrow-body aircraft, also known in the Air Force as narrow-body, with one aisle for passengers. As there were not enough jets at the beginning, the manufacturers did not manage to produce a sufficient number of aircraft to cover the transport of passengers and cargo. Therefore, some were converted to costly versions to complement the costly fleets of the companies. Other aircraft from The Boeing Company that went through the process of conversion to expensive versions were the Boeing 727 and 737. The legendary Boeing 747 also joined these representatives and was later supplemented by models 757, 767 and 777. Douglas designed another model. DC-10 and later after the merger with McDonnell in 1967 it was a larger version of the MD-11. These two models currently fly mainly as expensive versions, and very often they are rebuilt aircraft. As for the European jet models that started the conversion process, it was mainly the Airbus A300 and its smaller model A310 [5].

Newer types such as the Boeing 757 and 767 and the Airbus A330 were added to these models in the 1980s. Models 757 and 767 were later added by Boeing. Today's conversion providers offer services primarily for these aircraft, with models such as Boeing 777, Airbus A320 and A321 or Boeing 737 from the NG series gradually being added [5].

3.1. CONVERSION AND ITS INDIVIDUAL STAGES

A conversion is a physical transformation that changes an aircraft from the original to the new destination. In this case, it is a conversion from a passenger transport aircraft to a cargo version, also known in the aviation as a freighter, which will be able to compete with the original cargo versions on the aviation market. It will find its application with potential aircraft operators mainly due to financial advantages, more current availability of several types of aircraft, but also a shorter process of inclusion in their fleet [5].

The interior will be stripped of parts and unnecessary equipment will be installed, such as interior fittings and equipment in the form of seats, kitchens, passenger toilets, storage and storage areas, side and ceiling hand luggage consoles, oxygen equipment and a passenger entertainment system that includes touch screens or other control devices. During this phase, the intention will be to keep the interior of the aircraft as clean as possible to provide space for subsequent modifications and to maximize space for cargo containers (ULDs) [5].

Exterior parts of the fuselage such as windows will be completely covered with the help of special aluminum panels and light window bolts. There will be more interventions in the structure, while the most visible and characteristic part of this process is the installation of cargo doors (MDCD), which will be located on the left side of the fuselage, which will be sufficiently reinforced and reinforced. The door will be opened by a hydraulic or electric mechanism. The main deck will also be strong enough to withstand the new forces and pressures created by air containers, pallets and other goods. A new ceiling lighting, drainage system and cladding inserts will come into the cargo interior along with the new main deck to protect the cargo interior walls from damage. As containers, pallets and other goods will need to be moved across the main deck, a loading system (CLS) is required to allow easy movement without significant friction or damage to the deck or container surface. Older conversions have a non-powered floor, while newer converted aircraft will have electric rollers and ball bearings installed to move the container without the need for physical pushing by airport personnel [5].

A particular aircraft may go through the conversion process at several companies, which have their own designation for their programs, and the aircraft itself may then be designated as P2F, BCF, BDSF or PCF. Originally manufactured cargo versions of aircraft are marked with the letter F, while conversions have SF. This is actually the designation of the process itself, which has been described above. The P2F conversion may traditionally be performed by the original equipment manufacturer (OEM) or it may be a contracted third party or an independent company that is able to enter into a cooperation agreement with the original equipment manufacturer. The latter case of a provider of such conversion services is a third party who has the means for its own conversion solutions. Typical representatives of OEM manufacturers are already mentioned Boeing or Airbus. Third-party companies are, for example, EFW, which together with ST Aero provides conversion services for Airbus. Aeronavali or the

Israeli company IAI is cooperating with the American giant Boeing [6].

3.2. REASONS AND CAUSES OF CONVERSION

For companies and operators, this is a way to extend the life of an aircraft by 20 years, and for some aircraft it can double their current age in active operation. This process is primarily provided to older aircraft, which, as transport versions, would no longer meet sufficient comfort for passengers but still technically meet the criteria for operation in the countries concerned. For older transport aircraft, this is an ideal way to avoid their permanent grounding at airports or larger areas such as the Mojave Desert, or subsequent scrapping [6].

Financial reasons will be among the most crucial ones, which are often very burdensome for operators. When buying a new and original version of a cargo aircraft from Boeing or Airbus, the future owner will pay an average of four times the price of the conversion. The conversion prices for the smaller aircraft range from $ 10 million to $ 12 million. The price for a medium-sized category of narrow-body aircraft is between 15 and 20 million dollars, and for wide-body aircraft it can reach up to 20 or 30 million dollars. The largest categories range in price from $ 55 million to $ 65 million. By comparison, the price of a new medium-sized wide-body cargo plane is $ 70 million, and for even larger types, we get up to a whopping $ 150 million. These prices are a frequent reason that companies prefer to invest 25% to 30% of the price of a newly manufactured aircraft. [5].

Maximizing the cargo space and / or increasing the dimensions at the loading and unloading points are other reasons that will convince companies to choose this option. The conversion adjustment will also significantly increase the maximum weight of the goods and the maximum payload, which is also called payload in aviation. [5].

For these reasons, it is possible to point out the advantage of the conversion and the associated new functions and capabilities of the aircraft are associated with it. However, it should be emphasized that compared to a completely new aircraft, the price is significantly lower, but still not negligible. This step is a technically demanding solution and will pay off for companies over a longer period of time [5].

3.3. ADVISABILITY AND CHOICE OF AIRCRAFT TYPE

At present, companies can choose from several types of aircraft that can then be converted to expensive versions, and they can also choose a company or provider to provide the conversion process itself. With the right choice of aircraft, technical parameters such as fuselage cross section, payload, range, maximum speed, weight or sufficient center of gravity are often influencing for companies. On the other hand, low investment costs, compatibility with the infrastructure of the airports where they primarily operate, or compatibility with other types of aircraft can be decisive for the potential customer and the future operator. If a given type of aircraft also has an expensive version, then this may also be one of the more significant reasons that leads to the selection of a suitable model [5].

The age of the aircraft is also a very important factor and the ideal aircraft for conversion usually reaches a minimum age of 10 to 20 years. This is also associated with information on the number of hours flown and the service life of individual parts of the airframe, but especially the power unit. For this data, it is necessary to know and have records of the overall history of the aircraft during its operation [5].

The number of pieces produced and the overall expansion of a given model can also weigh on the choice of a given operator, as this can have a significant impact on the number of spare parts and their availability. If the aircraft in a particular fleet is more widespread with the operator, then for this reason it may be more successful in the selection [5].

3.4. COVID-19 PANDEMIA AND THE IMPACT ON AIR TRANSPORT

Over the last 2 years, the Air Force has received a severe blow in the form of a significant decline, especially during transport flights. With more thought, one could also find the benefits of this sharp drop in flights, in the form of reducing emissions, saving on operating costs or significantly reducing the workload of air transport workers. However, the operators did not find it positive even in the slightest point of view. It should be noted that the problem is still felt today and it will take years for it to return to its original state, which would correspond at least to the figures from 2018, or the period from 2019 [10].

As the need to transport goods continued to grow due to online orders, it was the only way for airlines to start filling their aircraft with these goods. The paradox is that with the decrease in passenger flights with passengers, the capacity to carry goods also began to fall, as in passenger versions of aircraft they could carry cargo in the cargo space itself, which was also designed for this together with passengers' luggage [10].

Prior to the COVID-19 pandemic, up to 45% of the world's air cargo was carried in the hold along with passenger baggage during civil flights. Simply put, with the decline in passenger traffic, cargo also suffered significantly, as approximately 50% of the required aircraft cargo space was lost [11].

4. CONVERSION PROCESS PROVIDERS THE BOEING COMPANY

Boeing is one of the world's two largest and leading aerospace manufacturers in the world. The multinational American company, which is interested in designing, manufacturing and selling, has annual revenues of approximately $ 85 billion. It is a global manufacturer striving for countless innovations in various technical fields. The company is currently headquartered in Chicago, Illinois. The company achieves significant commercial success with a large number of aircraft types, and also provides business services [4, 15].

With 40 years of experience in this field, Boeing currently offers Freighter models, expensive versions of the 747-800, 767-300, 777 transport aircraft, as well as the latest version 777-8. The conversion models are 767-300 and 737-800. These models are part of the Boeing Converted Freighter program, and therefore bear the BCF design [6].

Among the representatives of the Next Generation (NG) series, which has achieved considerable success with airlines, is the Boeing 737-800. At present, it forms a significant part of the fleet in companies such as Ryanair, Southwest Airlines, but also in leading ones such as United and American Airlines. It should be replaced by the latest fourth-generation MAX series over the coming years. This model is an ideal platform for the cargo version on short and medium routes, with a range of 3,750 km alone. The design payload is 23,950 kg and the total volume of the main deck reaches 141.5 m2. ULD Type 88´´x 125´´x 79´´ with a weight of 127 kg can be placed on the main deck in the number of 11 pieces and another ULD Type 60.4´´x 61.5´´ with a weight of 91.7 kg. The load volume of the lower part is 43.7 m³. At the ends of the wings there is a characteristic end in the form of winglets, which will ensure partial fuel savings. In terms of equipment, a fully digital cockpit with the Honeywell CDS system is installed for the two-member crew, which integrates up to 6 large liquid crystal LCD displays. There is also the option of being equipped with a state-of-the-art head-up (HUD) display, global navigation landing system (GNSS) or dual system for more efficient flight control [3, 18].

Figure 1: A view of the main deck of a Boeing 737-800BCF. [Aviation Week: ASL Aviation Orders Boeing 737-800BCF, 2019 https://aviationweek.com/mro/asl-aviation-orders-boeing-737-800bcfs]

Another converted model is the Boeing 767, which can also be considered a long-established transport aircraft. This medium-sized wide-body aircraft is mainly made up of version 300, which is again in this case converted from Boeing to a suitable expensive version for increased demand for goods, as well as a replacement for older types such as DC -10, Airbus A300 and A310, or its shorter version 767-200. It is a versatile and reliable type that is 18% per tonne of cargo more economical than the already mentioned Airbus A300 and produces lower noise emissions. Emphasis is placed on the quality of the process, which guarantees excellent flight characteristics and fuel savings. This is due to the fact that Boeing is the only one on the market to offer additional installation of winglets, which will ensure fuel savings of 3% to 5% on medium-haul routes. In recent years, we can see this model in the fleets of companies such as Air Transport Services Group (ATSG), Amazon Prime Air, UPS, FedEx and DHL, which are showing even greater interest. It should be noted that the first Boeing 767-300BCF was delivered to All Nippon Airways in 2008 [3, 20].

The cargo volume of the main deck is 336.5 m³, while it is possible to place 22 pieces of ULD Type 88´´x 125´´x 96´´ with a weight of 127 kg and 2 pieces of ULD Type 88´´x 125´´x 79´´ . The volume of the lower part is then 108.7 m³ and 4 ULD Type 88´´x 125´´x 96´´ containers weighing 131 kg and 14 ULD Type LD-2 Containers weighing 91 kg can be stored here. . With a range of 6,195 km and a maximum design payload of 52,980 kg, this aircraft is capable of transporting sufficient goods on medium or longer routes [21].

4.1. ISRAEL AEROSPACE INDUSTRIES

It is the largest manufacturer of military and civil aircraft in Israel. . The company was founded in 1953 and in 1959 they focused on their own design and aviation systems. From airspace, through land to the navy, the company is able to provide modern drones, weapons systems, radars, special mission aircraft, navigation and communication systems. [23].

IAI and Bedek Aviation provide IAI under one roof, while 3 divisions of Bedek Aviation Group have services focused on the maintenance of aircraft, power units and other components, respectively. parts. This provider, with more than 40 years of experience in the field of passenger aircraft conversion, is one of the world's best. With a total of up to 250 aircraft delivered, he has gained considerable knowledge of conversion procedures, and now offers this process for the Boeing 737-300 / 400 Classic Series and the 700 and 800 Next Generation Series. Especially in the past, it also provided a conversion for the Boeing 747, specifically its older versions 100 and 200, while nowadays it is only a newer version 400. The last representatives from Boeing are models 757-200 and 767-200 / 300. A great rarity is the offer for the MD-11, which already belongs to the very rare aircraft. They also plan with the Boeing 777-300 and Airbus A330-300 in the future [24].

The Boeing 747 is a long-range, four-engine long-haul aircraft. The first flight took place in 1969, where it was a version 100. Although the 747 model is a large-capacity aircraft, a total of 1569 pieces were produced. Such an adjustment is currently one of the last solutions to keep this type in its fleet, as four-engine aircraft are gradually disappearing from traffic. During the conversion, parts of the main deck such as the girders will be reinforced and additional inserts, new lighting and a loading system will be installed. Door no. 1 and no. 5 will remain fully functional and the rest of the door will be deactivated. There will also be one toilet, a kitchen, a rest area for staff and the part between the front of the cargo area and the cockpit will be separated by a partition. The design payload is 114,759 kg and the load of the main deck is 590 m³, while it is possible to place 23 pieces of ULD Type 96´´x 125´´x 118´´ with a weight of 370 kg and 7 pieces of ULD Type 96´´x 125 ´´x 96´´ with a weight of 350 kg. The load volume of the lower part is 152 m³ and up to 9 pieces of ULD Type 96´´x 125´´x 64´´ with a weight of 120 kg and 2 pieces of ULD Type 60´´x 92´´x 64´´ can be stored in this space. also weighing 120 kg. For companies, this aircraft is able to carry a considerable load up to a distance of 8250 km. Compared to the originally produced expensive version of the Boeing 747-400F, there is a difference that the BDSF version does not have a front nose opening door. With the help of these doors it is possible to load the goods along the entire length of the hull 56.4 meters. In the case of conversion, it will be a traditional location on the left side of the fuselage, as it is a technically and financially demanding procedure [2, 25].

4.2. ELBE FLUGZEUGWERKE EFW

EFW is currently a joint venture between the multinational airline Airbus, which accounts for 45%, and Singapore's ST Aerospace, with the remaining 55%. The company was founded in 1955 and today its headquarters are located at Dresden International Airport [27].

During the conversion of aircraft, the company focuses mainly on Airbus A320 / A321, A300 / A310 and A330 aircraft, which are subject to the P2F conversion process. The conversion is handled by experienced teams, which handle each aircraft independently and then provide logistics support for the customer [29].

5. DETAILED DESCRIPTION OF THE A330 P2F AIRCRAFT CONVERSION

At the beginning of the conversion, the Airbus A330-300 is taken over by technicians who perform preliminary operations in front of the hangar. Subsequently, the protrusions on the fuselage such as sensors, pitot tube, antennas, or other external parts are covered. Subsequently, hydraulic fluid and fuel samples will be taken as they need to be sent for quality testing. This process will take about one hour [31].

In the next part, the aircraft is stripped of its interior in the form of 400 seats, toilets and a kitchen. Then comes the group for removing the trim, ventilation grilles, side and ceiling panels in the cabin. Hand luggage storage is also selected and the last part is the carpets on the floor. All parts of the interior are dismantled to provide access for technicians during the conversion, maximizing future cargo space, and the equipment is either scrapped or sent back to the aircraft owner. It will take about 20 days for the workers to this point [31].

As far as power units are concerned, there is a possibility that a case of sale will occur. The original owner may decide to keep the engines, in which case the side trim and intake manifold inlet ring will be removed. The side covers are folded down. The technicians get to the auxiliary gearbox or drive housing and disconnect the engine and aircraft units. The motor remains suspended on 8 screws, which can only be unscrewed after attaching the orange support arms, which will help lift the mobile cradle to the motor. At the end of the process, these mobile cradles, which serve as a towing truck, will be taken to a hangar for storage and subsequent transport. [31].

The most noticeable change is the modification of the fuselage at the place where the cargo door (MDCD) is installed. The hull is stripped of the basic white color and only the green anti-corrosion spray will be visible. Subsequently, they will plan to install the door in place of the newly cut hole. In order to proceed safely during the individual stages, it is necessary to strengthen the torso in these places, proceeding in two stages to avoid possible deformation of the upper part of the fuselage [31].

As the windows for passengers will no longer be necessary, their subsequent covering with the help of milled aluminum plates will ensure a sufficient seal, while the fuselage will be partially strengthened. The more holes there are in the hull, the more it takes away from the overall fortress, which must be avoided. Once the aluminum sealing plate is in place, the technician attaches a black plastic frame from the inside [31].

Isolation is an important part, as outdoor temperatures are often below -50 degrees Celsius, so sufficient insulation is required. Cold and warmer air inside the aircraft will be prevented from colliding, which would result in excessive condensation and increased humidity. Insulating mats are ideal for balancing temperatures [31].

To sufficiently strengthen the main deck, a massive aluminum base frame is used, which must withstand loads of up to 62 tons of cargo. Subsequently, the loading system (CLS) will be installed. It also separates the main deck or upper cargo area from the lower one. This is the most significant modification in terms of the amount of material and the extent of the modifications. Floor, inter-rib beams and floor panels will be replaced or reinforced. The Airbus A330-300 gets the installation of a powered loading system that meets the highest criteria in this area and allows you to unload the entire space in 30 minutes. Container weighing sensors will also be built into the floor, with colored markings and numbering inside the cargo area to ensure that each container is precisely positioned for the best balance of the aircraft itself before departure. The container will be fixed to the floor with a locking system [30, 31].

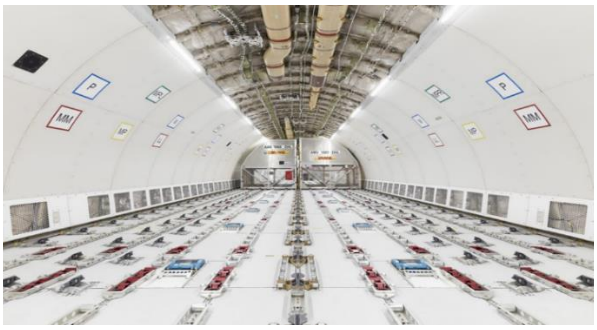

Figure 2: A view of the CLS system of the Airbus A330. [Asfaar by Airbus: First A330-300P2F enters service with DHL, 2017 https://asfaarbyairbus.com/asfaar/december-2017/first-a330-300p2f-enters-service-dhl/

In the event of a fire in any material, or the entire container or pallet, there will be a smoke screen in the front, which will protect the crew from the subsequent smoke directed to the front of the cargo area and especially the cockpit of the pilots. The front part of the cargo space is equipped with a safety net or a rigid barrier to prevent the possible release of containers, pallets and other goods, which will retain any released container and absorb the impact of up to 9G. Between the cockpit and the safety net there is a section for crew members or personnel who will be on the given flight. In case of release, a part of the crew could sit or stand against this part, so the protection is primarily for them and consequently also against damage to the aircraft itself [30, 31].

The last final phase will present the finished aircraft after a 4-month conversion, while only minor modifications in the form of cabling and insulation of the smallest cables are being completed. The Airbus A330 will then be weighed, using a total of 10 scales under each wheel. The price of the conversion will reach $ 18 million, but for comparison the price of the new Airbus A330 is about $ 230 million. These are the last steps before handing them over to the original or future customer [31].

Figure 3: Airbus A330-300 after conversion. [Mark Dwyer: First Passenger-to-Freighter A330 delivered to ASL Airlines, 2017 https://flyinginireland.com/2017/12/first-passenger-to-freighter-a330-delivered-to-asl-airlines/]

6. CONCLUSION

In this article, we approached and evaluated the conversion of passenger airliners to expensive versions. The amount of information on the topic was quite extensive, and the same is true of the sources themselves.

The conversion found its application in the earlier history of the Air Force, when the post-war period condemned military aircraft to the civilian field. The companies provided services for passengers and, of course, for various goods. The time has progressed further from piston aircraft, through turboprops, to modern jet aircraft, where even more attention has begun to be paid to the conversion process.

The reasons and causes have not changed significantly since the beginning of the current era until today. It was and still is possible for the airline to convert the aircraft more financially advantageous, without finding any differences in equipment and overall quality of workmanship compared to the original expensive version. It should be emphasized that the significantly lower price is mainly due to the age of the aircraft and its total time spent in active operation, which is in the range of 10 to 20 years. Another reason is to extend the life of the aircraft, especially from an economic and financial point of view.

It is even planned to convert even younger aircraft under the age of 10 in the near future. In the chapter on providers, we listed the main and most prominent representatives in today's market, and we also listed their own models, for which they currently provide a conversion program. The last chapter of the main text part belonged to a detailed description of the conversion, where we described the individual steps on the Airbus A330 aircraft.

Converting passenger airliners to cargo versions is a technically demanding process required by a company with an experienced team of mechanics. At present and in the near future, it will certainly not lose its application in aviation, on the contrary, it will strengthen it even more.

REFERENCES

[1] SEDLÁČEK, B. 2000 Letecká doprava . Žilina : Žilinská Univerzita . 1. vyd. 188 s. - ISBN 80-7100-674-2.

[2] RŮŽIČKA – OLDŘICH, 1958 Letecká doprava Díl 1 . Praha : SNTL . 230 s. - (ASK)

[3] BEŇO – LUDĚK, 1988 Lietadlá . Bratislava : ALFA . 248 s. – (AMG)

[4] TREBICHAVSKÝ – FERDINAND, 1981 Letecká doprava včera,dnes a zajtra . Bratislava : ALFA . 271 s. - (AMG)

[5] [5] Air Cargopedia: Passanger to freighter conversions. Dostupné na internete: http://www.aircargopedia.com/passengertofreightpg.htm (citované 2022-03-02)

[6] Aerocontact: Boeing´s converted Freighters. Dostupné na internete:https://www.aerocontact.com/en/videos/17253-boeing-s-converted-freighters-20-more-years-of-life (citované 2022-03-02)

[7] Freightwaves: Emirates invests in converted and new 777 freighters.Dostupné na internete:https://www.freightwaves.com/news/emirates-invests-in-converted-and-new-777-freighters(citované 2022-03-02)

[8] Simple Flying: Why Do Cargo Operators Fly Older Planes. Dostupné na internete:https://simpleflying.com/cargo-operators-older-planes/ (citované 2022-03-02)

[9] Runawaygirl Network: The Future of the conversion market. Dostupné na internete:https://runwaygirlnetwork.com/2021/10/28/the-future-of-the-passenger-to-freighter-conversion-market/ (citované 2022-03-12)

[10] IATA: Immediate and Severe Air Cargo Capacity Crunch. Dostupné na internete: https://www.iata.org/en/pressroom/pr/2020-04-28-01/citované 2022-03-12)

[11] Fortune: Air New Zeland´s new nonstop flight. Dostupné na internete:https://fortune.com/2022/03/22/air-new-zealand-nonstop-flights-new-york-jfk-auckland/ (citované 2022-03-12)

[12] The Air Current: As coronavirus empties the sky of passanger planes. Dostupné na internete:https://theaircurrent.com/airlines/as-coronavirus-empties-the-sky-of-passenger-planes-air-cargo-marches-on/ (citované 2022-03-12)

[13] South China Morning Post: Coronavirus: China´s mask. Dostupné na internete: https://www.scmp.com/economy/global-economy/article/3074821/coronavirus-chinas-mask-making-juggernaut-cranks-gear (citované 2022-03-20)

[14] ReedSmith: The use of passenger aircraft to cargo during the COVID-19 pandemic.Dostupné na internete: https://www.reedsmith.com/en/perspectives/global-air-freight/2022/01/carrying-the-load-use-of-passenger-aircraft-to-haul-cargo-during-covid19 (citované 2022-03-20)

[15] Boeing. Dostupné na internete: https://www.boeing.com/ (citované 2022-03-20)

[16] Boeing: Boeing Chronology. Dostupné na internete: https://www.boeing.com/resources/boeingdotcom/history/pdf/Boeing-Chronology.pdf (citované 2022-03-29)

[17] Airplane Update: Boeing 737-800BCF Specs Payload, Cockpit, and Price, Dostupné na internete: https://www.airplaneupdate.com/2019/11/boeing-737-800bcf.html (citované 2022-03-29)

[18] The Boeing Company: Boeing 767-300BCF brochure. Dostupné na internete: https://www.boeing.com/resources/boeingdotcom/commercial/services/assets/brochure/767300-bcf.pdf (citované 2022-03-29)

[19] Simple Flying: Boeing To Open Another 767 Freighter Conversion Line. Dostupné na internete: https://simpleflying.com/boeing-767-conversion-china/ (citované 2022-04-06)

[20] IAI: Company Profile. Dostupné na internete: https://www.iai.co.il/about/company-profile (citované 2022-04-06)

[21] IAI: History. Dostupné na internete: https://www.iai.co.il/about/history (citované 2022-04-06)

[22] IAI: Passenger to Cargo Conversions. Dostupné na internete: https://www.iai.co.il/commercial/aviation/passenger-cargo-conversions (citované 2022-04-06)

[23] Wikipedia: Boeing 747. Dostupné na internete: https://en.wikipedia.org/wiki/Boeing_747 (citované 2022-04-10)

[24] IAI: Boeing 747-400BDSF. Dostupné na internete: https://www.iai.co.il/p/b747-400bdsf (citované 2022-04-10)

[25] Wikipedia: Elbe Flugzeugwerke. Dostupné na internete: https://en.wikipedia.org/wiki/Elbe_Flugzeugwerke (citované 2022-04-10)

[26] EFW: Our History. Dostupné na internete: https://www.elbeflugzeugwerke.com/en/our-company/our-history/ (citované 2022-04-10)

[27] EFW: Freighter Conversion. Dostupné na internete: https://www.elbeflugzeugwerke.com/en/freighter-conversion/ (citované 2022-04-13)

[28] Ilan Berlowitz: Passanger Airplane Conversion To Freighter. Dostupné na interenete: https://www.icas.org/ICAS_ARCHIVE/ICAS2014/data/papers/2014_0001_paper.pdf (citované 2022-04-13)

[29] WELT Documentary: A cargo plane is born. Dostupné na internete: https://hydraulicdirectionalvalve.com/en/aircraft-conversion-xxl-a-cargo-plane-is-born-full-documentary.htm (citované 2022-04-13)

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

[31] BUGAJ, M. 2011. Systémy údržby lietadiel. vyd. - V Žiline : Žilinská univerzita, 2011. - 142 s., ilustr. - ISBN 978-80-554-0301-4.

[32] 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.

[33] 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.

[34] NOVÁK, A., HAVEL, K., JANOVEC,M. 2017.Measuring and testing the instrument landing system at the airport Zilina, Transportation Research Procedia 28, pp. 117-126.

[35] HRÚZ, M., PECHO, P., MARIÁŠOVÁ, T., BUGAJ, M. 2020. Innovative changes in maintenance strategies of ATO's aircraft. Transportation Research Procedia, 2020, 51, pp. 261–270. ISSN 23521457.

[36] 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.

[37] JANOVEC, M., ČERŇAN, ŠKULTÉTY. 2020. Use of non-destructive eddy current technique to detect simulated corrosion of aircraft structures. Koroze a Ochrana Materialu, 2020, 64(2), pp. 52–58. ISSN 0452599X.