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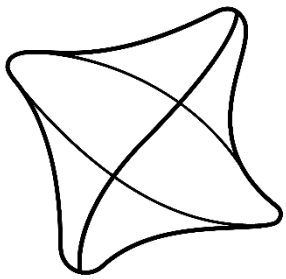
KATEDRA LETECKEJ DOPRAVY

AIR TRANSPORT DEPARTMENT

FAKULTA PREVÁDZKY A EKONOMIKY DOPRAVY A SPOJOV

FACULTY OF OPERATION AND ECONOMICS OF TRANSPORT AND COMMUNICATIONS



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prof. Ing. **Andrej Novák**, PhD.
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IGNITION SYSTEM AND THEIR PURPOSE IN AIRCRAFT RECIPROCATING ENGINES

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Abstract

This research describes the function and principles of ignition systems in aircraft reciprocating engines. Physical-chemical processes, which are part of combustion, and the factors affecting them are defined in detail. Types of ignition systems are divided based on main parts and frequency of appearance in aircraft engines. Components of ignition and their function in electric and magnetic circuits are individually described. The future development in ignition systems is defined. The research includes an analysis of the pros and cons of laser ignition in its application in aviation. It presents Low-Temperature Combustion or Volumetric Ignition using Low-Temperature Plasma. An example may be the Microwave-assisted Plasma Ignition System. Engine speed and vacuum in intake are the main parameters influencing the ignition timing curve in Electronic Control Unit Master developed by IMF Soft. This ECU is used in the designed ignition system of testing engine. The designed timing curves were tested, and the results of engine power and torque were compared. In conclusion, the optimal timing curve is evaluated for this reciprocating engine.

Keywords

Ignition system. Ignition. Spark Plug. Aircraft reciprocating engine. Laser. Low Temperature Combustion

1. INTRODUCTION

The purpose of the ignition system is to ignite the mixture of fuel and air in the cylinder. An electric spark is used for ignition, which is created between two electrodes of an electric spark plug as a result of a high-voltage discharge. We can obtain electrical energy from several sources. The main ones are accumulators and magnetos. Electric current flows from the battery to the primary winding of the coil, thereby inducing a magnetic flux in the core of the coil. If the flux is interrupted, a high voltage is induced in the secondary winding. That is proportional to the rate of change of the magnetic flux and the number of turns. [1]

1.1. Breakdown voltage

By ionizing the gas between the electrodes of the spark plug, a conductive path is created for the transfer of electrical energy, which passes from one electrode to another in the form of a discharge. A voltage that is higher than the electrical resistance of the gas is named a breakdown voltage.

If the spark jumps but does not have enough energy, the mixture will not ignite. Therefore, instead of the energy of 0.1 MJ, which is enough to initiate the spark, the energy of 50 to 120 MJ is required. Because of the highly ionized gas, it is also necessary to increase the voltage on the electrodes; it varies between 10 and 30 kV. [1]

Conditions for proper ionization may vary. If they are positive, the breakdown voltage value is lower and if negative, the breakdown voltage will be higher. Factors affecting the breakdown voltage include pressure inside the working space, the distance between electrodes, temperature, the composition of the mixture, and humidity or material of the electrodes. [2] [3] [4]

1.2. Combustion process

Combustion is a physicochemical redox exothermic oxidation reaction in which a combustible substance reacts quickly with an oxidizing agent to produce heat and light. For a combustion reaction to occur, three conditions must be met: the presence of a combustible substance (fuel), the presence of an oxidizing agent (oxygen), and the source of initiation, which in this case is represented by an electric spark. [5]

Combustion processes are associated with the transfer of substances through heat sharing under high-temperature gradients, while the transfer phenomena tend to be accelerated by turbulence, which overlaps the molecular transfer, which is abided by the kinetic theory of gases. [6]

The burning of the fuel mixture inside the working cylinder of the engine can be characterized as a flame of a spherical surface spreading from the point of ignition, the gradual speed of which increases with pressure and temperature and swirling of the cylinder. It also depends on the composition of the mixture and the ratio of combustible components to inert gases. [7] It can be divided into several stages, which, however, may overlap or take place in parallel in different parts of the combustion chamber. [6] For simplicity, the combustion process is split into two phases, where the first part of the combustion is referred to as the inductive phase and the second part as the visible combustion phase. [1] [2]

2. LASER IGNITION

Using a laser instead of a spark plug brings many significant advantages. One of the most important is the possibility of igniting the mixture anywhere in the cylinder, by focusing the lens, i.e. aiming the ray. This results in lower energy losses, which, among other things, are derived from the cooling of the mixture from the walls of the cylinder. By using multiple sources

of separate laser beams (especially two- to three-beam units), create multiple ignition points (shown in Fig. 1). Thanks to this, the burning process is more uniform and the flame is more homogeneous. The reduction of losses and increase in efficiency will be achieved. [8] [9]

igniting the mixture with a spark plug takes a few milliseconds. By using a laser, it is possible to speed up this process, and therefore the time interval for ignition of the mixture is in the order of nanoseconds, and the timing can be made even more precise. The ability to ignite a leaner mixture at a lower temperature and higher compression ratio makes laser ignition a much more efficient system than the older one. It contributes to lower fuel consumption and decreases CO2 and NOX emissions. [8] [9]

There are four types of laser ignition: non-resonant ignition, resonant ignition, thermal ignition, and photochemical ignition. The most promising type, which is also the most similar to conventional ignition with a spark plug, is non-resonant laser ignition.

Currently, the use of laser in the ignition is only at the theoretical and experimental levels. That is mainly due to the size of the entire mechanism and the very high energy emitted. The energy density in the ignition focus reaches 100 GW.cm-2 and the pulse energy is 10 to 100 mJ during 10 ns. Laser ignition should bring advantages mainly to multi-cylinder piston engines using a multiplex system (multipoint ignition), which sends pulses from a single laser to each cylinder through optical fibers. The problem is the rapid wear of optical fibers. The solution could be to split the laser module into multiple micro-laser units (the size of a spark plug) and then install them into the engine cylinders. These units would be connected to the energy source using the mentioned optical fibers, but with lower light intensity. [8]

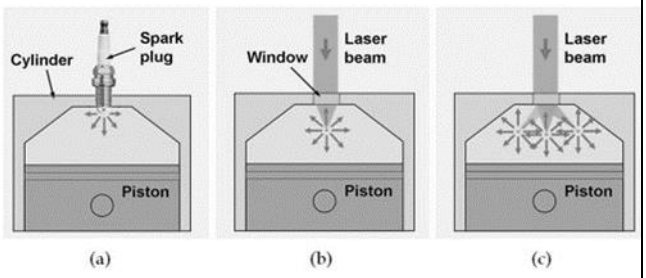

Figure 1 - Types of ignition. (a) spark plug ignition, (b) laser igition, (c) multipoint laser ignition

3. LOW-TEMPERATURE PLASMA COMBUSTION

In the use of low-temperature plasma, in contrast to the use of high-temperature plasma, heat loss and heat load of the ignition system are not a problem, because the highly excited particles are only electrons, not ions and neutrons. Chemical reactions can be enhanced by more efficient energy transfer between electrons and reactants. Today, the price of such a system is incomparable to classic ignition systems (TCI – transistorized coil ignition). However, at the same time, it shows a high potential for increasing combustion efficiency. Compared to laser ignition, it offers lower costs and higher efficiency, and there is no need to run optical cables to the engine. [10] [11]

Many kinds of research deal with low-temperature combustion (LTC) ignition systems such as "streamer discharge", "surface ignition", "nanosecond pulsed dielectric barrier discharge" and "high-frequency resonance plasma ignition". As it turned out, the use of low-temperature plasma in a real engine is inconvenient mainly because of maintaining a stable low-temperature plasma under high pressure. [10]

3.1. MAPIS

Due to the shortcomings, it is better to use a hybrid of low-temperature plasma and convection ignition. One of the projects is a Microwave-assisted Plasma Ignition System. [10]

Ignition is initiated by conventional ignition, which is subsequently extended by the emission of microwave radiation into the discharge area. The application of the MAPIS system successfully achieved a reduction in the amount of fuel in the mixture (leaner mixture), fuel consumption, and emission characteristics compared to convection ignition systems. [10]

Low-temperature plasma is known to have a higher electron temperature and is more active due to the rapid production of radicals (electron groups) and excited species by electron collision dissociation, excitation, and subsequent energy "relaxation". For the MAPIS system, the electron temperature increase and the electric field decrease are lower than in other low-temperature plasma systems. These are radio frequency systems or systems using nanosecond pulses. Compared to these systems, it has a more stable discharge that ensures convection ignition under all conditions. [10]

MAPIS is formed of four main parts: power source, transmission system, power monitoring system, and igniter. The energy source is a magnetron and an ignition coil. A magnetron is a generator of microwave electromagnetic radiation. In this particular case, a radiation frequency of 2.45 GHz needs to be achieved. [10]

In Fig. 2 the four phases of MAPIS ignition are shown. First, it is necessary to create an intense microwave field (I). Since the energy contained in microwave radiation is less than the minimum ignition energy, the spark plug is used first; it will form a small source of plasma (II). This plasma source absorbs microwave radiation and expands; radicals are formed, and microwaves improve combustion (III). During IV. phase final flame propagation in the engine cylinder occurs. [11]

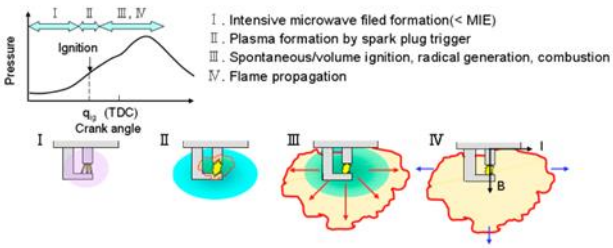

Figure 2 - Phases of MAPIS ignition

4. LOW-TEMPERATURE COMBUSTION

The trend in ignition systems and general in the process of ignition and combustion of the mixture is to reduce the temperature. Such systems are called Low-temperature Combustion (LTC). The temperature is reduced by greater use of exhaust gas recirculation (EGR) and with an excess of air greater

than 1 (□ > 1). Under stoichiometric mixture conditions, the fuel oxidizes with air at a higher temperature, which results in more NOX and soot emissions. To overcome evaporation and ensure proper atomization of the mixture a higher injection pressure of the mixture is used. To achieve proper atomization of the mixture, it is necessary to extend the ignition delay; different methods are used – reducing the compression ratio, higher use of exhaust gas recirculation, or variable valve timing. Usage of these methods in real conditions, while maintaining or even increasing the thermal efficiency of an engine, is a difficult task. Using Low-temperature Combustion is possible to achieve a decrease in NOX and other emissions by more than 80%. [12]

Low-temperature combustion has multiple models such as PPLTC (Partially Premixed LTC), HCCI (Homogenous Charge Compression Ignition Combustion), PCCI (Premixed Charge Compression Ignition Combustion), RCCI (Reactivity Controlled Compression Ignition), HECC (High-efficiency Clean Combustion) and SCCI (Stratified Charge Compression Ignition). Disadvantages of this combustion are imperfect combustion of HC emissions, lower operating range, unstable ignition control, transient response, and cycle-to-cycle variation. LTC is divided into three phases - pre-combustion, ignition, and post-combustion. The first phase depends on electric current and the change in its current; the middle phase is affected by the rate of a chemical reaction and the last phase depends mainly on the grade of mixing the mixture. [12]

4.1. HCCI

Homogeneous Charge Compression Ignition. Another name for the same principle could be "Controlled Auto-ignition Combustion". [12]

This type of ignition brings benefits from both gasoline and diesel engines that complement each other and improve the overall process. The advantage of this system is not only the reduction of NOX and soot emissions but also a much higher thermal efficiency reached for HCCI engines, which exceeds the value of 50%. It is also achieved thanks to the perfect mixing of the mixture before ignition; it can be mixed inside the cylinder, or in the space of the intake channel above the valve. As a rule, a leaner mixture is used, which produces flue gas at a lower temperature. Experiments have shown that the limit ratio of excess air at high pressure is □=2.9 (conventional ignition has a limit of around □=1.7). The maximum measured ratio during stable engine operation is □=6.2. That was achieved at a very high pressure and temperature supply. [12] [13] [14]

This method is therefore based on compressing a homogeneous mixture of fuel, air, and minor gases to a temperature corresponding to the auto-ignition temperature. The main advantage over ignition with a single spark plug is the ignition of the mixture in different places in the cylinder at the exact moment, without significant flame spread. Knocking may occur due to unpredictable auto-ignition and high-frequency oscillation due to high pressure. [13]

Great emphasis is put on controlling the moment of ignition of the mixture (self-ignition), which is affected by several factors that change with engine speed and load. Compared to standard ignition systems, where the ignition advance is mainly regulated, in this case, it is necessary to change a wide range of parameters, such as the composition of the mixture, temperature, pressure in the cylinder, etc. To prevent early ignition of the mixture, a change in the compression ratio, the richness of the mixture, or the number of recirculated gases (EGR). If the ratio of recirculated gases to intake air increases, the specific heat capacity of the cylinder increases; the temperature rise in the cylinder is much lower and the mixture ignites much later. If the ignition timing of the mixture is optimized by reducing the compression ratio, the heat of compression will be reduced, and the ignition will also occur later (closer to the top dead center). [15]

5. RESEARCH

5.1. Systems installation

The practical part of the research aims to prepare the Rotax 915 iS engine (Fig. 3) so that it can be connected to the ECU Master control unit from IMF Soft. The way the research is being held can be called reverse engineering. In the next phase, the ignition system is tested concerning the performance parameters of the engine.

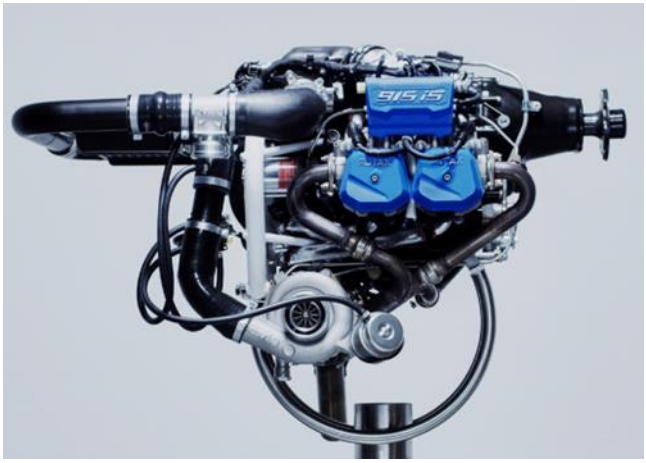

Figure 3 - Rotax 915 iS [16]

Our Rotax 915 iS engine was not equipped with fuel, oil, ignition, starting systems, and a control unit. Therefore, it was necessary to install the missing components on the motor. The fuel system consists of a tank from which fuel flows to the first pair of cylinders, then through an internal pipe and the remaining two cylinders. From them, a waste branch for unconsumed fuel leads to the second tank. The engine is fitted with eight injection ports, but for our purpose, we use only four (the other four are backups) - each for one cylinder. The control unit is equipped with two injection control outputs, and therefore fuel is injected into each cylinder twice in one cycle. The first injection is applied at the end of the expansion stroke, and the second during the exhaust stroke. The second application of fuel helps to cool the walls of the working cylinder; therefore, the engine can run properly.

The starting system consists of a power source, an electric starter, a switch, an electromagnetic relay, and wiring. The negative pole is grounded to the engine block, and the positive is connected to the relay (Fig. 4). The control signal from the switch on the control panel (small connector on the right side) and the negative pole (small connector in the middle) are

connected to the relay, which electrically operated switch. When the switch is turned on, the contacts inside the relay are closed, and the 12 V current flows through the connector, which is found on top of the relay marked in yellow-green color, to the electric starter, which rotates the engine.

Figure 4 - Starting relay

The ignition system consists of an electrical power source, electromagnetic coils (TCI), a spark plug, and low and high-voltage wiring. The mechanical circuit breaker and distributor are replaced by an electronic control unit. The scheme according to which the components of the system are connected to the control unit is shown in Fig. 38. The wiring is connected to the control unit using FASTON connectors with a sealing rubber grommet. For crimping, we used standard FASTON crimping pliers 1.5-2.5 mm. And we put appropriate rubber seals in unused TYCO connectors to maintain IP65 protection.

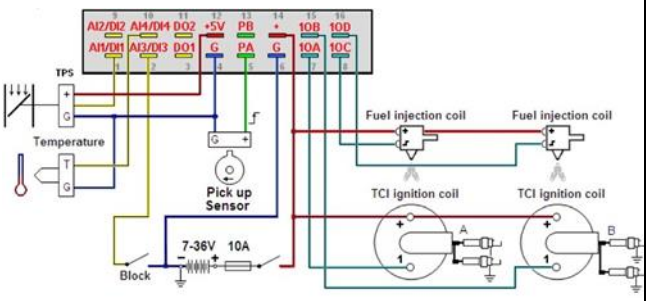

Figure 5 - Schematic of ignition system

The connection of coils had to be distinguished and connected. The outputs from 10A and 10B are provided to the negative contacts of the ignition coils. The signals from these outputs control the induction of high voltage, which is conducted by high-voltage cables to the spark plugs. From the positive output (14) an electric current is led to both coils. Because two spark plugs are connected to one induction coil, a spark is created in each cylinder twice in one cycle. First in the compression stroke, and the second spark is created in the exhaust stroke. Thanks to this, only two control signals from the control unit can be used.

The spark plug used in the test engine is a 297656 series manufactured by Rotax and is a dual-electrode type. Under normal circumstances, the engine has eight spark plugs, so there are two separate spark plugs in each cylinder, which are connected to different ignition coils. Such a solution is used in aviation mainly for backup purposes in the event of a single spark plug or coil failure, but also for better combustion of the mixture. However, in our case, we fitted the engine with only four spark plugs, i.e., there is only one in each cylinder.

5.2. Engine control

After successfully equipping the engine with all the necessary systems, it was necessary to set the control unit for starting and correct operation of the engine. Since we were working with a control unit with undefined functions of the engine manufacturer, it was necessary to figure out most of them by the experimental method.

As already mentioned, the first thing to do was to set the Pickup crankshaft position sensor. The scanned disc consists of 34 teeth and a gap that represents 2 teeth, so we used the setting defined as 36-2. Each tooth corresponds to a size of 10°, where it is also necessary to enter the beginning and end of the tooth in degrees (Fig. 6). By measuring, we found that the angular value of the disk, when the first cylinder is at top dead center, is 90°, but on the opposite side of the direction of rotation of the crankshaft. Therefore, we set the PA offset value to -90. This is therefore a shifted beginning of the cycle.

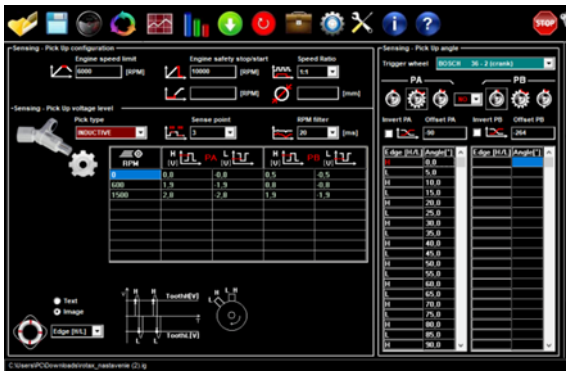

Figure 6 - Configuration of position sensor

Fig. 7 shows the ignition advance curve used, and its final one was created based on tests while the engine was running. Its minimum advance value is 9° at zero revolutions. It increases logarithmically up to 3500 revolutions per minute and subsequently flattens out and increases linearly up to a value of 40° at 6000 revolutions per minute, which represents the maximum engine revolutions. In our conditions at 17 °C, i.e. a standard air density of 1.1567 kg.m-3, the engine reached a maximum of approx. 3500 rpm. In the entire range of revolutions, the engine was running adequately for its condition and without major signs of detonation.

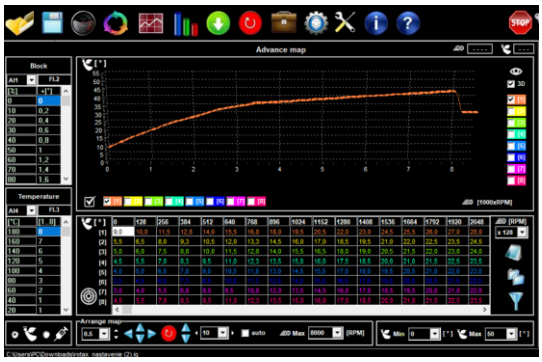

Figure 7 - Ignition curve

Setting the injection time of the fuel and air mixture into the cylinder spaces is done in the "injection map" tab, and the curve used can be seen in Fig. 8. Its modeling was also created while the engine was running, and its final version is reflected in the smoothest and cleanest running of the engine. The basic time of open injection is 0.6 ms at zero engine speed, its initial phase is flatter and only at about 800 rpm, when the timing is set to 1.3 ms, there is a steeper growth. This phase ends at approx. 2400 rpm, when the injection timing is 4.5 ms. The curve subsequently has a more gradual linear growth and the maximum injection opening value is 6.3 ms at 6000 rpm.

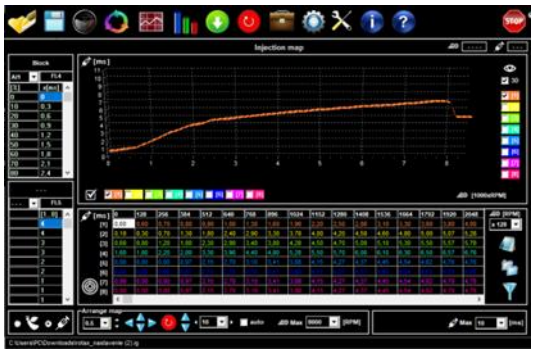

Figure 8 - Fuel injection map

6. CONCLUSION

The aim of the research was to put into operation the exhibition engine Rotax 915 iS, which was without any functional systems. In the first phase, it was, therefore, necessary to determine the condition of the engine and propose a solution for the individual systems. Among them were cooling, oil, fuel, starting and ignition systems, or intake systems. After installing the systems, the question of starting and controlling the engine arose. The ECU Master control unit from the manufacturer IMF Soft was used to operate the engine on the software side. Since the engine manufacturer does not supply any operating software for third-party control units, it was necessary for us to find the correct settings ourselves. Such a process can be named reverse engineering, where one proceeds in the opposite direction; a way to adapt the engine to the control unit was sought. And due to the lack of documentation, it was necessary to find the settings experimentally. The first task before actual commissioning was to define the offset of the induction sensor control wheel. Subsequently, the ignition advance curve and the fuel injection map were modified. After the successful start of the engine, it was necessary to further modify both curves to achieve the correct operation of the engine without detonations. The goal, which included mounting the engine and starting it, was achieved. The indisputable advantage of the research is the possibility of further scientific and practical research on the given engine, which will undoubtedly follow.

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DIGITAL TWIN – NEW TREND IN AIRCRAFT MAINTENANCE

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Abstract

Safety has always been the main concern of successful aircraft operation. Key part of the operation has to be maintenance, which not only removes defects should they arise, but also prevents them from happening in the first place. For this very reason it is necessary to have a reliable maintenance program and practices. In recent years emphasis has been posed on thorough analysis of aircraft and its systems. This is made ever so easier thanks to tools such as the digital twin. Our goal is to research this recent trend and showcase its possibilities. This wouldn't be possible without our previous underlying studies about Industry 4.0, its related matters including maintenance, as well as digital twin itself. Finally, it is important to note that the main goal of our work is not necessarily the creation of the twin, but rather the subsequent measurements, tests and analysis.

Keywords

keyword 1, keyword 2, keyword 3

1. INTRODUCTION

Maintenance is a key component of a successful aircraft operation. Rapid advancements of not only aircraft, but also their systems, instruments and engines require adequate maintenance program. In such programs, there is an ever-increasing need for modern technology and advanced procedures. Should companies take steps towards optimised maintenance, including recent solutions with complex systems, there will be an abundance of data. Our researched topic, digital twin, integrates well with these operations. Its use is becoming common, especially in commercial aviation. Different applications exist, where our aim is to explore the potential of digital twins in general aviation, more specifically in maintenance therein.

2. BACKGROUND

Each period in history is marked with certain characteristics of its industry. Industrial revolutions brought extensive advancements which completely changed set practices. Optimised workflow connected with new technologies meant lower overall costs for even better results. However, progress never halted, on the contrary it only pushed even further. It had never taken long before the next breakthrough has taken the market by storm. Not only from economic standpoint, was it necessary to swiftly adjust to keep up with the competition. Furthermore, new trends improved the speed, effectiveness, ecology and quality of products and operations [1].

First industrial revolution dates to the end of the 18th century when steam machines improved productivity. They reduced the need for manual labour of people and animals. Trains also helped with the distribution of materials and products. Nevertheless, machinery took its toll on the environment with severe pollution. In return, their work was also not reliable which perhaps foresaw further advancements in the future [2].

From 1870 we may talk about the second industrial revolution which continued the boom of first revolution with its own additions. Forth came inventions such as the first plane of the Wright brothers. Cities took the opportunities of electricity while production plants made use of production lines. Even the beginnings of connectivity in large cities could be seen in the form of telephone lines [3].

After the casualties of first and second world war researchers got inspired by revolutionary equipment used in said wars and here came the third revolution. Characteristic to this era which concerns us even today is the transfer from analogue and mechanical to digital technologies and data. Industry 4.0 further enhances these technologies and puts emphasis on maximum usage of internet and virtual space in general [3].

That brings us to one of the highlights of our current era in fact, which is IoT (Internet of Things). It enables seamless connection between physical objects and computer systems. Thanks to the integration of electronics, software and sensors, it is even possible to control devices remotely [4].

3. DIGITAL TWIN

With all the advancements, the idea of mirroring a physical object has become very attractive. By creating a virtual copy of a real product, we can make all the operations from design through manufacture to maintenance much easier and more precise. This concept has already seen various definitions and interpretations, but the general idea always stays the same:

- Exchange data between both versions and further analyse them.
- Ensure interchangeable work on either version by keeping both identical.
- Maintain and update each version [6].

While the concept of a digital twin stems back all the way to the end of 20th century, it was not until 2003 that dedicated research started outside specialized organizations like NASA. That year M. Grieves proposed his paper on a digital twin as we know it today. The proposal stood on three bases which are the physical product, its virtual copy and their connection. In 2005 he also came up with three categories of digital twin:

- DTP (digital twin prototype) – created before the physical product,
- DTI (digital twin instance) – with the intention of testing and
- DTA (digital twin aggregate) – which gathers data and diagnosis [7].

The breakthrough of this technology worldwide came from 2012 through 2014, when said technology was applied in various sectors around the world. In 2017, digital twin was said to be one of the best technological trends [8].

3.1. Principle

The basis of digital twin is the collection of data fed from sensors on the physical object. These data allow the system to analyse and compute the past, present and future states of the product. That comes with higher safety in the form of anticipation of errors and relevant troubleshooting, and overall, a smoother operation. From the point of view of manufacturing, digital twin presents an assurance of the success of the actual product. On the other hand, in maintenance it ensures optimal and most importantly safe operation. There is even an aspect of comfort, where a mechanic for instance does not have to work in proximity of physical object at all times. The possibilities are without a doubt limitless but certain requirements stay in place no matter what [9].

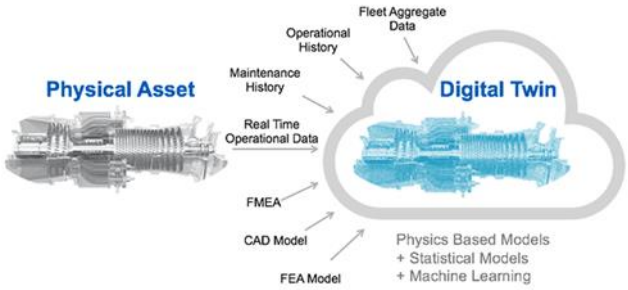

Figure 1 - Relationship between physical asset and digital twin [4]

Each of the twins exist within their own space (virtual and physical). It is far more beneficial during the development of a new product to create the digital twin first. That goes for updates further down the line as well. In the digital space mistakes and faults do not pose as much of a threat as in the real world. Therefore, this space serves as an excellent testing ground. Furthermore, it contributes with various useful built-in functions depending on the specific software used. It must not be forgotten however, that the ultimate focus should be placed on the physical object, because without it, the whole concept remains a fantasy so to speak. Digital twin integrates itself by also communicating with both the object and people involved in the operation. It is of utmost importance therefore, that the concerned personnel understand the innerworkings of the entire system. This may be achieved by the digital twin sharing its data including the applied processes. In this manner, humans can interfere in time should the system malfunction. By storing and analysing actions leading to an error, it is also possible to prevent similar accidents in the future. This can be further automatized by assigning such preventive action to the system itself [10].

3.2. Preparation

Before even pursuing just the creation of digital twin it is often necessary to carry out tests and simulations. One of these is FMEA (Failure Mode and Effect Analysis) which can uncover underlying threats and imperfections before even starting the project itself. Upon discovery, threats can identified and their consequences specified. Controlling and decision-making of hazards is a science of its own. FMEA has been already used during APOLLO program in order to optimise and verify the project. The method is made of two phases:

- Identification – where we identify:
    - potential errors,
    - their consequences and
    - their root.
- Numerical phase – where we calculate the extent of risks [11].

Another key element of the preparation for a project is FEA (Finite Element Analysis), where the effect of outside forces on tested subject are found. Most products are expected to function in various conditions which can sometimes be extreme. During the analysis, object is meshed with finite elements as the name implies and subsequent calculations are made feasible. With more powerful hardware comes the opportunity to create more detailed mesh leading to more precise results. However, computing time can still be extended [12].

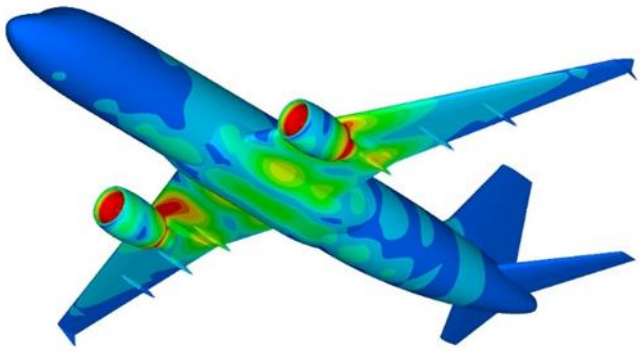

Figure 2 - FEA [13]

Overall, the general goal during preparation phase is to gain awareness. Heap of data presents little to no benefit to a human being unless it is further processed. In order to make data easier to digest for the human mind, we can transform it, simplify it and present it in a more appealing way. Such ways include but are not limited to:

- Visualisation – which makes the task more transparent.
- Simulation models – which serve as the core of most research.
- Signal processing – graphical interpretation
- Deep learning – which is the most complex way by means of artificial intelligence [14].

These days we have the option to walk the extra mile by using AR (Augmented Reality) and similar technology to further optimise our work. The ability to work in both virtual and physical environment at the same time has never been easier. All previously mentioned factors, especially awareness, pose perfect candidates for utilization of combined workspace. In such space outputs are not limited to numerical and linguistic data but rather present prime opportunity for visualisation in real time. In complex operations with multiple large components it might prove very beneficial to connect multiple digital twins, where output data are exchanged and compared for maximum synergy [10].

With the open interconnected operation that digital twins present, come certain liabilities. There are cybernetic threats which pose multitude of threats on their own. However, even within the specific organisation lie threats. It is not uncommon for companies to incline towards cheaper materials for the sake of lower costs. Such materials endanger every phase of operations and they should be avoided. Digital twin infrastructure protects against inferior components by means of RFID (Radio Frequency Identification). This technology is similar to bar codes and they assure that every part used is of adequate quality [10].

Although digital twins are appreciated for their benefits, they are not guaranteed for every stakeholder. Not all products and services are complex enough to justify the large investment and upkeep. Its costs come mainly in the form of required hardware, software and their maintenance. In general, projects that can greatly benefit from digital twins are:

- Physically large projects,
- Mechanically complex projects,
- Heavy machinery and
- Production [15].

Digital twin market saw a severe decline during COVID-19. Logistics suffered the most and the other areas followed. Albeit the motivation for application of the technology in medicine, the delays posed too big of a hit for the entire market. Before the pandemic there was an ever-increasing demand for smart technology in cities but with the arrival of COVID-19 these projects got postponed [16].

4. AIRCRAFT MAINTENANCE

In order to operate aircraft safely, it is vitally important to maintain them in not only functional state but rather durable. Every component of an aircraft is vital to safe flight and it is therefore necessary to have a proper maintenance program in place. With the development of more and more advanced aircraft come the need for cutting-edge maintenance as well. Basic maintenance procedures are not sufficient anymore and companies have to apply modern methods [17].

Looking back at the development of maintenance throughout history, the first generation provided bare minimum to keep aircraft in the air. Faults were repaired after they had already materialised. With the arrival of jet aircraft came a need for adequate maintenance. Airlines had hundreds of lives in their hands and any incident meant immoderate financial losses. Authorities also started applying regulations which have been getting stricter by the year to ensure safety of all lives onboard. Extensive maintenance at the time meant performing inspections, replacements and repairs at fixed times. This methodology went by the name “Hard-Time maintenance” and while its practices are to some extent used until now, on its own it presents very inefficient operation. Direct upgrade to Hard-Time maintenance is “On-Condition”, which is defined by the FAA (Federal Aviation Administration) as:

“a preventive primary maintenance process that requires a system, component, or appliance be inspected periodically or checked against some appropriate physical standard to determine if it can continue in service. The standard ensures that the unit is removed from service before failure during normal operation. These standards may be adjusted based on operating experience or tests, as appropriate, IAW a carrier's approved reliability program or maintenance manual.” [18]

Upon the arrival of large airliners involved parties discovered that even the most recent methods are insufficient and there is an immediate need of further advancements in maintenance. Old ways were impractical and costly for such complex machines and they posed unacceptable time contribution. Various interested parties including Boeing formed MSG (Maintenance Steering Group) which placed focus on reliability with RCM (Reliability Centered Maintenance) [17].

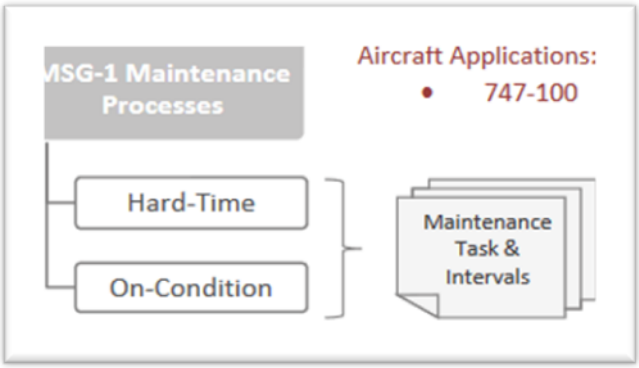

Figure 3 - MSG-1 [19]

4.1. Digital twin in maintenance

The digital twin concept was used in 2011 by researcher E. J. Tuegel and his team for forecasting and life management in the framework of predicting aircraft structural life [20]. Later, B. R. Seshadri and T. Krishnamurthy used it for damage detection, classification and isolation [21].

Effective damage detection is key, but despite developments in computing and mathematical optimization, the human component remains essential. Autonomous maintenance

systems need to evaluate different situations with the help of a digital twin. For a digital twin, the following aspects must be taken into account:

- Structural – contains information about the structure, including the interrelationships and functioning of the components
- Product - it is a representation of components
- Performance - collects data generated by the system in real time [22]

These aspects highlight why technology data is needed at every stage of the system's life cycle. The ability to generate and store information is essential for the proper operation of autonomous maintenance. Information must be stored in a standard format and delivered to the relevant interfaces. The digital twin integrates sensor data from onboard systems, maintenance history, and other historical records [23].

One of the research questions in recent years on the topic of digital twin and maintenance automation is: "If the simulation and the physical environment are shaped in the same way, will this allow the self-learning algorithm to guide itself without manual intervention?" This would solve the previously mentioned problems and reduce the necessary human factor. It is a promising solution as previous parameters would not be needed to fine-tune the system. The system could be adapted to more complex situations using the information collected so far [22].

As already mentioned, we know several types of maintenance, each type applying a different strategy to achieve the same goal - a functional product. In the aviation sector (and others), maintenance represents a significant cost that justifies the investment in a digital twin. The main idea would therefore be the optimization of maintenance processes in order to reduce costs [24].

By predicting the condition of the product, the digital twin can adjust the maintenance schedule accordingly, which is all the more important in the harsh conditions in which the product (in our case, the aircraft) operates. In these activities, there is still not enough emphasis and the possibilities of the virtual environment are not appreciated. For optimal results, it is necessary to connect the virtual and physical environment. However, there are basic requirements without which the process cannot function properly:

- The digital twin must describe the physical object in detail.
- The connection between the virtual and the physical world must take place naturally and without problems.
- Individual information must be combined and appropriately processed [24].

4.2. 5D Digital twin

While initially all digital twin research focused on three-dimensional architecture, Tao et al. were devoted to 5D. In the case of 3D, the twin is built on the basis of a physical object, a virtual model and their connection. The remaining two dimensions in the 5D structure are data and functions. In this structure proposed by Tao, we can obtain more comprehensive and accurate information by combining the output data from the virtual and physical versions [24].

The proposal also accurately describes the principle of the new architecture, in which a 5D digital twin is used to create PHM (Prognostics and Health Management). Within this structure, we distinguish two types of faults. These are gradual disturbances that we can predict and intervene in and sudden disturbances that occur unexpectedly. The principle is shown schematically in fig. 4. The scheme is divided into three parts, namely: observation, analysis and decision-making [24].

In the first part, observation, 3 primary steps are covered. First of all, it is necessary to model and calibrate the digital twin. Tao refers to a physical object and a virtual copy with the abbreviations PE (Physical Entity) and VE (Virtual Equipment) respectively. In case these two objects differ, it defines the following solutions: either we manually calibrate the VE using the simplest method or we maintain CN_PV (Connection model_Physical Entity-Virtual Equipment) to ensure constant communication between PE and VE. In this step, we can also notice other relevant factors that also have their own abbreviations. Ss (Services model) includes services for both PE and VE. It optimizes PE operation and ensures VE accuracy by continuously calibrating VE parameters based on PE activity. DD (Data model) is a subset of data from individual sources, namely: Dp – data from PE; Dv – data from VE; Ds – data from Ss and other data [24].

In the second step, we focus on simulations and interaction of objects. Tao describes this and other steps mathematically using a number of parameters. Simply put, in step 2 we address the work and state of the PE. This step is directly related to other steps that build on it. Step 3 just compares the work and status of the PE with the VE and makes sure the values are the same/similar with tolerances. If the results are correct and consistent, we move smoothly to step 4, where we detect the wear of the device. Otherwise, when the results do not meet expectations, we skip to step 5, where we look for the cause of the discrepancy, which is caused by either PE or VE, where PE is the more dangerous case, and we continue to step 6. In the sixth step, we identify and predict the cause of the malfunction, which can be:

- gradual or
- sudden [24].

If step 5 detects irregularities in the VE, it goes back to step 1 and the whole process is reset. If we get to the last step, it defines the strategy of the maintenance itself. The maintenance is adapted to the detected results and is tested first on the VE [24].

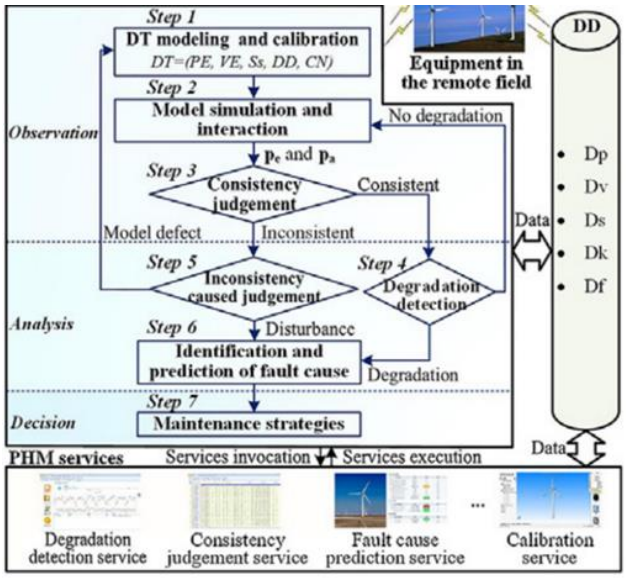

Figure 4 - PHM structure with 5D digital twin [24]

5. WORK RESULTS

With the help of software such as Autodesk Inventor and Unity, we were able to create a prototype of our own. Our digital twin is based on Lycoming AEIO-360-A1B6 aircraft engine used amongst others in Zlín 242. Our proposal incorporates a functional 3D model of said engine and a custom program which displays necessary maintenance steps for the requested engine part.

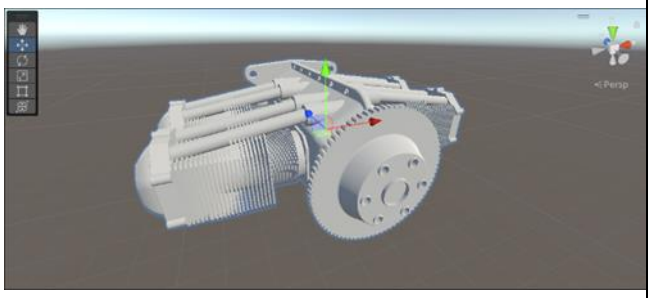

Figure 5 - 3D model

First, we modeled all of the required parts individually based on maintenance documentation, real life observations, measurements and calculations. Making the parts separately made it not only easier to adjust them and keep track of them, but also later proved useful in their detection for the purposes of our virtual checklist program.

We were able to assemble the parts into the final object including their adequate movements, clearances and synchronization. By exporting the object from Inventor to Unity, we could further work with it as a part of the virtual checklist. We set the desired camera angle and distance, keeping in mind pleasant and simple user experience and started coding.

We coded the program in C#, creating 3 separate scripts. First script controls the camera when the program is running based on the user input. This allows not only the inspection of the model, but also makes it possible to select parts which may not be in view, thus not selectable.

```
// Handle camera rotation
if (Input.GetMouseButtonDown(1))
{
    previousPosition = cam.ScreenToViewportPoint(Input.mousePosition);
}
else if (Input.GetMouseButton(1) && !isZooming)
{
    // Rotate the camera around the target
    Vector3 newPosition = cam.ScreenToViewportPoint(Input.mousePosition);
    Vector3 direction = previousPosition - newPosition;

    float rotationAroundYAxis = -direction.x * 180;
    float rotationAroundXAxis = direction.y * 180;

    cam.transform.position = target.position;

    cam.transform.Rotate(new Vector3(1, 0, 0), rotationAroundXAxis);
    cam.transform.Rotate(new Vector3(0, 1, 0), rotationAroundYAxis, Space.World);

    // Move the camera back to the target
    cam.transform.Translate(new Vector3(0, 0, -distanceToTarget));

    // Finally, update the previous position
    previousPosition = newPosition;
}
```

Figure 6 - Camera control script showcase

Next, we created the maintenance instructions script, which creates a pop-up window on user interface, displaying necessary maintenance procedures on selected component. This is the core of the whole program, and all the other parts involve around it. We decided to split the window into a header and main text which show the name of maintenance step and instructions correspondingly. These elements are also editable outside of IDE (Integrated Development Environment) making the program even more user-friendly and adjustable to ones liking.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;
using TMPro;

public class InstructionsPanel : MonoBehaviour
{
    // Singleton instance so that other scripts can access the instructions panel
    public static InstructionsPanel instance;

    private void Awake()
    {
        if (instance == null)
        {
            instance = this;
        }
        else
        {
            Destroy(gameObject);
        }

        // Hide the instructions panel by default
        gameObject.SetActive(false);
    }
```

Figure 7 - Maintenance instructions script showcase

Lastly, it was necessary to develop a way for the user to view instructions of the desired part but also open the maintenance instructions window in the first place. For the sake of simplicity, track-keeping and troubleshooting we decided to implement this in a separate script too. Since right mouse click controls camera, we assigned left click to opening of the window.

```
using UnityEngine;
using UnityEngine.UI;

public class ClickForInstructions : MonoBehaviour
{
    // Name of the part that the instructions are for
    public string partName = "Placeholder Part";
    [TextArea(50, 10)]
    // Instructions to display in the UI object
    public string instructionsText = "Placeholder instruction text";

    void OnMouseDown()
    {
        // Show instructions panel and update instructions text
        // Access the instance of the instructions panel
        InstructionsPanel instructionsPanel = InstructionsPanel.instance;
        instructionsPanel.gameObject.SetActive(true);
        // Call the ChangeText method on the instructions panel
        instructionsPanel.GetComponent<InstructionsPanel>().ChangeText(instructionsText, partName);
    }
}
```

Figure 8 - Maintenance window initiation script showcase

6. CONCLUSION

One of the beneficial technologies in aircraft maintenance is the digital twin. A virtual copy of a physical object carries countless advantages, and additional functions and uses are constantly being developed. We transform the necessary information from a paper form, in which it is confusing and needs to be constantly manually updated, to a digital form, in which new possibilities open up. Data can be automatically updated and forwarded via the Internet. Their representation is much clearer and the system will produce other adequate outputs.

In our work, we investigated the use of a digital twin in general aviation, in the form of a virtual checklist. From the operator's point of view, it may seem like modern technologies and digitization are not economically advantageous, as they present a significant investment. However, our proposal represents a simpler concept that would not represent such significant costs in terms of maintenance and overall operation.

The first phase of our project was the creation of a Lycoming engine model. The modeled engine was used to create a virtual checklist, which we developed in the Unity software environment. We programmed it in the C# programming language.

One of the shortcomings of our program that we encountered is the problem of getting to the internal components. Parts that are inside the crankcase, cylinders, etc. are not possible for users to select and display their relevant maintenance procedures. We propose to solve the problem by splitting the object by means of a standalone function into individual components that the user can see and choose. An alternative solution may be to list the components in a separate window when selecting the unit.

The concept can be used even more effectively for the aircraft as a whole, not just for the engine. In such a case, all the obtained information would have a greater value, as it can be compared and merged with the values of other sub-assemblies and parts. Such a project presents a number of additional challenges and is clearly beyond the scope of our work.

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OVERHAUL OF THE PIPER CUB AIRCRAFT REPLICA IN ULTRALIGHT CATEGORY

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Abstract

The subject of this article is focused on the description of the overhaul process involving a classic aircraft design, which is registered under the administration of the Light Aircraft Association of the Czech Republic. The research is divided into three chronological parts; the introduction, the main part and the conclusion. The first part outlines the subject of the research and its individual objectives. The main part deals with the historical background of the Piper Cub type and the current state of operation in the Czech Republic and Slovakia, both from the technical and legislative point of view. A description of the given aircraft will follow and then, mainly, the elaboration of each part of the overhaul process and its individual procedures. Among the individual steps, there will be a description of the required process for increasing the maximum take-off weight of the overhauled aircraft. In the final part, the evaluation of the inputs described above will be performed and the results of the given study will be outlined. The research should provide a comprehensive description of appropriate maintenance and the overhaul process in complexity involving the vintage classic aircraft design under the legislation of the ultralight aircraft category. Another output will be the definition of a procedure for increasing the maximum take-off weight thanks to new, updated legislation.

Keywords

Ultralight, Aircraft Overhaul, Restoration, LAA CR

1. INTRODUCTION

The intention of this article is to describe the overhaul procedure of an airplane of classic design, operated in the category of ultralight aircraft, and the process of restoring its airworthiness. While classic construction generally refers to airplanes made using materials such as wood, canvas and steel fuselage frames.

The aircraft in question, described in this work, is an ultralight named Kaero. This is in fact a replica of the very popular training and sports aircraft type Piper J-3 Cub, which was first flown in the late 1930s and its derivatives are still produced today.

The subjected Kaero aircraft was damaged by a hangar collapse in the past, its airworthiness was lost, and it has not yet been put back into service.

In the first part of the article, the history of the Piper Cub aircraft is outlined as an introduction to the issue, the circumstances of the conditions of operation of these aircraft in the Czech Republic and Slovakia and the current situation are further described. This will be followed by a characterization of the technical specifications of the aircraft and a comparison of the design differences with the Kaero aircraft.

The practical part of the article is focused on describing the condition of the aircraft before the overhaul. This will be followed by an evaluation and choice of the methods applicable for the processing of the overhaul process itself and its technical aspects.

The article will then propose an overhaul procedure and its steps, while the given topic provides an opportunity to develop comprehensive documentation that will describe the methods and available technologies used today in the repair and maintenance of ultralight aircraft of classic design in the given category. This comprehensive output will then serve as documentation for restoring the airworthiness the Kaero / Piper J-3 Cub replica. Furthermore, the output can also be used as background material for determining the procedure and choice of repair technology by other operators of the given category of ultralight aircraft.

2. PIPER CUB HISTORY

Despite its age, the Piper Cub is still very popular in the sport aviation segment today. This is mainly due to its excellent flight characteristics, simple yet robust construction, and the resulting low costs of operation and maintenance. It is often referred to as a Ford Model T of aviation with its later revolutionary approach to the aviation market in the USA.

The beginning of the development can be dated back to 1930, when Clarence Gilbert Taylor at Taylor Brothers Aircraft in Bradford, Pennsylvania, designed and built the Taylor E-2 Cub, first predecessor of the famous line of Cub aircrafts.

Company goal at the Taylor Brothers Aircraft was to construct an all-round cheap airplane that could bring aviation closer to wider social strata with its affordable price and enable them to buy and operate their own airplane. This idea met with success, and from 1931 to 1936, when the production of the Taylor E-2 Cub type ran, a total of 353 units were produced at a price of 1,325 US dollars of the time [1].

This initial success motivated the manufacturer to further develop and innovate the design. However, in the meantime, the company's structure also changed. Businessman William Thomas Piper, originally an investor and partner who saved the company from collapse during the economic crisis of the early 1930s, decided to buy out the remaining shares in the company

after internal disputes with Taylor Brothers. Thus, a company named Piper Aircraft Corporation was born. After Clarence Gilbert Taylor left the company, Walter Jamouneau became the new chief type designer [1].

Development continued with an innovative type already named Piper J-2 Cub. The new J-2 had better designed wing tips with oval shape, and the shapes of the horizontal and vertical tail surfaces were also modified. The design of the main landing gear was partially changed, which now used bigger low-pressure Goodyear Airwheel tires. The cockpit was now also glazed and fully enclosed. Production of the Piper J-2 Cub type ran from 1936 until a fire at the company's production facilities in 1938. A total of 1,207 units were produced [1].

After a fire at the factory in Bradford, the Piper Aircraft Corporation moved to the city of Lock Heaven, where the production of the later most popular type Piper J-3 Cub began from the end of 1938 [1].

Modifications of the J-3 type compared to the previous generation consisted primarily of strengthening the structure of the fuselage and wings, which also had new aluminium alloy ribs. The main landing gear was equipped with hydraulic brakes. At the customer's request, the aircraft could also be equipped with a steerable tailwheel. The choice of Powerplant has also been greatly expanded. Franklin, Lycoming and Continental flat four-cylinder engines with higher power were also newly offered. The most widespread Powerplant then became the Continental A-65 engine with an output of 48 kW (65 HP). The aircraft modified in this way was certified in the United States on July 14, 1938 and received the type certificate A-691. The aircraft achieved considerable popularity at the time, which was reflected in great sales successes. A total of 3,016 were produced in 1940 alone, the year before the United States entered the war [1].

The military also showed interest in the aircraft for its front-line observation and courier aircraft program. After bad experiences with larger types, such as the Stinson L-1 Vigilant or the Curtiss O-52 Owl, which were difficult to maintain and operate in field conditions it was decided to choose the light aircrafts for this role.

The army's requirement for this category was to obtain an aircraft with a short take-off and landing, which would be easy to operate and which would be able to be maintained by ground personnel in front line conditions without special training [2].

The modified army version was then designated L-4 Grasshopper. Modifications, were not extensive. It mainly included new modified cabin glazing for a better view for air observing tasks. The Military versions were produced extensively in the four following variants, designated as L-4A, L-4B, L-4H and L-4J. Depending on the version, the aircraft could be further equipped with an electrical system and a radio station. In total, from 1941 to the end of the army contracts in 1945, more than 5,400 L-4's of all versions was produced for the army [2].

After the end of the Second World War, a significant number of these aircraft remained in Europe, which were sold off to the civilian market later on. Thanks to this, Cubs are still widely popular across all the countries of Western Europe, where they helped to restore sport aviation after the war.

The production of the J-3 variant continued from 1945 to 1947 and its popularity is also evidenced by the fact that there are still about 3,000 Cubs registered and operating in the USA as of the date of publishing of this article [3].

3. FURTHER DEVELOPMENT

Due to the success and constant demand for aircraft such like the Piper Cub even after the end of factory production, several other companies took the initiative. With their activities, they continued and helped to keep a considerable fleet of these aircraft in operation and gradually developed and further modernized this concept. Initially, they focused on the production of spare parts, kits and later even complete aircraft.

One of such companies is a Wag-Aero. American company that first started producing spare parts for and later complete kits for amateur construction led by the American Experimental Aircraft Association. It has also released construction plans for their Piper J-3 Cub replica, which is called the Wag-Aero Sport Trainer.

4. PIPER CUB IN CZECH REPUBLIC AND SLOVAKIA

After the end of the Second World War, there was urgent need for new airplanes that could be used in re-established aeroclubs in Czechoslovakia. Therefore, at the beginning of 1946, the Ministry of Transport decided to proceed with the purchase of 200 used Piper L-4 Grasshopper aircrafts from the surplus of the US Army in Europe. Another 100 L-4 aircraft were also purchased by the Ministry of National Defense for the needs of the army. Aircraft operated in the army were then assigned the code type designations C-8 and K-68.

With the gradual rise of the domestic aviation industry in Czechoslovakia, the Cubs began to be replaced by more universal airplanes of the Zlin Trener series, which enabled both basic pilot training, aerobatics and glider towing. A few ex-Czechoslovak were sold off to the western countries and the rest was scrapped at the end of 1950's.

Today the Piper Cub can be certified either as a GA category aircraft or as a Light-Sport under Light Aircraft Association. The Czech Light Aircraft Association Light-Sport category is primarily suitable for aircraft replicas and amateur built aircraft with MTOM up to 600 kg.

5. TECHNICAL SPECIFICATIONS

The aircraft is designed as a two-seater cabin high-wing monoplane of mixed construction with a tailwheel landing gear. Information and performance data are valid for Piper J-3C-65 Cub powered with Continental A-65-8 engine.

The fuselage frame structure is welded from chrome-molybdenum steel tubing. Access to the cockpit is from the right side. The arrangement of the pilot's seats is in a tandem configuration with dual flight controls.

The wing is of rectangular shape. The construction is of mixed type. The wing spars are wooden, made of solid spruce wood. There are 12 ribs in total, they are riveted and shaped from duralumin profiles. The airfoil used throughout entire wingspan is USA 35B which ensure good slow flying characteristics [4].

The Continental A-65-8s aircraft engine used in the Piper Cub is an air-cooled flat-four with a displacement of 2.8 litres. Maximum engine output is 48.5 kW (65 HP at 2250 RPM. It primarily uses a Sensenich 72C-42 propeller with 1830 mm diameter [4].

The fuel system consists of a fuel tank with a capacity of 45 litres, which is located in the forward part of the fuselage, between the engine firewall and the instrument panel.

6. COMPARISON WITH THE KAERO AIRCRAFT REPLICA

The Kaero aircraft is technically identical to the Piper J-3 Cub, but differs in several design points. When compared, the design changes are in the following points.

The original solid type wing spars were replaced with partly hollow type spars, which are glued together from spruce flanges and plywood webs. The construction of the new spars was designed in order to maintain the same strength as the original solid type spars.

The fuselage was built in accordance with the drawing documentation, but metric tubes were used for the structure. Where it was not possible to use the dimensions of the tubes specified in the drawing documentation, an alternative metric tubes were used, either with a larger diameter or with a thicker wall, so that the strength of the structure was at least maintained or increased.

The building took approximately 3000 man-hours and the aircraft was first test flown in 1995. Since then, it has accumulated 323 flight hours and 900 landings.

7. KAERO CERTIFYING LEGISLATION

The Kaero, as an amateur-built ultralight aircraft, falls into the category of ultralight aircraft. Currently, Kaero is registered under the administration of the Light Aircraft Association of the Czech Republic, which is authorized by the Ministry of Transport to perform state administration in the matter of ultralight aircraft.

8. DAMAGE ASSESMENT BEFORE START OF THE OVERHAUL

Aircraft was damaged by a hangar collapse. This resulted in mechanical damage to individual elements of the aircraft structure.

Ceconite covering on the fuselage was torn and the wooden elements and the steel reinforcements of the fuselage superstructure were subsequently broken through and bent.

On the left wing, the end ribs number 11 and 12 were broken. Furthermore, the adjacent steel members supporting the wingtip were bent.

The damage that was found was common to the total flight time and type of the operation of the aircraft. Further inspections would be carried out during disassembly of each airframe subassemblies and overhaul process of the aircraft.

9. KAERO SERVICE LIFE

During the operation, maintenance and repair of aircraft, it is necessary to assess the overall service life of the airframe structure. This is the time period during which the aircraft is safely airworthy.

In order to determine possible critical elements affecting the overall life limits of the Kaero aircraft structure, we can also use available information on the operational reliability of the Piper J-3 Cub aircraft, due to its structural similarity.

Analysis of the published airworthiness directives and issued service bulletins revealed that corrosion may be the biggest problem of the Piper Cub airplanes in terms of service life. While this problem can be most critical when the wing lift struts are affected. There it is relatively difficult to detect under normal operating conditions as the corrosion mainly affects the inside structure [5].

Because of this critical issue, the US FAA has issued a continuing airworthiness directive AD 2015-08-04. This document mandates the periodic inspection and possible replacement of the original wing struts on all Piper Cub series airplanes [5].

Therefore, during the restoration of the Kaero aircraft, it will be necessary to pay increased attention to the occurrence of corrosion in the wing lift struts and, where appropriate, thoroughly treat the structure of the aircraft against the formation of corrosion.

10. KAERO OVERHAUL METHODOLOGY

To characterize the term Overhaul in aviation and its methodology, we can quote the definition from Czech national Aviation Regulation L 8/A, which describes this term as follows:

"Overhaul is the restoration of an aircraft, engine, propeller or other aircraft component products by inspection, repairs and replacements, carried out to maintain their operational service life in accordance with an approved standard." [6]

Overhaul process of aircraft itself can be then generally defined by the following scope of work:

- The airframe is completely disassembled into individual parts and components.
- Inspection is carried out to making the findings and to evaluate the overall condition of the structure.
- Classification of the assemblies and individual parts into usable without repair, requiring a repair before returning to service and unrepairable.
- Application of NDT inspections to critical structural elements.
- Repair of damaged parts of the airframe.
- Repair of damaged airframe parts or replacement with new ones.
- Execution of mandatory bulletins for safe operability.
- Applying new surface restoration paint and top coat to airframe, including internal and external construction.

- Assembly of the airframe and its subassemblies.
- Checking and testing of the individual aircraft systems.
- Final test flight to verify full airworthiness.

According to the findings of the identified defects and damage found on the airframe of the Kaero aircraft, the size of the work necessary to restore its airworthiness fully corresponding with the scope of the overhaul in its entirety, according to the list of individual maintenance tasks listed above.

11. AICRAFT FABRIC COVERING SYSTEMS

An important step during the overhaul process of classic fabric-covered aircraft is the choice of suitable covering material. Its overall characteristics can significantly affect the difficulty of operation and maintenance of the entire aircraft.

Among the key parameters of aircraft fabric is the type of material used, and its lifespan. Materials used for aircraft covering today are mostly synthetic. Another important parameter is the strength and specific weight of the given material, which then affects the resulting empty weight of the aircraft.

Nowadays, the market offers a choice from multiple of available fabric covering systems, both certified and non-certified.

11.1. Oratex

Oratex is a synthetic covering system for aviation developed by the German company Lanitz-Prena Folien Factory in Leipzig. The fabric is made of high-strength polyester fabric, which I coated with a patented polyurethane top covering compound and paint finish already during the production process. The resulting coating material is resistant to UV radiation, temperature extremes and chemicals [9].

That means that after the aircraft has been covered, there is no longer any need to apply additional layers of stabilizing and protective paint layers. In this way, the entire process can be simplified and it is thus possible to achieve a significant reduction in the necessary time and other costs required to paint the aircraft [9]

One of the key advantages of Oratex, on the one hand, can be a faster coating process of the entire aircraft, when the canvas does not need to be further treated after coating, and thus the solution of another production technology of painting is omitted.

On the other hand, due to the fact that the canvas is already coated with a protective paint finish from the factory, it is not as flexible as other covering materials, and it is not easy to remove possible imperfections and wrinkles during the covering process, caused by inaccurate initial placement on the fabric to the structure. This can be a disadvantage for less experienced builders and restorers. Another disadvantage can also be the limited number of available colours options in which the fabric is supplied.

11.2. Ceconite

Ceconite is a range of aircraft covering materials that are also made from synthetic, polyester fibres. Ceconite fabric has been on the market since the 1960s. Nowadays, Ceconite is already the standard in the industry and ranks among the most used [10]

Compared to the Oratex system, Ceconite is delivered as a plain fabric without any surface treatment. Therefore, after the covering and shrinking process, the fabric needs to be further treated with a stabilizing varnish and a top coat.

Its advantages include, in particular, that it is easier to work with. Thanks to its initial state without a covering layer of paint, it is easier to work with during the covering process. Another advantage is better applicability for local in-service repairs of damaged fabric during service life of the aircraft.

12. WING LIFT STRUTS NDT INSPECTION

After disassembly of the individual struts, it was decided, due to the issued AD for the Piper J-3 Cub aircraft, to subject the struts to a borescope inspection to determine the condition of the inner walls of the tubes. A subsequent inspection revealed the occurrence of corrosion inside of all struts in their lower parts, close to the fuselage. Therefore, it will be necessary to proceed with an NDT inspection to determine the remaining wall thickness of all four strut tubes using ultrasonic measurement.

The paint was stripped and a grid was marked around the external surface for measurements in four axes. Measuring spots were divided by 20 mm. The total length of the measured section of the tubes was 600 mm.

The Olympus Panametrics NDT - 35DL Ultrasonic Precision Thickness Gauge was used for NDT measurement of remaining wall thickness in accordance with the ČSN EN ISO 16809 norm. This instrument can measure steel as thin as 0.10 mm with an accuracy of 0.001 mm [7].

Calibration of the device's sensitivity settings was performed for thicknesses of 1 and 2 mm in the test range of 0 - 5 mm. The measured values are summarized in Table below.

Table 1 - Remaining wall thickness of individual struts.

Strut	T_{MAX}	T_{NOM}	T_{MIN}	$T_{NOM} - T_{MIN}$
A	1,327	1,200	1,207	-
B	1,297	1,200	1,127	0,073
C	1,317	1,200	1,170	0,030
D	1,286	1,200	1,147	0,053

After consultation with the LAA technician inspector, it was decided to use a 10% material loss limit of the nominal wall skin thickness for the evaluation of the strut tubes condition. Therefore, for a wall with a nominal thickness of 1.2 mm, the maximum allowable loss is 0.12 mm and the minimum remaining wall thickness limit is 1.080 mm.

Table 2 - UTT NDT Measurement Evaluation.

Values	***Acceptable max. loss***	***Measured max. loss***
T_{NOM}	1,200	1,200
T_{MIN}	1,080	1,127
Loss in mm	0,120	0.073
Loss in %	10%	6,0833%

all the measurements made is 1.127 mm. The largest measured loss of material is therefore 0.073 mm, which corresponds to 6.0833%. So, all struts passed the NDT inspection.

13. UPDATED MTOM LEGISLATION

In 2019, the LAA approved an amendment to the UL 2 - Part I airworthiness requirements regulation. A substantial modification that was included in the regulation during this amendment was the increase in the operational limit for the maximum take-off weight. Compared to the original form of this regulation from 2002, the MTOM limit was increased from the previous 450 kg up to 600 kg.

The opportunity to implement this legislative amendment at the national level was made possible by the ratification of the new Basic Regulation of the European Union 1139/2018 on common rules in the field of civil aviation and on the establishment of the EASA agency. The amended basic regulation gives the member states the option for the OPT OUT solution. This provides an opportunity to transfer the legislative management of aircraft with the limits described above, which have not previously been certified in accordance with Regulation (EC) No 216/2008, to a national level [8].

The OPT OUT solution and the amended legislation allow already registered and approved ultralights to operate within the limits, as they were previously approved for operation, or, after providing the appropriate documents, allow their MTOM to be increased up to the new limit of 600 kg. This situation will also apply to the Kaero aircraft, which was originally certified with MTOM of 450 kg but the real design limit is 555 kg which is also the MTOM limit of the original Piper J-3 Cub type. This change would make it possible to use the full potential of the Kaero aircraft.

14. MTOM INCREASE PROCEDURE

Czech LAA also defines the required procedures for verifying the airworthiness of ultralight aircraft. The legislation requires to prove the strength of the individually built ultralights in the following points:

1. By calculation
2. Quality evidence of used material
3. Wing static load test
4. Additional tests at the discretion of the technical Inspector [11].

When the Kaero aircraft was first released to service in 1995, all the mentioned points were already fulfilled. However, according to the applicable legislation at the time, a load test was performed only for the then required MTOM limit of 450 kg.

1. In order to approve the new higher MTOM limit, it will be necessary, according to the above-mentioned requirements, to carry out the following range of tests:
2. Check of the wing spars static calculation
3. Preparation of documents for a new wing static load test with a higher load value, which will practically verify the calculated strength values of the structure for operation at an increased MTOM limit.
4. Design of wing fixtures for static load test and subsequent processing of the drawing documentation for their actual production, as the original preparations have not been preserved.
5. Practical execution of the static load test according to the given input parameters.

The actual practical procedure will consist of placing the wing in the fixtures and continuously distributing the calculated designed load on the wing spars. This will be followed by the measurement of the deflection of the wing structure under load and comparison with the calculated values. After the specified time, the load is removed and wing inspected for any permanent deformations of the structure.

15. CONCLUSION

Overhaul of an aircraft is the procedure that allows maintaining and extending the airworthiness of a given aircraft. In the case of the Kaero ultralight aircraft, which was damaged by the fall of the hangar, this work made it possible to describe the overall process, its steps and individual activities that were necessary to restore its airworthiness.

In the first part, the technical parameters of the aircraft and its description were outlined. Furthermore, the article focused on the service life of the Kaero airframe and defined the critical elements given the operational experience on a similar type of aircraft, Piper J-3 Cub. The second part was then focused on determining the individual repair steps that will need to be carried out and further offered a description of practical NDT measurement with evaluation of the measured values.

The most critical part of this overhaul was the finding of the wing struts corrosion, which could potentially threaten the further safe operability of the aircraft. Thanks to the use of today's available non-destructive testing methods, mainly a borescope inspection and subsequent measurement of the minimum remaining thickness using the ultrasonic method, it was possible to check their actual condition, evaluate the level of the damage and propose a repair procedure.

This comprehensive output will be further used as a basis for restoring the airworthiness of the Kaero aircraft and can further serve as inspiration for other operators who will overhaul the aircraft of similar design in ultralight category.

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IMPACT OF THE COVID-19 PANDEMIC ON AIRCRAFT LEASING

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Abstract

The article deals with the impact of the COVID-19 pandemic on aircraft leasing. It describes the current state of leasing and airline companies and the overall impact on the aviation industry worldwide. The main objective is to analyze the impact of the COVID-19 pandemic on aircraft leasing and to correctly interpret trends in aircraft leasing during and after the time when the virus was prevalent. The conclusion is devoted to the description of the most advantageous solutions for this sector. As a result of all the issues examined, we have tried to predict what the aviation industry might expect in the coming years.

Keywords

COVID-19, aircraft leasing, trends in aircraft leasing

1. INTRODUCTION

At the beginning of 2020, the COVID-19 pandemic put the aviation industry under unprecedented challenges. This virus has spread all over the world and caused a global crisis. In response to travel restrictions resulting from the outbreak of the pandemic, domestic and international travel has been affected by measures implemented by individual countries around the world. This caused a steep decline in air travel and the airlines face an uncertain future in regaining passengers. The restrictions created by this virus, combined with the condition of large parts of the global economy and travelers fear of virus infection, have caused passenger demand to plummet. Airlines responded to the sudden drop in bookings, revenue, and overcapacity of limited services by laying off employees, grounding aircraft in temporary storage, and asking national governments for financial support. According to Eurocontrol, after the outbreak of the pandemic in early 2020, almost 5,000 aircraft were grounded in 39 Eurocontrol countries. This sudden grounding of aircraft for an unknown period represented immediate challenges for the airlines but was also announced. So, it could be concluded that COVID-19 had a much greater impact on aviation than other recent epidemics.

In recent years, aircraft leasing has become more common than ever. The services of leasing companies are used by low-cost air carriers as well as traditional air carriers. After the outbreak of the virus, many wondered what impact COVID-19 would have on aircraft leasing. As a result, leasing companies experienced a significant drop in revenue as many airlines requested deferred payments on leased aircraft.

It is undoubted, that the COVID-19 pandemic crisis has done serious damage to the aviation industry which has not been encountered in the history of civil aviation. We collected available data from various studies and analyzes and tried to evaluate the impact of the COVID-19 pandemic on aircraft leasing in world regions, namely the USA, China and Europe.

2. CURRENT STATUS OF THE SOLVED PROBLEM

COVID-19 had the most dramatic impact on the airlines and aircraft leasing industry. According to statistics, in April 2020, air traffic decreased by more than 70% compared to the previous year 2019 [1].

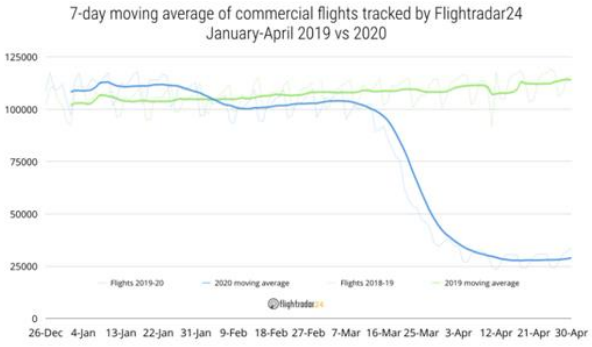

Figure 1 - Commercial flights tracked by Flightradar 24 January-April 2019 vs 2020. Source: [1].

The following images show the capture of the number of flights on the same day 30 April 2019 and 30 April 2020. Before the 2019 outbreak of COVID-19, the density of flights was much higher than in the 2020 outbreak.

Figure 2 - Number of flights on 30 April 2019 Source: [1].

Figure 3 - Number of flights on 30 April 2020 Source: [1].

Currently, disruptions related to the COVID-19 pandemic have begun to ease. Airports are full again and individual flights are occupied. Demand for business and leisure travel has rebounded faster than airlines expected. People are starting to travel again and learning to live with COVID-19. Airlines have also become more flexible because they realize that passengers will tolerate flight cancellations. Before the pandemic, airlines felt they had to continue to operate routes that marked a loss, but today it is crucial to remain profitable, even if it means losing key routes. However, not all airlines were so lucky to survive this crisis. Airlines around the world have declared bankruptcy. The future of the pandemic is still uncertain. This crisis affects all parties in the aviation industry, and each company approaches the decline in sales differently [2].

The COVID-19 pandemic has also affected aircraft leasing companies. With declining demand for air travel, reduced airline revenues due to the measures that have been issued to prevent the spread of the COVID-19 virus, and their inability to pay leases for leased aircraft, leasing companies have also been affected by reduced revenues. After the COVID-19 pandemic subsided in 2022, another unforeseen event hit the leasing companies. February 24th 2022 went down in history when the invasion of Ukraine by the armed forces of Russia began.

After the arrival of the Russian invasion of Ukraine, international sanctions against Russia were introduced after a short time, which has a impact on the aircraft leasing sector. This crisis affected approximately 589 aircraft operated by Russian airlines and lessors based outside of Russia. The sanctions required the lessors to get these leased aircraft back, but flights between Russia and many other countries were banned and it was very difficult get their aircraft back.

The war in Ukraine has an overall impact on aircraft leasing. However, the impact of the war on aircraft leasing will show in the future, because the situation continues to evolve [3].

3. IMPACT OF COVID-19 ON THE TRANSPORT PERFORMANCE OF TRADITIONAL AND LOW-COST AIR CARRIERS

Most airlines tried to operate a normal flight schedule after the outbreak of the COVID-19 virus until the virus-related measures prevented it. During this period, airlines began to experience a decrease in passengers, which was reflected in a sudden decrease in the number of flights from mid-March 2020, when the borders began to close. As a result, the impact was stronger in international markets than in domestic markets [4].

The following picture shows the decline in domestic air traffic over the same time period as in the graph above. Interestingly, at the end of January 2019, the decline in air traffic in Asia began, but in March 2019, demand began to rise and then the decline came again. Another point of interest is the increase in air traffic in the Middle East at the beginning of March 2020. In other parts of the world, the situation was very similar, in March 2020 the demand for air traffic within domestic flights began to decline.

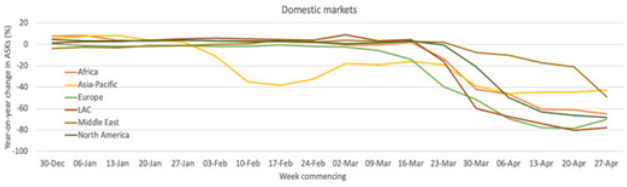

Figure 4 - Domestic Market. Source: [4].

The next picture shows the decline in air traffic in individual world regions in the period from 30 December 2019 to 27 April 2020. Due to the fact that the COVID-19 virus broke out in China and subsequently spread throughout the world, the first declines occurred in Asia at beginning of February 2020, then other world regions were added gradually. In mid-March 2020, demand for air transport in Africa, Europe, the Middle East, North America, and LAC began to decline.

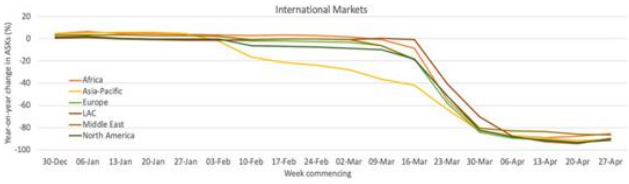

Figure 5 - International Market. Source: [4].

4. AIRCRAFT LEASING DURING THE COVID-19 PANDEMIC

In recent years, aircraft leasing has become more common than ever. Aircraft leasing is mainly used by low-cost air carriers and start-up airlines. Also, traditional air carriers, by leasing gain access to the newest and most comfortable aircraft on the market. After the outbreak of the COVID-19 pandemic in March

2020, many had the question, what impact this virus would have on aircraft leasing. The reality was that many leasing companies experienced a significant decrease in income due to the postponement of lease payments. Some airlines received state aid, but many did not [4] [5].

Airlines have lost a lot of money during the COVID-19 pandemic, but forecasts for the next years point to a profit. In 2022, there was a resurgence in passenger numbers and confidence in travel, which in some regions means a surge in revenue. The rise of aircraft leasing companies accelerated during the pandemic, thanks to the ability to obtain cheaper financing than airlines [7].

In the coming years, aircraft leasing is likely to be a popular otion for airlines. It is expect, that the demand for air transport to increase and leasing can provide flexibility and cost saving to airlines, which want expand their fleet.

However, the leasing industry may face some challenges. One potential problem is the availability of aircraft. As the COVID-19 pandemic has led to reduced air travel, which in turn led to reduced demand for new aircraft, this could lead to a shortage of available aircraft for lease. In addition, there may be changes in environmnetal regulations that could affect the industry. Governments around the world are increasingly focusing on reducing carbon emissions, which could lead to changes in regulations that affect the types of aircraft available for lease.

Overall, it can be concluded that the aircraft leasing industry may face some challenges, but is likely to remain a favourite option for airlines. Flexibility and cost savings provided by leasing will continue to be attractive for airlines wishing to expand their fleet [8].

5. ANALYSIS OF THE IMPACT OF COVID-19 ON AIRCRAFT LEASING IN SELECT WORLD REGIONS

5.1. USA

Like other sectors of the aviation industry, the US aircraft leasing market has been affected by the COVID-19 pandemic. Low-cost airlines were particularly affected, and many of them faced significant financial problems due to reduced demand for air travel. This led to the restriction of activity and the suspension of part of the fleet. The ability to pay for leased aircraft was also affected and many airlines were forced to agree with lessors to renegotiation leasing contract to reduce their costs. Some airlines have been forced to return leased aircraft to lessors to cut costs. In response to the crisis, some aircraft lessors in the US proceeded to lower rents, extend leases and delay payments, which helped airlines with financial pressure. It was most beneficial to low-cost airlines, because they have tighter budgets and less financial flexibility than traditional airlines.

Overall, leasing companies in the US improved significantly in 2021. The sector roughly halved its economic loss in 2021, although performance varied widely. Despite the pandemic, most airlines pay rent for leased aircraft either adjusted to the leasing contract, which are the most advantageous for the airline in question or by deferring payments for aircraft lease [9].

5.2. China

In recent years, the COVID-19 pandemic has affected aircraft leasing companies in China. The virus brought the airline industry to a standstill, resulting in billions of losses. COVID-19 has led to significant reductions in air traffic and grounding of aircraft fleets. Most of the airlines had financial problems and were unable to pay the leases for the leased aircraft, which led to the airlines taking care to delay payments until the demand for air travel returned to normal. Orders for aircraft that the airline wanted to lease were postponed or canceled altogether [5].

Despite the problems, the strongest airlines in China continued to aircraft leasing, especially low-cost airlines, because when measures were relaxed in some part of the country, airlines could expand their operations there and increase their market share, which required leasing more aircraft [5].

The world's largest aircraft leasing companies have adjusted their business strategies and increased their expansion in the Chinese market, intensifying competition in the Chinese aircraft leasing market. In this context, the market for Chinese aircraft leasing companies has declined. With the revival of China's economic growth in 2021, the market share of Chinese aircraft leasing companies was projected to return to the level of 2018 and maintain a steady growth trend. According to a study by the Civil Aviation University of China, the market share will reach 69,65% by the end of 2025.The table bolow showa the market shares and the number od leased aircraft from 2018 to 2025.

Table 1 - Market shares and number of leased aircraft in China 2018-2025. Source: [5].

Year	Number of leased aircraft	Market share
2018	193	61,27%
2019	107	60,11%
2020	36	51,43%
2021	111	63,43%
2022	125	64,77%
2023	142	66,67%
2024	160	68,38%
2025	179	69,65%

5.3. Europe

The COVID-19 pandemic had as significant an impact on the airline industry in Europe as in other parts of the world, as travel restrictions and reduced demand for air transport have led to a drop in revenue not only for airlines but also for leasing companies. In the early stages of the pandemic, many airlines reduced part of their fleets, which led to a drop in demand for leased aircraft. As a result, some aircraft lessors have encountered difficulties in finding lessees for their aircraft, leading to an increase in the number of idle aircraft in their listings. In response to the challenges the industry has faced, some lessors have implemented measures to mitigate the impact of the pandemic. Some have negotiated lease extensions

or deferrals with their tenants, while others have focused on rent adjustments to manage financial difficulties during the pandemic period. Unfortunately, some airlines have been forced to return leased aircraft due to financial difficulties, leasing to an increase in aircraft holdings. Some European governments have provided financial support to airlines to help them meet their aircraft lease obligations.

Within the world regions, Europe is among the regions with the largest fleet of aircraft that are operated based on leases from leasing companies. It includes more than 3 500 aircraft currently maintained as leased. The temporary grounding of aircraft and uncertainty about the future forced the airline to ressess its current fleet and future requirements for aircraft. Some airlines announced changes to the size and composition of their fleet, which include the permanent retirement of a particular aircraft type, the reduction or standardization of the fleet or the delivery of new aircraf

In a crisis, the leasing companies had the option to take their aircraft back and lease them to other airlines. However, the COVID-19 pandemic was unique in that there was no other airline that could lease the aircraft. In this volatile period, the flexibility that airlines offered proved to be a very attractive option. The pandemic has led to sales and leasebacks between airlines and leasing companies, meaning the transactions have been worth billions of dollars. Unfortunately, some of these transactions contributed to the liquidity of the airlines as they were forced to sell the aircraft they owned to leasing companies and lease them back. The pandemic has strengthened the relationship between leasing companies and airlines [10].

Table 2 presents global aircraft leasing companies in 2020 by fleet size. The two main aircraft lessors were General Electric Capital Aviation Services business and AerCap [11].

Table 2 - Aircraft leasing companies in europe and their fleet size. Source: [11].

Aircraft leasing company	**Fleet size**
GECAS (Ireland)	more than 1 500 aircraft
AerCap (Ireland)	more than 1 000 aircraft
SMBC Aviation Capital (Ireland)	more than 700 aircraft
Avolon (Ireland)	more than 570 aircraft
BOC Aviation (Singapore with a strong presence in Europe)	more than 500 aircraft
Nordic Aviation Capital (Denmark)	more than 500 aircraft
Air Lease Corporation (California with a strong presence in Europe)	more than 400 aircraft

During 2022, demand for air travel increased in most markets, with the exception of China, where tough measures were only eased towards the end of the year. Total global passenger traffic has grown significantly this year and in November 2022 was about 75% higher than in 2019. Most world regions are expected that surpass pre-pandemic levels by the end of 2023. However, these forecasts may be subject to downside risks if travel restrictions are re-imposed [12].

6. CONCLUSION

The COVID-19 pandemic had a significant impact on the entire aviation industry, but the industry appears to be gradually recovering. As airlines continue to adapt to the post-pandemic situation, leasing companies must be more flexible and innovative to meet the changing needs of airlines.

We found that due to the COVID-19 pandemic, the impact was stronger in international markets than in domestic markets, because domestic markets experienced a slower response to the spread of the virus. The deterioration in the financial situation of airlines due to the COVID-19 pandemic, the conflict in Ukraine, an inflation, higher prices for jet fuel increases the risk that aircraft lease payments will be delayed, reduced or remain unpaid.

Leasing companies were doing very well before the COVID-19 pandemic. One of the key factors was the growing popularity of low-cost carriers, which often use aircraft leasing to reduce their costs. Another factor was the growth of air travel in emerging markets, particularly in Asia, where new airlines were established and older airlines expanded their fleets. After the outbreak of the COVID-19 pandemic, this growth trend changed. Many airlines demanded that leasing companies postpone their payments for leased aircraft and this meant a decrease in their revenues. Demanded payment deferrals negatively affected leasing companies, but despite that, they did not fare too badly.

While commercial air travel recovered significantly in 2022, the COVID-19 pandemic continues to introduce risks for leasing companies. The emergence of new variants, the development of the situation in the public health, the re-introduction of travel restrictions and other complications related to the pandemic could have a negative impact on the business of leasing companies. Also, the COVID-19 pandemic may continue to have a negative impact on the financial situation of airlines and this would mean a disandvantage for leasing companies, because their income could decrease again.

One of the factors for the growth of aircraft leasing after the end of the COVID-19 pandemic could be the leasing of smaller and more fuel-efficient aircraft. As many airlines looking to reduce costs and improve their environmental sustainability, they are more likely to lease these types of aircraft than buy them outright. Another factor is stabilization within the industry. As airlines want to reduce their costs and make their operations more efficient, they can lease aircraft from larger lessors who can offer a wider range of services. The development of new technologies could also create new opportunities for the aircraft leasing industry. Since new technologies require significant investment, i tis more profitable to lease them than to buy.

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SOCIAL MEDIA AS A TOOL FOR AIRLINE SERVICE QUALITY ASSESSMENT

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Abstract

Our study investigates the perception of service quality of 12 airlines by using a mixed-method approach that consists of numerical analysis of key performance indicators (KPIs) and qualitative examination of Twitter customer service. Our findings reveal that Twitter is the most popular social media platform in the airline industry, with U.S.-based airlines being the most active. The analysis of customer feedback on Twitter showed noticeable differences between full-service and low-cost carriers, with the former receiving more complaints regarding booking and in-flight service quality, and the latter receiving more complaints regarding delayed or cancelled flights and poor customer service. Overall, our research provides valuable insights into the significance of social media as a tool for promotional activities and customer service, while highlighting common issues in service quality perception by airline customers.

Keywords

airlines, social media, service quality, key performance indicators

1. INTRODUCTION

The growing significance of social media in the world of airline business management is hard to ignore, with the number of internet users around the globe increasing each year, with 59.4 % of world population using social media [1]. This trend is particularly evident in the airline industry, with airlines leveraging social media for purposes such as marketing, customer service, and revenue generation. The availability of social media data also provides airlines with a means of evaluating their service quality and customer satisfaction. This research paper proposes a methodology for analyzing social media channels to evaluate airline service quality. The paper examines the social media activity of 12 airlines on Facebook, Twitter, and Instagram, assessing the satisfaction of their customers with targeted KPIs. Additionally, the paper evaluates the customer service of these airlines on Twitter, analyzing their performance and quality of communication. Finally, the paper discusses the findings and compares them to Skytrax ratings, one of the most commonly used platforms for airline service quality evaluation.

2. STATE OF THE ART

2.1. Importance and utilisation of social media by airline industry

Dynamic implementation of new technologies, especially ICT, is currently typical for airline industry, in order to increase the quality and safety of provided services. Useful features of social media to airline industry include speed of change, immediate communication, and instant reply to customer's questions. Social media may be used in a long run to build a brand image, and to develop positive relationship with its customers, as well as a communication channel between airline representatives and customers [2]. Social media are also a way for airlines to promote positive word-of-mouth (e.g., indirect, by using third parties, such as customer reviews) advertising, which is one of the largest influencers when it comes to making travel decisions, and ultimately, boosting revenues. Twitter officials state that a resolved negative tweet leads to three times more revenue potential in comparison to positive tweet [3]. Social media also offers a possibility to run advertising, or other kinds of marketing campaigns. As a number of global social media users grows, running social media campaigns may be one of the most effective ways to promote airline products, thus significantly increasing revenue. social media is becoming increasingly important to marketers as it represents an effective, highly economic marketing tool which provides fast and cheap dissemination of content. Knoblich et al. described a strong affinity of the social media users towards the social media activity of German airlines. Authors of this study described the roles of social media users mostly as a passive observers and recommended that social media users should be encouraged to engage in more interactive activities [4].

Before we discuss possible ways of utilisation of social media by the airline industry, it is important to note that each social media platform has its own unique features and should be used accordingly. While Facebook and Twitter are suitable for as a tool for providing up-to-date information, and for the purposes of social media customer service (especially Twitter), Instagram and YouTube are mostly utilised as a promotional platform.

2.1.1. Social media as a tool for sustainable marketing

Sustainable marketing can be defined as planning, controlling, pricing, and distributing products in a way that meets customer's needs and organizations' goals, but also meets other regards, such as environmental, or social. As general population demands more sustainability from the airline industry, there is an opportunity for airlines to strengthen its public relations. Social media provide a suitable space for airlines for sustainable marketing activities, as social media are known as very visual communication channels, which are likely to grab user's

attention. Lehtonen states that 11 % of the studied Instagram posts are promoted to promote sustainability, while most of the studied posts promoted social sustainability (e.g. equality). [5]

2.1.2. Social media as a tool for customer communication

Technology advancement, such as the introduction of Internet, has enabled customers to participate in more interactive means of communication, and to maintain a constant dialogue between customers and airlines. One of the latest developments of such technology is introduction of social media, which led to the increase of real-time communication between customers and airlines. With the introduction of AI-based chatbots, there is a possibility to automate responses to the frequently asked questions. [6] Zhang and Lin state (as of 2015) that airlines are lacking in the area of social media communication. From the sample of 20 airlines, authors have shown 40 % response rate on airline-authored posts and 47 % response rate on customer-authored posts [7]. Social media may be also an important tool for the purpose of crisis communication, as many people may need to be informed in a short period of time. The good example of how crisis should be communicated by social media, is the case of crash of Germanwings flight 4U9525. In total, Lufthansa and Germanwings posted over 200 updates regarding the crash on Twitter. The intense and clear communication of both companies helped to mitigate the negative effect of the accident and to restore their reputation more quickly [8].

2.1.3. Social media as a tool for revenue boosting

With the rapid expansion of social media and mobile applications, the new era of digital world provides new opportunities for airline industry to promote, and to increase revenue. Since there are multiple social media, and other digital platforms, target marketing and customer analysis needs to be emphasized. 2021 Air Transport Insight states that in 2020, 88 % of the airlines were using mobile applications, including social media, for passenger services, while this figure is expected to grow in upcoming years. Airlines, as any other businesses, are using social media to obtain wide range of customers' personal information, to explore their opinions and preferences. Thus, social media can be seen as a tool for market segmentation to develop different marketing strategies for different groups of people. Social media may also be used to persuade passengers into taking revenue boosting actions. Significant example of doing so may be the 'Christmas Miracle' video uploaded by WestJet. WestJet generated 1,6 million $ in additional revenue and about 6000 new bookings from the campaign. Utilisation of social media by KLM may serve as a good example of revenue boosting through social media. Over the last years, KLM has introduced a number of successful social media campaigns. In addition, social media of KLM are being monitored non-stop. By doing so, KLM is able to generate 3 € in each 1 € spent on social media campaigns [9].

2.2. Current approach to service quality assessment

Service quality assessment is multi-disciplinary topic, which has been used in many disciplines, such as marketing, or operational management. As customers are increasingly using social media to share their experiences associated with a product, or service, exploring the customer-generated social media feed will generate rich and valuable information about the product, or service quality. It is relatively easy and cost-effective to collect a large amount of data by using social media, in comparison to traditional survey-based methods. Taking advantage of social media content to measure service quality is becoming a promising tool for business analytics.

2.2.1. Key performance indicators

In a relation to social media, key performance indicators (KPIs) can be described as a measurable metrics that displays how effectively is company achieving critical business objectives. Monitoring KPIs may provide suitable real-time overview of the social media performance. We may divide KPIs into several focus groups. Engagement refers to the amount of interaction that social media posts receive. As engagement grows, more potential customers will see company's content. Reach indicates how many people have seen company's message. Unlike engagement, the value of reach is often estimated. Leads indicate the number of engaging fans, which are interested in making a purchase. Measuring leads is a suitable tool for the purposes of market segmentation. Finally, customers refer to number of users, which made a purchase generating from social media campaigns. All mentioned groups may be represented by various constructs or indicators [10].

Measuring KPIs – current approach

In the case of social media performance of airlines, there are several KPI-based methods for the purposes of social media service quality evaluation. Leung, Schuckert and Yeung proposed a use of 13 types of KPIs in order to evaluate the 4 areas of interest: ability to connect (linkage from other apps, n. of likes) engage (mentions, posts per day, comment replies), influence (posts, shares, comments) and integrate (n. of external apps) with customers. This method, applied to Facebook pages, was used to find relation between the size of the airline's social media channels and engagement ratio of customers. Prados-Pena et al. proposed a method for examining crisis communication on Facebook. Posts of the airline, regarded as a crisis communication, were examined based on 4 areas of interest: popularity (reach, likes, mentions), customer brand (number of total posts related to crisis communication), engagement, and virality (number of shares, percentage of shared posts). This method was used to evaluate the effectiveness of crisis communication of two Spanish airlines during the COVID-19 lockdowns. Carnein et al. proposed a method for evaluation of average response rate time, and its relation to the time of the year, or other events. Response rate KPI may reach 2 values: 1 if answered, 0 if not. Average response time was calculated based on the response time of a large sample of individual posts by using API tools and MySQL database. Athari proposed more complex KPI-based method for the social media performance analysis of 4 airlines. Author used a set of 8 KPIs. While some KPIs were collected as a form of quantitative data (e.g. response rate, response time), the main method of determining KPIs was based on proving their validity based on interviews, or other sources. Based on their social media performance, airlines were divided into 3 categories. While this method is suitable for evaluating social media

competencies, limitations may include a lack of qualitative testing and a potential informational bias.

2.2.2. Examining perception and behaviour of customers

Social media has become an important tool for delivering reviews of products, or services. By looking at social media reviews, customers can quickly assess service quality of given company, as social media reviews are great electronic word-of-mouth carriers. It is important to note that social media reviews are highly subjective, hence they may provide less clear image about service quality. There is a growing concern about fake, or irrelevant reviews, which may be difficult to filter out. Currently, there is no unified approach to review-based service quality assessment [11].

Examining perception and behaivour of customers – current approach

Ma et al. described a twitter-based method for evaluation of crisis communication of United Airlines and reaction of customers after 2017 overbooking incident. This method was aimed to collect key words related to this incident (such as overbook, drag, CEO, apology...). Authors examined the frequency of the key words related to the incident during the first 24 hours. Response rhetoric of the company was divided into 7 types of answers. Following feedback from the users was divided into groups and rated based on a sentiment analysis, where higher values represented more negative sentiment. Gunarathne et al. proposed a method for examination of differential customer treatment on social media. Over 7300 tweets related to seven airlines were analysed. Each tweet was reviewed whether it contains harsh words, hashtags, mentions of other users, or URL address. Tweets were divided into several types of complaints. Authors have proposed numerical approach, describing different variables in empirical analysis. Brochado et al. proposed a method for evaluating main themes in social media reviews. While this method is not explicitly tied to service quality assessment, it helps to highlight the most problematic areas among passengers. This research used both quantitative and qualitative analysis to examine the data originating from 1200 reviewers of six airlines. Authors revealed the existence of 9 main themes in social media reviews. Each category was evaluated based on its value for money, which can be described as a trade-off between what customer gets and has to give up. Value for money for each category was rated from 1 (worst) to 5 (best) by each reviewer.

2.2.3. Effect of social media on purchase intentions

To the author's best knowledge, the ability of company to generate revenue via social media may be seen as a most significant indicator of service quality. It is often the case that while airline may have good social media service quality results by using other methods, the ability to generate revenue is lacking. Revenue generating ability may be described by a set of specific KPIs, primarily from the leads and customers KPI groups. Academic scholars have also described the ability of third parties' content to help the companies to engage with potential customers, thus increasing revenue. Despite the wide adaptation of social media, the revenue-generating abilities of social media remain widely unknown to companies [12].

Tümer et al. proposed on method for evaluating the impact of social media marketing on customers' brand trust and purchase intentions in the Turkish airline market. Authors used a method of collecting questionnaires from 365 Turkey-based airlines passengers. A set of 25 questions was used to evaluate the brand trust and purchase intention of passengers.

3. METHODOLOGY

Our research aims to assess the overall satisfaction with social media service quality of selected airlines from the point-of-view of airline passengers and social media users. We have chosen a sample of 12 airlines operating with both FSC and LCC business models, divided into three geographic markets: Europe, USA, and Middle East. We will assess social media service quality based on data obtained from Facebook, Instagram, and Twitter. Our research is divided into three main parts: analysis of airlines' social media activity, numerical evaluation of overall satisfaction with social media service quality, and evaluation of social media communication between customers and airlines. For the first and second parts, we will use KPIs specifically targeted to measure user activity and Fanpage Karma analytical tool, considering data from 1. January 2023 until 15. March 2023. For the third part, we will use data obtained from Twitter to determine the quality of social media reviews and analyze the most occurring themes in reviews and responses from airlines, considering Twitter data from 16. April 2023 until 18. April 2023.

4. SOCIAL MEDIA AS A TOOL FOR AIRLINE SERVICE QUALITY ASSESSMENT

4.1. Choice of the airlines

Table 1: Choice of the airlines, FSC segment

Airline	**Geographical market**
Lufthansa	Europe
KLM Royal Dutch Airlines	Europe
American Airlines	USA
Delta Airlines	USA
Emirates Airlines	Middle East
Etihad Airways	Middle East

Table 2: Choice of the airlines, LCC segment

Airline	**Geographical market**
Ryanair	Europe
EasyJet	Europe
Southwest Airlines	USA
JetBlue	USA
flyDubai	Middle East
Air Arabia	Middle East

Airlines examined in our research are all present and active on all types of social media, with the only exception being the presence of flyDubai on Twitter – which has not posted any content since its creation in April 2011, has the overall lowest number of followers, and does not have verified account.

4.2. Airlines social media activity evaluation

This chapter evaluates the social media activity of airlines and the efforts of their online marketing teams. It assesses the frequency of content posting using the average daily posts KPI and the size of the follower base on all social media channels. Additionally, the Advertisement value KPI is used to determine the cost of social media marketing, but only for Facebook pages due to limited access on Twitter and Instagram. The data collected covers the period from January 1, 2023, to March 15, 2023. This data is compared with other KPIs used to assess the perception of social media service quality, providing a more comprehensive view of the research area.

On Twitter, U.S.-based airlines have the highest number of average daily tweets, which is contributed to their use of Twitter as a customer service platform. In the case of Facebook, average daily posts are more constant than on Twitter, with values for the selected airlines much smaller as it is mostly utilized for promotional purposes. Instagram also sees lower average daily posts and is more suitable as a solely promotional platform, with LCC airlines utilizing it more actively than FCC airlines. Some airlines repost the same content on all social media channels. Based on the analysis of Twitter, Facebook, and Instagram accounts of selected airlines, it is clear that the number of followers is not solely related to the frequency of posting, but also to the quality of content and customer service. KLM and Emirates have the highest number of followers on Twitter and Facebook respectively, which may be attributed to their effective social media marketing strategies and strong brand image. Instagram is primarily used for promotional purposes, and airlines from the Middle East area are currently utilizing it the most. The size of an airline's Facebook advertisement budget is generally related to its size, but there is little correlation between the budget size and the number of followers. KLM has the highest number of Facebook followers despite having a low advertising budget, while Etihad has the highest budget but is only ranked fifth in terms of Facebook followers.

Analysis of the sample of airlines reveals that Twitter is the most utilized social network in the airline industry, both in terms of average followers and average daily posts. This is because Twitter is the most suitable social network for the purpose of social media customer service. Twitter is predominantly used by US-based airlines, with the highest number of average daily posts, which includes replies to customer inquiries. This supports the findings in the first chapter. Our study also found very little to no relation between the average number of daily posts and the number of followers. Moreover, there is no clear relation between the estimated size of the Facebook marketing budget and the number of followers. In this area, the quality of the content posted is likely the most important factor.

4.3. Perception of airline social media service quality by customers

This chapter presents a numerical analysis of social media user feedback on the content posted by airlines, with the aim of evaluating customer-perceived service quality. Key Performance Indicators (KPIs) such as follower growth, post interaction, engagement, total reactions, and mentions (in the case of Twitter) were used to evaluate user feedback and interaction on each social media platform. The performance of selected airlines was compared using performance analysis, with top-performing airlines being analyzed further. Data obtained from January 1, 2023, to March 15, 2023, were used for the analysis.

Most airlines experienced low follower growth on Facebook, with the exception of Lufthansa which had a 56% increase likely due to their crisis communication during airport strikes. FlyDubai had the highest follower growth on Instagram and Twitter, but the reasons for this remain unknown. KLM and JetBlue experienced negative follower growth, indicating a decline in their social media performance. Post interaction is the average number of interactions on a profile's post per follower per post, indicating the success of individual posts in encouraging user interaction. Southwest and Etihad achieved the highest post interaction on Facebook, while Southwest, American Airlines, and Delta scored the highest on Instagram. The success of Southwest's post interaction may be due to its sentimental marketing strategy, while the high post interaction of Emirates may be due to its luxury image and frequent content posting. Engagement is the average number of interactions on an airline's posts per follower per day, indicating how successfully the airline encourages users to interact. Etihad reached the highest Engagement on Facebook (0.72%), while Ryanair achieved the highest Engagement on Instagram and Twitter, which may be attributed to its unique approach to social media marketing. The values of Engagement tend to be lower than Post Interaction, as it is calculated to one follower per day. Emirates had the highest number of total reactions on Instagram, likely due to their large number of followers on the platform. However, Ryanair and Southwest also achieved significant numbers of total reactions despite having fewer followers, indicating that their content may be more engaging or shareable. Overall, the type of content being posted is likely a key factor in driving total interactions on social media.

Facebook has 7 types of reactions that represent different emotions, and for this research, each reaction type has a different sentimental value. "LOVE" was the most occurring reaction, representing 75.6% of all types of reactions, and "CARE" reactions were excluded from the analysis. "HAHA" was the most common reaction for Ryanair, as their ironic content seems to be highly effective in social media marketing. Lufthansa had a higher proportion of "ANGRY," "SURPRISED," and "SAD" reactions, likely due to flight cancellations during strikes at German airports.

The analysis shows that KPI-based analysis provides limited insight into social media users' perception of service quality. The type of social media marketing strategy employed by airlines has a stronger correlation with users' reactions than overall service quality. Sentiment and reactions are also influenced by real-time events. Overall, the analysis of reaction types on Facebook provides valuable insight into users' perception of service quality. The unique social media strategy of Ryanair improves its

online word-of-mouth, despite perceived weaknesses in service quality. Lastly, we have concluded that social media users' perception of service quality is not necessarily linked to an airline's business model or geographical location.

4.4. Examination of customers feedback

This section of the research focuses on analysing the customer service provided by airlines on Twitter, which is the most utilized social media platform for customer inquiries. The analysis will consider the number of inquiries, average response time, and the most occurring remarks of social media customers. FSC and LCC airlines will be analysed separately, and separate Twitter channels for customer service will be considered, if being used by airlines. The findings will be compared with Skytrax rating of the selected airlines.

FSC airlines received a similar number of customer requests on Twitter, with US-based airlines receiving slightly more. Delta performed the best in terms of response time and answering the highest number of customer inquiries. Complaints about the booking system were the most common, followed by complaints about in-flight service and lost baggage. FSC airlines generally avoided responding publicly to customer inquiries, redirecting them to private messaging or other means of communication. In general, average response time on Twitter has decreased compared to the findings in the literature review, with Delta having the lowest response time among FSC airlines, followed by Lufthansa and Etihad.

LCC airlines received slightly more customer remarks than FSC airlines, with Southwest, Ryanair, and JetBlue receiving the highest numbers. US-based LCC airlines tend to respond more to customer remarks than European or Middle Eastern LCC airlines. LCC airlines receive more complaints about delayed or cancelled flights and issues with the booking system, but fewer complaints about in-flight services and missing or damaged baggage. LCC airlines also receive more public praises, mainly related to good service of the staff. Ryanair faces a significant number of customer demands for compensation for cancelled or delayed flights and has been unresponsive to their requests, which could harm their service quality in the long-term and have legal implications. Response times among LCC airlines varied, with JetBlue achieving the shortest response time of 3.02 minutes and Air Arabia having the longest response time of 978.2 minutes (over 16 hours) for the lowest number of requests answered.

4.5. Comparing skytrax rating with our findings

The Skytrax consultancy and rating agency specializes in evaluating airline and airport service quality worldwide. They provide comprehensive annual ratings of airlines using a star system, where 1 star represents the worst service quality and 5 stars the best. The ratings are based on various factors, and the company is widely recognized as a leading authority in service quality assessment [13]. Our analysis compares Skytrax ratings with perceived service quality gathered from social media, highlighting three of the worst aspects of service quality for each airline. KPI-based analysis has some correlation with Skytrax ratings in terms of Facebook PPI values and post interaction, but little correlation was found on Twitter and Instagram. Analysis of customer service on Twitter provided better insight into perceived service quality, as airlines with lower values of average response time tended to have higher Skytrax ratings, and we found some association between the most occurring themes and the most problematic areas in Skytrax ratings. Our analysis shows some correlation with Skytrax ratings primarily in terms of in-flight service quality.

5. CONCLUSIONS

In summary, our analysis reveals that Twitter is the most widely used social network by airlines, mainly due to its effectiveness in providing customer service. U.S. airlines tend to use Twitter more frequently than others, with the highest number of daily posts, including responses to customer inquiries. There is little correlation between airline geographic market and preferred social media platforms, but airline size does not significantly impact social media followers, except on Instagram. KPI-based analysis provides limited insight into “real-life” service quality perception by customers, except for Facebook, which is complemented by sentiment analysis of Facebook reactions. Our analysis of Twitter customer service shows differences in customer feedback between FSC and LCC airlines, with FSCs receiving more complaints about booking system issues and in-flight service quality, while LCCs received more complaints about delayed or cancelled flights and poor customer service. The response time to customer inquiries varied greatly among airlines, with significant differences in how they prioritize and handle customer service inquiries. Finally, there is some correlation between Skytrax rating and PPI values on Facebook but little correlation in the case of Twitter and Instagram. Our research highlights the significance of Twitter for customer service and the value of KPI-based analysis for gaining insight into service quality perception by customers on social media.

It is important to note that our research has some limitations. Author was unable to obtain Twitter API access, which would allow for more in-depth analysis. Future research could employ this tool for the purpose of analysis of Twitter customer service among given airlines. In addition, the utilisation of social media by Chinese airlines, such as Weibo, or WeChat, with the respective perception of service quality among airline passengers could be examined.

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DESIGN AND IMPLEMENTATION OF ENGINE TEST DEVICE FOR THE M601 ENGINE

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Abstract

The aim of this article is to create a proposal and documents for the implementation phase of the engine test device for the Walter M601 engine, which after implementation will serve as a teaching and research aid for researching new alternative fuels, testing different variants of propellers and others. As part of our work, we are dedicated to the development of two entire future test segments of device, namely the test stand and the design of the monitoring and regulation part, where we use the original devices, manufactured in compliance with LUN, which was directly designed in the past for the M601 engine and its installation in the L-410 Turbolet aircraft. The design of the test stand will include a 3D design and documentation. The monitoring part will consist of the design of the monitoring panel, which will contain selected engine indicators and LUN sensors, which will be used from the defined solutions of specific requirements and the design of electrical wiring and power sources and modules for the operation of the monitoring and regulation part.

Keywords

aircraft engines, aircraft engine testing, engine monitoring, engine regulation

1. INTRODUCTION

The aim of development was to design and prepare an initial version of documentation for the implementation of equipment for static and ground testing of the Walter M601 aircraft turboprop engine. The specific goal is to create a test stand and an engine monitoring and regulation system. The engine test facility for the M601 engine is intended for future use by the Department of Aviation of the University of Žilina . In the future, the engine test facility will form a teaching and research aid, namely for research into for example alternative fuels, testing of various propeller variants and various others. The implementation of the design of a specific test device for the M601 engine is created on the basis of technical documents and specifications and the implementation document is created using software tools Autodesk Inventor and Microsoft Visio.

2. WORK METHODOLOGY

2.1. Outputs of article

The outputs of the work will include 3D design, documentation created in mentioned software tools. The monitoring part will consist of the design of the control station, which will contain selected motor indicator devices of the LUN series, as well as the design of the connection of the LUN motor sensors, which will be used from the defined solutions of specific requirements and the design of electrical cabling and power sources and modules for the functioning of the monitoring and regulation part. The proposal also deals with the ignition and starting system.

2.2. Archival form of data collection

2.2.1. Method of observation

We used the observation method in the design of two units of the test device. The first unit was a test stand, where we took in consideration existing solutions of motor stands for the M601 engine, which are used, for example, in maintenance or laboratory conditions. We also effectively used the observation method during browsing of Maintenance and Installation documentation, especially the Maintenance Manual of the M601 engines installed in the L-410 aircraft. Analyzing these materials using the observation method was very helpful for creation a realistic idea about used technology of used devices for control, monitoring and another modules exclusively designed for M601 engine.

2.2.2. Analysis

Based on collected information, we tried to select and apply the best practices to our solution and at the same time not to use solutions that seemed inappropriate to us. Based on analyzed information, a technical solution was created, which is in our opinion the best possible. In terms of instruments, we were convinced that the use of original LUN instruments is the most "tailor-made" solution for the M601 engine, because the instrument ranges are designed for parameters that exactly occur during the M601 standart operation. Also, the physical application of the sensors is fully compatible with the M601 engine. In this case, complications could arise with the electrical supply of these devices mainly due to some specific devices, however, after analyzing the available electrical sources on the market, we can declare that thanks to the available solutions, the implementation of the power supply is also feasible with relatively high energy efficiency.

2.2.3. Synthesis

Chronologically, We put the solutions obtained during the method of observation and analysis into one for both units, which created a unified concept and discovered mutual influences of the units on each other and thanks to it the possible complications, which were solved within the framework of constructing both units as a unified device.

2.2.4. Development with software tools

For visualization and preparation of technical documentation, it is appropriate to use software tools which are available on market. We could divide them according to the display into: 2D and 3D.

It is convenient to use 3D tools for engineering construction of parts, assemblies, and the like, in this case for the design of a test stand. The most suitable software tool for this design and the one we used is Autodesk Inventor. The Inventor program allows us also to create drawings from 3D models.

Another used 3D modeling "tool" is the SketchUp program, which is generally designed for tasks solved by architects, especially in interior design field, however due to our experience with both above-mentioned software tools, we decided that SketchUp software is more suitable for the 3D model of the control stand, mainly due to the design and structural differences compared to the test stand.

2D tools are suitable for creating drawings and documentation such as electrical diagrams or for visualizing functional contexts. Here we consider it appropriate to use tools such as Microsoft Visio and AutoCAD, where both software are used in practice for the above-mentioned activities.

Visio is more suitable for drawings of functional relationships, layout of modules in a rack or a drawing of the location of devices on a monitoring panel. AutoCAD is more suitable for monochrome display such as electrical diagrams or component drawings. From our point of view, we would say that Visio is more suitable for documentation created for a more layman's view, for example also for the creation of documents such as system descriptions, maintenance or assembly manuals, and AutoCAD is more suitable for implementation drawings, where the documentation will be used mainly by professionals.

Considering the future purpose of the test device, we agreed about that it is more appropriate to use the Microsoft Visio software.

3. TEST STAND AND ACCESSORIES

3.1. Test stand

During designing the test stand, we determined that the first step which is requiered shall be the design of the engine mounting itself. For this part of the stand, while gathering information, we found out that there are anchor points on the engine to attach the engine itself to the aircraft, which were designed to be attached to a 60cm diameter ring made of steel tubes. Such a ring, based on the location of the anchoring points, was used in addition to the L-410 aircraft also in test or laboratory stands for the M601 engine, and therefore basically, in the design of this component, there were not many options to implement this specific attachment in a different way than with a similar ring.

To attach the ring to the stand itself on the bottom side, two welded steel plates with a thickness of 5 mm and a rectangular shape with a size of 280x100 mm will be used, which will form a monolith with the ring. Holes with a diameter of 10 mm will be drilled in each plate. We chose the spacing of the holes at 150 mm, which will be intended for the screws connecting the body of the ring to the log profiles forming the stand. During the manufacture of the ring, a cut is made in the ring at the location of each plate. A plate is placed between the two parts divided by the cut, and a weld joint is formed on each side of the plate with the cut surfaces of the ring using MIG technology.

On the upper side of the ring, the ring will be fixed to the stand by means of a pair of sleeve fixing elements, each consisting of a top and a bottom part. The lower part of the sleeves forms part of the upper horizontal beams, and the upper part forms a separate element, which will be connected to the lower part by means of a pair of M10 screws and nuts, which, after screwing, will create a sufficient compression of the upper and lower parts, so that the surfaces of the ring and the bearing surfaces of the sleeve fastening elements they press sufficiently and secure the ring. The spacing of the holes for screw connections is 60 mm.

During the development of the test stand, there was a decision that the test stand should also allow the measurement of the generated thrust in a certain way, for example in the future when testing different types of propellers. In order for this idea to be realized, the separate stand and especially the motor cannot be fixed firmly, but the engine has to have freedom of movement in the longitudinal direction. Based on knowledge and experience, we decided to use a linear bearing, which on the one hand will create a solid mechanical connection between the separate stand and the base, but at the same time we will achieve freedom in a certain limited range, which could be fully sufficient for the needs of the mentioned measurement.

However, due to the size and weight, we discovered during development that the use of linear bearings is not suitable, as they are more suitable for applications with smaller loads, especially weight.

A suitable solution for the required specification is the use of so-called linear guides, sometimes referred to as carriage guides. These linear guides are basically developed for the use of higher heavy loads, mainly because the contact surfaces on which they move have an order of magnitude larger total area and thus the total pressure load is lower.

For a specific implementation, we decided to use linear guides from the manufacturer Fisatech, where we decided to use the SGL45HTE type guide block. The use of this particular type was conditioned by the fact that only SGL series from this manufacturer is available with lengths over 1000 mm. The second reason is that we probably have the largest contact area of the selected guide blocks, where we see a benefit in distributing the load over a large area, which has a positive impact on safety, but also on the durability of the attachment[6].

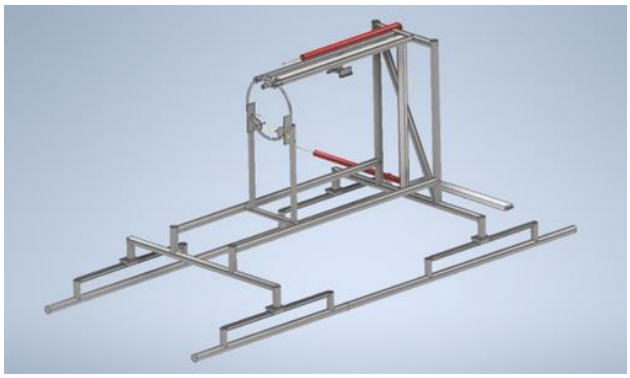


Figure 1 - Test stand with implemented guide block

The test stand is also equipped with cable duct and protected fuel line. The input for cable duct is placed in the lower left part of stand, where the bundle from control station is connected. On the right side, there is fuel line from 1000 l fuel tank which use DN19 antistatic pipe up to the place of separation, where the diameter change to 15mm steel flexible pipe which is protected by red aluminum protection pipe. The 15mm steel pipe is used because of inlet of used fuel control unit LUN 6590.05-8 FCU.

3.2. Control station

During the design, we decided that controls and control station won't be directly part of the test stand but will be implemented by a separate device that will be placed outside the test stand. From our point of view, this brings several benefits, especially from the point of view of health and safety, since the personnel who will operate the test equipment and the engine are at a safe distance from the working engine and propeller, which fundamentally reduces the potential for injury caused by indiscipline, failure of a certain part of the engine and propeller and also against the negative effects of exhaust gases, whether chemical or thermal. In addition, the negative impact of vibrations and noise, which will affect the operator's human body when the unit is working, is partially reduced.

The effects of the produced heat and vibrations also have a negative effect on electrical power supply devices, as they are not designed to work in such conditions and their service lifetime is shortened.

That's why we decided that part of the control post will also include an electrical distribution source, respectively a switchboard used to distribute and adjust electrical energy for the needs of individual devices and a battery used to start the engine. The placement of indicator and control devices in the control post is of course logically since the control post is intended for control and monitoring and therefore this equipment will be installed in this post as well.

The transmission of electrical energy and signals will be realized by a cable bundle, which will form a line between the control station and the test stand. We decided to use bundle due to require freedom of movement of engine on the test stand during the thrust measurement, so we weren´t able to use some fix solution. This bundle with predesigned length of 10 meters will transmit signals from the measuring sensors to the indicator devices in the control station and at the same time will serve to power the measuring sensors and supply control signals and power to the linear servo drives that control the displacement of these servo drives.

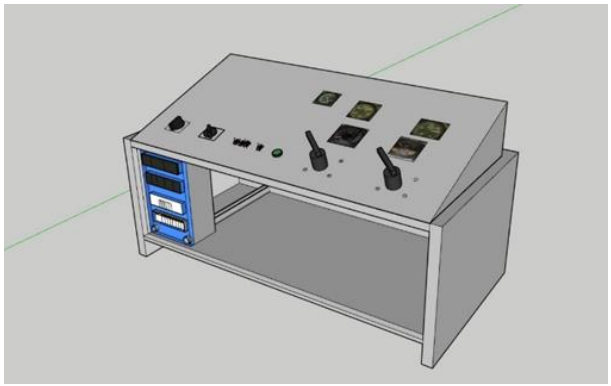


Figure 2 - Control station

3.3. Connection box

For the operation of the control and monitoring part, it was necessary to prepare and ensure its power supply. As we generally know, it is necessary to consider the specification of the devices that will be powered when designing the power supply. We are talking mainly about the type of current, whether it is direct current or alternating current, where it is also important to consider the frequency and also whether it is a harmonic or PWM type of signal. Last but not least, it is important to clarify what peak or working performance we can achieve in powered devices, based on which we have to choose the elements of the power supply system appropriately, including elements that ensure protection against overload or short circuit and of course the cross-sections of the wires through which the currents will flow.

The source of electrical energy for the test equipment will be the distribution network in the form of a single-phase 230V/50Hz power supply in the TN-S system from local distribution networks at the testing location. The supply line will be realized with a copper flexible cable H05VV-F 3Gx4, which will be connected to the distribution network via a standard plug and at the other end will be connected to the Hensel Mi 1444 switchboard with IP65 protection, which will be installed within the control station. The cores of all cables and wires mentioned in this proposal are made of copper.

At the input of the electrical circuit of the switchboard, a combined residual current device with circuit breaker, a RCD1 will be placed, which will ensure the protection of the entire control and monitoring part against short circuit and overload using the fuse part, and protection against electric shock will be provided by the residual current device. We decided to choose the residual current device mainly because of the relatively "delicate" environment in which the test stand and parts of the control and monitoring part can be placed during operation, namely: high temperature environment, humid and wet environment in combination with a metal structure, where it is not possible no way to make a double-insulated implementation.

For additional protection against short circuit and overload we implemented circuit breakers FA1-FA8 for AC input of each circuit and fuses FU1-FU8 for DC section of circuits.

As for the AC/DC sources, we chose the manufacturer Traco Power, specifically the TBL, TPC and TXH series, which are intended for industrial automation and suitable for installation in a switchboard with mounting on a DIN rail, except for the TXH series, which will be attached to the control station with steel profiles. Sources intended for mounting on a DIN rail will be placed together with safety elements in the Hensel Mi 1444 switchboard within the control station. Based on the required voltages of 12V and 28V DC, we decided to use three specific types. The 12V power supply will be provided by TBL 150-112 type with 120W power at 84% efficiency and TXH360-112 type with 360W power at 89% efficiency. We implemented the 28V power supply using a TPC 120-124, with a power of 120W and a voltage range of 24 to 28.8V. The efficiency reaches 87% [8].

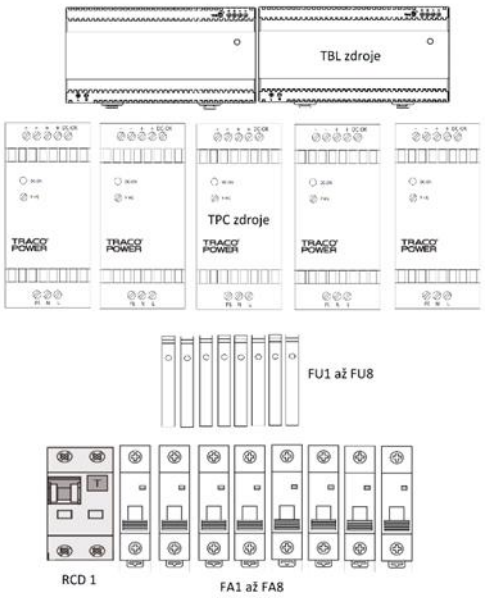


Figure 3 - Design of Connection Box

3.4. PWM regulation

Engine regulation is performed mechanically in the rear part of the engine, in the part where there is space for auxiliary aggregates, through the already mentioned complex device LUN 6590.05-8 FCU, on which the intake regulation is carried out with a mechanical tie rod. Unfortunatelly, our specimen of M601 doesn´t allow us to use any FADEC solution.

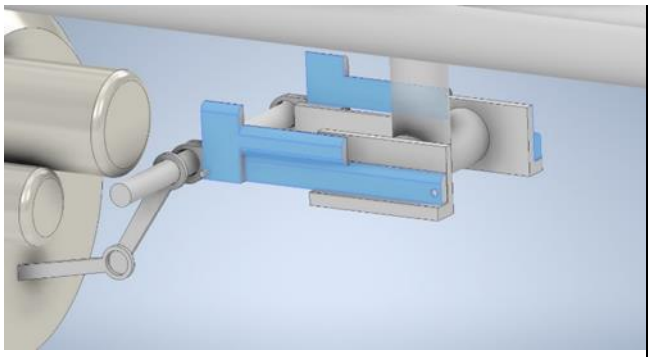
For this particular implementation, we decided that the control rod will be moved by means of a linear servo drive, which will change its extension/retraction and thus also the position of the control rod through the PWM signal. As part of the research on the servo drive market, we can find different variants of servo drive displacement regulation. This is usually either via limit switches or timers, but the position can only be set at points where the switch/time positions can be realised, the direction is set by changing the polarity of the supply and the displacement speed is fixed. In the case of PWM regulation, the advantage is that the exact shift position can be set without the need to define a specific point by a certain element, but the exact length of insertion/extraction is defined at a specific position of the rotary controller. The direction and speed can also be regulated using the rotary controller, where these quantities are defined by the direction and speed of rotation of the rotary controller. Such regulation is carried out by electronic PWM regulators, which create a pulse-width modulated signal based on the position of the rotary controller from the DC power supply.

As a PWM controller, we decided to use the so-called goBILDASERVO COMMANDER, which just provided PWM regulation for such an implementation by its design. In order to function and especially to generate a PWM signal, it is necessary to provide power in the voltage range from 5 to 15V at the terminals marked + and -, on the bottom of module. The generated PWM signal reaches the regulated device through the three-pin connector on the upper part of the regulator.

So, as a linear servo drive, we decided to use the HDLS-4-30-12V type, which is a servo drive that can be controlled by a PWM signal and has an additional 12V DC power supply to ensure the same performance and displacement force. This particular type has a maximum travel speed of 0.762 cm per second, which is one of the lowest speeds on market. We chose this variant, as we think that high precision is necessary for the regulation of the mentioned rod, and the choice of a faster servo drive would be counterproductive [15].

In order to maintain a sufficient degree of redundancy, we decided to use a pair of these servo drives to control the tie rod, where both will be mechanically connected to the tie rod, but only one will be active at the same time.

So one will be the main servo drive and the second servo drive will be a backup, referred to as back-up. The reason why we decided to duplicate this servo drive system is that if, in the case of a working engine, there was a malfunction in the main PWM control circuit, either on the electrical wiring and control, or on the servo drive itself, it would not be possible to control, or safely under safe conditions and circumstances reduce power to at least idle mode. The engine would be in this state of very limited control, controllable only by blocking the fuel supply with a valve, which would make it possible to bring the engine and equipment into a safe mode. However, apart from the safety point of view, this is also not suitable due to the long-term service lifetime and technologies of the engine, namely for turbines and shaft bearings, as when switching off in nominal or maximum mode, without prior smooth cooling in idling mode, such a sudden shutdown could mean a significant weakening of the components, respectively affecting the structure of the turbine material or significant carbon deposits on lubricated surfaces. Of course, if such a scenario occurs, it may not automatically mean its immediate damage or destruction, but it is advisable to minimize it, as it is not easy to predict when for example the structural and fatigue state of a certain component will occur.



Fiure 4 - Principial 3D model of Linear servo drive

4. CONCLUSION

We think that with the outputs of this article, we have created a guideline and a solution for a test stand that will fully serve its purpose, will be safe and reliable enough for test operation, and will be able to be comfortably operated by an operator who has lay knowledge of electrical engineering and at the same time, it will offer sufficient modularity for all possible future experiments and modifications. We are satisfied with the design of the test stand and we think that my design represents a mechanically solid solution that also allows the desired measurement of the generated thrust due to the implementation of linear guides. Regarding the storage and supply of fuel, in our opinion, it was really impossible to find another better solution for the given conditions. The issue of supplying not only fuel but also electrical signals resulted from the need for physical freedom of the engine and the observance of certain safe distances from the working engine, and therefore it was necessary to use a flexible hose of 10 m length and also a cable harness of the same length, which are not additionally protected in any way due to mechanical flexibility. We tried to protect the fuel pipes and cables, at least in the most critical place, near the engine, on the structures from negative influences as much as possible. We tried to design the control station intuitively and ergonomically and from our subjective point of view this declared solution is correct. The advantage of the design of the control post is also that the question of the location of the distribution switchboard for electronic systems was solved relatively easily. We are extremely satisfied with the used AC/DC sources, which have very compact dimensions, very good operational and electrical parameters for the given implementation, including efficiency, and almost all of them could be placed in a common switchboard. During the design, we tried to make the electrical part as simple as possible for maintenance, not only for its implementation, but also for the price and the possibility of supplying spare parts, and therefore in the end we decided not to use the technology of IGBT transistors in the starting system for switching, since the auxiliary electronics, which would solve the regulation of this transistor would be too unnecessarily complicated, especially for maintenance. However, the truth remains that the used relay solution is also quite complicated, which was mainly caused by the very specific switching parameters of the coils and it is energetically extremely disadvantageous due to the need to use a source with a power of 300W, but its activation and function will take a few seconds, so the energy efficiency is negligible, which refers to the consumption of electricity and the advantage is that the circuit consists of really simple and accessible elements, without the need for special tools and possibly even a layman can handle the repairs. It was quite difficult to solve the motor regulation, which for a specific piece of the M601 motor can only be solved mechanically via the LUN 6590.05-8 FCU module, and therefore it was necessary to come up with a mechanical solution. That's why we decided to use linear servo drives, which thanks to PWM regulation allows us to control the shift very precisely and intuitively. Here, we also tried to ensure sufficient redundancy of the regulatory and execution elements of the regulation to ensure sufficient safety. Within the given conditions, we think that is the only possible solution and we really cannot imagine any other more suitable solution with the used LUN 6590.05-8 FCU control module. For monitoring engine parameters, we decided to use LUN devices, which we found suitable, especially with regard to the interval of the displayed parameters, which are precisely within the operating parameters of the engine and at the same time are compatible with LUN sensors, for which holes/mounting places are also created on the engine . It was also relatively easy to design a power supply system for these devices through AC/DC sources. The last system solved was the ignition system. However, after inspecting the engine, it was obvious that there was no point in developing a solution other than using the existing ignition system, where it was only necessary to supply a source and cabling for the 28V DC power supply. In conclusion, we would like to add that this proposal represents the initial or basic version of the test stand, however, in our opinion, this proposal has a wide variety of modifications for selected testing and great possibilities for improvement in the future, at least within the electrical part. Namely, we thought of modern technologies such as FADEC for regulation with newly designed fuel control unit, or the use of digital recording devices, for example using cloud solutions for long-term monitoring and many, many others.

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ANALYSIS OF THE IMPLEMENTATION OF PART-147 IN THE ENVIRONMENT OF AIR TRANSPORT DEPARTMENT AND AVIATION TRAINING AND EDUCATIONAL CENTRE

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Abstract

The following article is announcing author analysis of EASA Part 147 regulation and its application for the creation of the Maintenance Training Organization under Aviation Training and Educational Centre (ATEC), and Air Transport Department (ATD) in the University of Žilina (UNIZA). Introduction of article includes main targets and methodology of its processing. In the beginning of the work, it deals with theoretical outcomes derived from current regulations relevant to Part 147 with corresponding Applicable Means of Compliance (AMC) which brings essential basics of the MTO. The main part consequently elaborates substantial chapters with direct overview of conditions and requirements to be fulfilled by personnel, environment and full scope of manuals and procedures included in the facilities of UNIZA located in the Airport Žilina. Upon current (existing) conditions it identifies all requirements to be implemented in MTO to satisfy its initial audit and certification. To the most practical outcome of this article belongs MTO manual processed in line with all regulations and their local implementation on the ATEC and ATD environment including training modules and training conditions for on job training itself. In the final chapter there are instructions and recommendations for MTO development as well sustainability of the processes to satisfy also the students' knowledge, skills and abilities for their future transport Authority examination and also for their successful applicability in practice.

Keywords

maintenance, training, environment, manual, handout, Part 147, EASA, regulation, education

1. INTRODUCTION

The aim of this scientific paper is to examine the introduction of Part 147 in the Aviation Training and Educational Centre (ATEC) as a combined organization under Part CAO with the participation of the Air Transport Department (ATD) in the University of Žilina (UNIZA). To achieve the desired result, it is necessary to use methodology of acquisition, consolidation analysis of the current state data. Such base is followed by processing of real scenario using induction and deduction to reach desired conditions. Firstly, we used the method of analysing the current state of Part 147- related regulations and context. Subsequently, we dealt with further analysis assuming LVVC organization CAO activities to be extended to compliance with Part 147 regulations in order to be able to fulfil the requirements and to adjust required needs. From this point of view, we chose another specific method of creating a SWOT analysis that could outline the strength and opportunities of the current background, coupled with treats and weaknesses that could occur in the implementation phase. The last issues of this article are the output, which already evaluates the final results of the research and dedicated proposal for ATEC Part 147 manual in the wording of the latest changes and additions.

2. LEGISLATION DISCUSSION

The first legislative debate included problems related to general aviation, where the general aviation community had a problem with excessively expensive and long courses at certified maintenance training organizations. This was particularly the case for ELA1 aircraft, where a category B2 license requires up to 2400 hours of training and mostly people who obtained this license had no incentive to devote themselves to aircraft used in general aviation, which meant that there was a shortage of personnel able to maintain their aircraft in the required condition. As a result, a B2L category license was created, giving general aviation access to more licensed maintenance personnel. As a result, new maintenance programs had to be developed in certified maintenance organizations, thus creating new course developments and new job opportunities [1].

The reason for adding and defining this update was EU Regulation No. 1142/2018, which defines in new tables the minimum duration also for the B2L license, stating that the number of hours may be increased depending on the selected qualification of the additional system. For this reason, an additional table has been drawn up, which is presented in our work as table No. 3. This table presents the minimum duration (in hours) and the proportion of theory for individual systems such as COM/NAV, instruments, automatic flight control, surveillance and airframe systems [2].

The second legislative debate addresses the problem of so-called unofficial refresher courses, which certified maintenance training organizations practiced and guaranteed students would pass theory and practical exams in less time, which posed a safety risk because the personnel could commit releasing an aircraft into service without having the basic knowledge required by regulation. The solution was to modify the competences of the maintenance training organization, namely that the organization must not conduct tests on behalf of the competent authority. However, it may conduct examinations on its own behalf for its students who have attended the organization's maintenance training courses or for students who have not attended type training and basic training. It also discusses the choice of a site that must comply with the

certificate or permit and questions from the European Central Question Database (ECQB), setting these questions by the competent authority if it is not available [3].

Another legislative discussion that includes broader views for Part-147 is from 2016. It addresses the issue of the implementation of a safety management system (SMS) in the field of maintenance, focusing on Part-M, but in a way also intervening in maintenance training organizations, because they have found that these organizations should also have an SMS system. This creates a requirement for maintenance training organizations to create a new nomination of a person or group of persons for this segment to monitor stimuli. Of course, this implies the obligation to further certify these persons [4].

One of the most recent legislative discussions, which is currently in the approval process, solves several problems that have arisen. The first problem that has arisen here is similar to what has been dealt with in general aviation, but this time it deals with Group 1 aircraft, which are morally and technically obsolete and certified maintenance personnel are no longer available for these aircraft, and maintenance training organizations do not provide such type courses due to costly constraints, or due to lack of interest. The second problem relates to updating individual modules of training between different licensing subcategories. The third problem relates to on-the-job training, where they found that there was a problem with the doubled requirement for license confirmation, which was causing duplication. The fourth problem concerns Part-147 in terms of new training methods and teaching techniques. As aircraft technology evolves forward, it is necessary to adapt to this trend. This means that, in line with Part-66 and Part-147, the creation of new type courses to provide future maintenance technicians for aircraft is important, as Regulation 1321/2014 itself does not reflect the current developments and training tools described in the legislative debate. By having a pandemic period here, it was found that the regulation did not allow teaching outside the maintenance training organization for type courses. It was also found that Part-147 does not list specific practical aids that should be applied when appropriate practical aids are used, with a lack of integrated procedures. However, it is also a problem that the current regulation does not allow combining different training methods in order to improve the effectiveness of courses in a maintenance training organization. Emphasis also applies to multimedia training (MBT), which does not yet have sufficient criteria for implementation [5].

If we look at this legislative debate even more closely, we can see that it regulates the requirements for the organization and in such proportion that it not only strictly defines closed spaces for training processes, but also the possibility of a virtual training environment. Of course, this does not apply to the theoretical and practical exam, which should continue to be in face-to-face form. It is also the responsibility of the maintenance training organisation to inform the student of the form of training under what conditions and in what environment it will be conducted before the start of the course [5].

The organization should develop or acquire so-called maintenance training simulation devices (MSTDs) to replace artificial training equipment. Also, distance learning requires the maintenance training organization to be equipped with the means provided for this purpose [5].

The duration of distance learning has also been influenced by teaching materials, which should be recently available on suitable media (CD, USB, server database, etc.). The student must have access to the materials intended for training during his course. Thus, the maintenance training organization is required to provide material in an appropriate form for the presentation of the teaching materials, or to provide the hardware and software appropriate to the course for its students [5].

Within the examinations carried out by the maintenance training organization, the concept of supervised environment is added, with the condition that the exams should be carried out only in such an organization that is certified and regularly audited by an independent inspection body (the Transport Authority of the Slovak Republic) as well as carefully secured materials for conducting the exam to prevent their theft or misuse for the benefit of the student [5].

The length of extension courses will also be shortened depending on the courses, as distance learning and the combination of some basic elements will be allowed, as well as the possibility of more individual plans for students. The terminology will also be changed and the word "examination" replaced by "summary of type/basic training" [5].

3. ORGANISATION REQUIREMENTS

In general, lecturers who wish to teach in a CAO organization with an approved Part-147 organization should meet the basic requirement of competence with Part-66. Competence in this case implies that such a person has knowledge of the issue, has experience in aircraft maintenance and a positive attitude. Knowledge must be demonstrated by the final Part-66 examination. The evaluation of what is expected of the instructor is mainly that the instructor should know what training procedures to choose correctly and how to carry them out in order to meet the conditions and course tasks. He should also be familiar with the pedagogical approach. This person should be able to know well the environment (application of protection and safety at work) in which he will conduct lessons of training. Lecturer shall understand the individual systems which are included in the courses, also he should be able to explain how the systems work, describe their functionalities and how to handle with them as part of maintenance. He should also have knowledge in areas that require higher professional attention, such as specific locations typical to the type of aircraft and experiences which are typical for practical training and they should not be trained on simulation devices. That person should be able to use, read and interpret the records. It is also necessary for the instructor person to be able to read the relevant aircraft documentation, to navigate in it and to perform the prescribed maintenance procedures. They must to be able to perform maintenance to demonstrate the safe maintenance and operation of aircraft, engines, components and the selection of the appropriate tools. Last but not least, to create a record of the maintenance performed and test whether the aircraft meets the parameters that comply with the regulations. It is important to take into account the following training attributes: clarity, efficiency, time availability (flexibility), suitability (adequacy), constructiveness and proper organization. But how to achieve this? EASA advises that it is necessary for the organization to ask itself a number of

questions in order to achieve the above attributes [6]. Those questions are as follows:

- What are the success factors for the job?
- What are the typical characteristics for a task to achieve compliance?
- What criteria should be observed and focused?
- Is there a standard available according to which the task, maintenance, is to be conducted?
- What is the pass mark (minimum point that meets the requirements)?
- What minimum and maximum time do we need to reach the goal? Efficient use of time.
- What if an aircraft maintenance technician student fails to meet the requirements? How often will such a fact be allowed to be admitted?
- When and how will an aircraft maintenance technician student be ready for assessment?
- What proportion of instructor assessment outside of student collaboration is needed during the assessment phase? [6]

It is these questions that can facilitate access to how an organization should approach both personnel issues and other issues, such as scoping and content training itself, or at least be inspired by them. It is always necessary to include all the factors that go into it.

3.1. Classrooms and spaces in the organization

Currently, ATD is equipped with a sufficient number of classrooms for theoretical training of maintenance technicians. It shall also meet the parameters for a sufficient number of administrative premises required for the purpose of offices and rooms to hold all records that require retention. In the case of conducting practical training, both the ATD and ATEC have at their disposal premises and hangars in which practical training of maintenance technicians can be carried out. The library requirement is also met, because currently there is a central library for the entire university at the university premises and a second aviation dedicated library, which is located in the UNIZA building at the airport in Dolný Hričov, where ATD lessons are carried out and at the same time there are also ATEC premises, including maintenance hangars. However, we cannot specify whether this library contains all technical materials, because we cannot verify it in this state of art and it will be necessary for the formation of this organization to carry out a search and necessary additions. However, we can say that most of the technical materials (hardware) are already included in this library [7].

3.2. Equipment and tools in the organization

From the point of view of equipment and maintenance tools, it is important that inspection and regular calibration to standards is allowed, as these tools are expected to be used for day-to-day basis. These tools, which are used on daily basis, should be inspected at least once a year or every 100 hours of work with tools that may be calibrated as a result of the performance of the work. Each of such checks shall be recorded by the organization. The availability of these tools should be ensured by the organization [6]. There are also available the fleet of real small aircraft on which maintenance is carried out and our opinion is that they can be also used for training aircraft maintenance technicians. We had consulted this fact jointly with the head of the diploma thesis, who confirmed that the current CAO organization performs comprehensive maintenance performed on ATEC aircraft fleet. In addition, decommissioned aircraft are also available, so it is possible to carry out the assembly and disassembly of aircraft units on them, including engines, propellers, landing gears, wings, avionics, etc. From this point of view, we can say that the organization meets the requirements required by the regulation for basic training of maintenance technicians. If we intend to meet the requirements of higher categories with type training, specific types of larger (complex) aircraft and engines would have to be available. However, we will not be currently focusing on such type training within the Part-147 organization [7].

4. SWOT ANALYSE

Strengths

The biggest strength this organization will have is that it will be part of the university. This means that it will have technical and material resources in terms of appointing a responsible manager, because universities generally have some exemption from the regulation in this case if a competent person is appointed. In addition, it has the possibility of teaching, i.e. it has the means to provide teaching with high quality and more comprehensively than defined by the regulation. By creating an organization in an environment of cooperation between ATD and ATEC, it is ensured that qualified management is available in these institutions who have experience and are able to meet the conditions of the regulation. Another very important strength, however, is that there is the potential of a quality organization for maintenance training due to the existing CAO and high standard of training, and therefore they tend to move this organization to the highest quality. The size of this organization can also be an advantage, because we cannot consider it as large organization, which can be a considerable positive [7].

Weaknesses

The mentioned size can also be positive, but we also consider it to be partly negative, i.e. a weakness also because a smaller organization may not have such a large impact on those interested in training aircraft maintenance technicians. However, we consider a significant weakness mainly the incompatibility of some theoretical areas that should be integrated into teaching, i.e. it is a weak point with a temporary period, since it may be eliminated in the future. On this we can capture students, i.e. create an imaginary "sieve" through which potential candidates can get through, and also by such a step secure and increase the competence of future personnel if they successfully complete the training. It is also worth mentioning the LVVC fleet, which is sufficient for basic training, but we consider this to be a potentially weaker point, because if the organization had more technical resources at its disposal (meaning more complex or complex aircraft), it would ultimately

be much better for it because of the attractiveness for potential students of technical aircraft maintenance. A smaller organizational weak point we also see the location where most of the teaching is carried out, which is the Dolný Hričov airport. Accessibility to this place is comfortable only from the point of view of passenger road transport and this method can attract potential clients who currently do not have a personal means of transport for various reasons. In the future, there is a need to carry out research and provide other forms of transport, whether in terms of buses, or a closer train stop, which could be created and later operated at minimal cost [7].

Opportunities

In the occasions we have written 4 points that we consider to be possibilities that are necessary nowadays or will arise by creating a maintenance training organization. Currently, we have noticed a significantly increased demand for aircraft maintenance technicians and based on current trends, we can assume that this demand will continue to grow instantly. So the creation of such an organization has justification. We can say that these technicians will not have a license valid only in the territory of the Slovak Republic, but in all organizations that meet the requirements of EASA, especially within EU member states. An opportunity that we can really define as significant is the possibility of using sub-contractors. This means that if an organization meets the theory requirements for categories for which it will not be able to provide practical training, it can create new specialized courses under contract with sub-contractors. Also, in the event of a shortage of staff, it is possible to employ instructors on a temporary basis, but must have a sufficient minimum number of staff (13). However, good cooperation remains a strong motivation, where all parties involved will benefit. The creation of an organization according to Part-147 will help not only the organization of LVVC but also the whole university from the point of view of research, when the university can directly participate in research activities and will create not only a positive reputation for the organization itself, but also for UNIZA abroad [7].

Threats

In threats, we have defined only 4 points, which are often repeated, but need to be correctly identified. First of all, a fundamental threat that can occur practically anytime there is a world crisis in any proportion. We have overcome the Covid-19 crisis, which has receded over time and negatively affected virtually all sectors. Currently, the war in Ukraine is still ongoing, which also affects the entire continent of Europe and other potential disasters that may arise. Another threat can be significant inflation and rising costs, when the company can become insolvent and get into a problem that it may not be able to control. The way of changing and supplementing new technologies can also be a threat, for which the organization may not have sufficient resources to adapt to new trends. This is also related to legislation and amendments to regulations, due to which the organization will have to suspend or terminate its activities in view of new conditions that it may not be able to fulfill. Therefore, these threats are very sensitive and also in general, but it is necessary to always be alert and monitor what is happening so that we can partially eliminate these threats [7].

5. CONSLUSION

The final evaluation of our work leads us to individual points, which we state in the conclusion. The context of the work includes the application of specific regulations that define the organization for maintenance training. These rules are often accompanied by additional documents that already specify individual interpretations of the regulations. They include the essence of the application, and some provisions are described in more detail, and others less so. In this we see the space that, from the point of view of maintaining the safety and airworthiness of aircraft, the approach of the institutions concerned is, from our point of view, not exactly the strictest and has significant gaps that should be identified more directly by the organization itself. It is good that some institutions are merging these regulations into one, because over the years, as legislation changes and is updated, it is issued separately with each and every change.

The findings that we have identified in this article in the case of the theory currently performed at the university were partially surprised us, since we had identified significant differences that, in our opinion, act negatively, that is, to the detriment of the creation of quality teaching of the theoretical component according to Part-66. This is not to say that the ATD and ATEC will fail to form an organization, but to point out specific problems in the mismatch of the thematic areas of the theory that can be eliminated by reconciling the future change that will have to occur to ensure that the curriculum is as consistent as possible with those required by the regulation.

However, we are giving a big warning finger especially to the competent authority, which is responsible for inspections and stable support for all regulations, because there we have found that since 2016 the procedures for setting up a maintenance training organization have not changed, while legislation has also changed in this area, in particular by identifying new and old teaching methods as well as aids, which are suitable for each and every method. From this point of view, the Transport Authority does not sufficiently ensure a quality procedure that would include new teaching techniques. We also confirm that the procedure developed by the Transport Authority in the mentioned year 2016 does not mention a number of issues regarding practical training. However, we know that even the regulation does not directly define the specific steps towards this task. Therefore, we recommend that the competent authorities begin to think about the question of how to set an indicative period of practical training in the organization in accordance with Part-147. Specifically, we analyzed this problem, and it was precisely because of this absence that we could not make adjustments to the curriculum for practical training.

The aim of this article is not only the solving the problems, but through the provided SWOT analysis, we also point out a state that, after some shortcomings, can be useful for all parties involved. Through the performed analysis, we found out that the organization for maintenance training has the potential of a quality and successful organization not only from the point of view of normal operation, but also by being part of the university and can confirm its justification by cooperating with ATEC and ATD on the basis of research and improvement of maintenance processes.

Our final assessment of whether it is possible to create a maintenance training organization under ATD and ATEC conditions is yes, it is feasible and possible, it is a must to meet the requirements of Regulation Part-147 in accordance with Part-66, which is essential for the certification of aircraft maintenance personnel. That is why we have also updated the relevant maintenance training organization manual in the appendix, which is already up to date with the regulation.

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AN ANALYSIS OF THE OBSERVATIONS AND EXPERIENCES IN REGARD TO THE NEW FORMAT OF SNOWTAM REPORT

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Abstract

This paper presents a new ICAO methodology for assessing and reporting runway surface conditions, commonly known as the Global Reporting Format (GRF) and its impact on flight crews and airline operation. It explains the background of the system and its effect on safe operation. Furthermore, it compares the current format of the SNOWTAM message with the old one applicable until November 2021. It also presents research which aims to enhance winter operations safety by gathering observations and experiences with the new format of a SNOWTAM report applicable as of 2021. The paper points out the experiences of flight crews gathered with a survey created by the author of this thesis. It also summarises the impact of the new methodology on airplane performance calculations backed by the research. The new system is expected to provide better understanding of the runway situation and give clearer information about contamination of the movement area.

Keywords

SNOWTAM, GRF, winter operation, RWY conditions

1. INTRODUCTION

International Civil Aviation Organisation (ICAO) considers runway safety as one of the top three priorities in their safety program. The goal is to reduce a number of runway (RWY) excursions. Roughly 90% of such incidents occur on contaminated runways, where the RWY is slippery because of wetness, snow, slush, or ice [1].

ICAO introduced a new methodology of Global reporting format (GRF) which replaced existing system of reporting runway conditions from November 2021. The new system covers new methods for assessing and reporting runway surface conditions. The introduction of GRF represents a source of change to each State's aviation system [2].

2. WINTER OPERATIONS

Winter and snow can be a source of frustration to airports, crew, and passengers. Beside snow coverage on ground, ice on the wing can reduce lift by as much as 30% and increase drag by up to 40%. This can result in a significantly negative impact during the takeoff roll [3].

2.1. Runway excursion

Furthermore, contamination on airport RWY and taxiways (TWY) causes increased drag on aircraft wheels when taxiing and reduces braking effects. During landing, the necessary distance to stop the plane is extended, while the braking can be different compared to dry RWY [4]. It is therefore the duty of airport operators to keep these areas clean, without any visible dampness.

A runway excursion is defined as a "veer off or overrun of the runway surface", which can happen during landing or take off [5].

The International Air Transport Association (IATA) has performed a study of incident and accident. They reported that between 2005 and the first half of 2019, 23 percent (283) of accidents in IATA's global accident database involved a runway excursion [6].

European manufacturer Airbus has developed the Runway Overrun Prevention System (ROPS) as a response to runway overrun events during the landing phase. ROPS takes into consideration external elements, such as change of wind velocity and direction, and evaluates whether the aircraft can safely brake on the remaining length of the runway [7].

Technological development can easily help pilots to understand the runway situation and adjust their decisions during final approach segment.

2.2. Runway contamination and Snowplan

ICAO defines runway surface conditions in document PANS-Aerodromes (Doc. 9981) as well as ICAO Annex 14 – Aerodromes.

a) "Dry runway. A runway is considered dry if its surface is free of visible moisture and not contaminated within the area intended to be used.

b) Wet runway. A runway is considered wet when it is covered by any visible dampness or water that is 3 mm or less in depth.

c) Slippery wet runway. A wet runway where the surface friction characteristics of a significant portion of the runway have been determined to be degraded.

d) Contaminated runway. A runway is contaminated when a significant portion of the runway surface area (whether in isolated areas or not) within the length and width being used

is covered by one or more of the substances listed in runway surface condition descriptors." [8]

Airport operators have to be ready for winter operation as well as flight crew. The winter organization and airports Snowplan have to prioritize the cleaning procedures in coordination with air traffic control services [4].

The new runway condition reporting and assessment format, based on a series of recommendations from ICAO, has brought fundamental changes to the reporting of the surface condition of the airport's moving areas throughout the entire year. It is because the new methodology describes the assessment of not only runways contaminated by snow and ice, but also wet runways contaminated by standing water. This addition can create better view on situation at the airport for flight crews when receiving the condition report [8] [9].

3. GLOBAL REPORTING FORMAT

The GRF is intended to cover conditions found in all climates. It provides a means for aerodrome operators to assess runway surface conditions rapidly and correctly, whether they are exposed to wet runway conditions, snow, slush, ice, or frost, including rapidly changing conditions, such as those experienced during winter or in tropical climates [2].

The new methodology was introduced by the adoption of Amendment 39 to ICAO Annex 15 issued on 1 April 2016 with the effective date of 11 July 2016. The second part of the amendment (39B - about new SNOWTAM format) is applicable as of 4 November 2021 [10]. The original date was supposed to be set a year earlier, but due to due to the COVID-19 pandemic ICAO adopted amendments on the postponement of the applicability date, from 5 November 2020 to 4 November 2021 [11].

European Union Aviation Safety Agency (EASA) issued a regulation aimed at ensuring the adoption of the new GRF methodology at an earlier date. The GRF related requirements applied in European Union as of 12 August 2021. EASA wanted to prepare flight crews for the new system gradually by adopting GRF during the summer season so operators will be fully prepared when winter in Europe will fully start [12].

In the Slovak Republic, the GRF methodology together with the new SNOWTAM report format has been implemented on 12 October 2021 [13].

3.1. Background

In 2016 ICAO reported 59 accidents, of which more than half were due to runway excursions. The catalyst for the change of the reporting system started with the overrun of a Southwest Airlines 737 in December 2005. Boeing 737-700 was preparing to land at Chicago Midway International Airport during a snowstorm. From reading the investigation report, the initial touchdown went as expected, but it quickly became apparent that the aircraft was not decelerating as expected even though snow cleaning was reported as completed [5] [14].

During an investigation in 2006, the Federal Aviation Administration (FAA) formed the Take-off and Landing Performance Assessment Aviation Rule-making Committee (TALPA ARC) to address and properly investigate runway overruns. The core outcome was the Runway Condition Assessment Matrix (RCAM). In 2008 ICAO established the Friction Task Force which aimed to cooperate with TALPA ARC and create new system for assessing and reporting runway conditions [15].

New changes became applicable by the beginning of 2016 when airline manufactures started to implement Take-off and Landing Performance Assessment charts (TALPA) to help pilots understand the runway situation and different methods of braking action assessments [15].

3.2. Assessment of RWY condition

An aerodrome operator has to assess the runway surface conditions, including contaminants, for each third of the runway length, and report it by mean of a uniform runway condition report (RCR). The information received via RCR is than published to end users by Aeronautical information services (AIS) in SNOWTAM report format or distributed by Air Traffic Services (ATS) by Automatic Terminal Information Service (ATIS) or radio [9] [16].

The RCR should give a complex picture of the situation on moving areas on a given aerodrome. Because of that the report is divided into two sections:

- Aeroplane take-off and landing performance calculations.
- Situational awareness of the surface conditions on the runway, taxiways, and aprons [16]

New RCR shall be established when a significant change in runway surface condition occurs due to water, snow, slush, ice, or frost. A runway is also considered contaminated when more than 25% of the surface (whether in isolated areas or not) is covered by one of the following contaminants:

- Standing water, slush, loose snow with depth of 3mm or more
- Compacted snow
- Ice, including wet ice [9]

The methodology for reporting and assessing runway surface conditions include eight descriptors, which can be presented on the runway surface:

- Compacted snow
- Dry snow
- Frost
- Ice
- Slush
- Standing water
- Wet ice
- Wet snow

These contaminants can be presented either alone or combined with each other. The RCR is a validated method that replaces subjective judgements with objective assessments. All of the

assessments done by trained professional aerodrome personnel are done visually and no special equipment is needed [9].

During the assessment of runway surface conditions, the airport operators should use a tool called Runway Condition Matrix (RCAM) to help them either assess the required criteria or downgrade the existing assessment [17].

The RCAM compares a runway surface descriptor presented on the RWY with its depth and outside temperature and gives an adequate Runway Condition Code (RWYCC). Each RWYCC is directly connected to a pilot report of runway braking action previously measured by special equipment (Fig. 1). The RWYCC code designation ranges from 0 to 6, where 6 represents the best runway conditions and 0 the worst [9] [17].

Table 1 - RWYCC compared to pilot braking action [17]

Pilot report of runway braking action	*Runway condition code (RWYCC)*
N/A	6
GOOD	5
GOOD TO MEDIUM	4
MEDIUM	3
MEDIUM TO POOR	2
POOR	1
LESS THAN POOR	0

By introducing the new methodology, the ICAO wants to increase safety at airports and provide flight crews with better information about the current state of airport movement areas. The ICAO member states had to implement the new GRF system into their national regulations to reflect the possible pitfalls of winter operations in the given country.

4. SNOWTAM REPORT

For better understanding of available information about contaminated areas at the aerodrome, ICAO had to establish a unified reporting system. In 1967 ICAO published a tenth Amendment to Annex 15 for the first time specifying Snowplan and definition for the SNOWTAM report. The SNOWTAM was applicable since 8 February 1968 and no major changes had been implemented until 2016 with introduction of the new GRF methodology [18].

4.1. Old format

Old SNOWTAM format was applicable until 3 November 2021. "A special series NOTAM notifying the presence or removal of hazardous conditions due to snow, ice, slush, or standing water associated with snow, slush and ice on the movement area, by means of a specific format." [18]

Old format report was valid for 24 hours and divided into 17 items labeled with letters A to T. Items A and B formed heading and introduction for the given SNOWTAM message. Items C to M described the runway condition and the following items (N - T) referred to the remaining movement areas of the airport. Runway conditions were reported for each third of the RWY and type of deposit was published in coded language using numbers [19].

The information published in the SNOWTAM report, especially the type of deposit and the braking action, were used by the pilots to calculate the performance of the airplane. The Onboard Performance Tool system (OPT) from the manufacturer Boeing is used to calculate the performance, which can provide flight crews with the necessary calculations for landing and takeoff in real time according to the actual conditions at the airport [20].

4.2. New format

In April 2016 the ICAO published an amendment of regulation Annex 15, Appendix 39. Second part (39B) presents new format of SNOWTAM report applicable as of 4 November 2021 [10].

"A special series NOTAM given in a standard format providing a surface condition report notifying the presence or cessation of hazardous conditions due to snow, ice, slush, frost, standing water or water associated with snow, slush, ice, or frost on the movement area." [18]

The SNOWTAM report is part of the new global methodology GRF applicable in European Union as of August 2021 [21].

The introduction of the new SNOWTAM report aims to simplify the report itself and thus speed up its deciphering by the flight crews during the flight. The validity of the new SNOWTAM report is 8 hours compared to 24 hours in the old format applicable until November 2021. New SNOWTAM should be published every time an aerodrome operator publishes a new RCR report.

New SNOWTAM should also be published when there is a significant change in in the runway surface condition in RCR.

"A change is considered significant whenever there is:

a) any change in the RWYCC

b) any change in contaminant type

c) any change in reportable contaminant coverage

d) any change in contaminant depth according to attached table (Fig. 2)

e) any other information, for example a pilot report of runway braking action, which according to assessment techniques used, are known to be significant." [17]

Table 2 - Assessment of depth for different types of deposits [17]

Contaminant	*Valid values to be reported*	*Significant change*
STANDING WATER	04, then assessed value	3 mm up to and including 15 mm
SLUSH	03, then assessed value	3 mm up to and including 15 mm
WET SNOW	03, then assessed value	5 mm
DRY SNOW	03, then assessed value	20 mm

The new SNOWTAM is divided into two sections same as RCR. First section should help pilots to get their aeroplane performance calculations and second section should give them situational awareness around the aerodrome itself [10] [17].

The letters used to indicate items are only used for reference purpose in new format and should not be included in the messages. Each item also includes additional letter that mark the usage and information – M (mandatory), C (conditional) and O (optional) [19].

The new SNOWTAM does not include estimated braking action, but the item is replaced by RWYCC derived from RCAM. For this reason, TALPA conversion charts have been upgraded by airlines to help flight crews correctly assign the RWYCC code to individual braking effects. The new format also includes a number identifying the percentage coverage of a contaminant for each runway third [17].

5. RESEARCH

A part of the paper is also research which aims to enhance winter operations safety; gather observations and experiences with the new format of a SNOWTAM message applicable as of November 2021.

The author created a survey for pilots only. The survey compares old and new SNOWTAM format from different angles. It mainly focused on new changes such as RWYCC and percentage coverage of a contaminant on RWY and its impact on airplane performance calculations.

As of now, there has already been two winter seasons worldwide using the new methodology GRF for assessing and reporting runway conditions. The goal is to show whether ICAO made a good decision in creating this new methodology and whether pilots find the new system better to understand and easier to work with.

The survey had been distributed to different airline companies in Europe such as Smartwings, Air Explore, Norwegian and Finnair. A goal was to gather observations and feedback on the topic of the new SNOWTAM report and find out how flight crews understand these changes, whether their companies have prepared them correctly and whether they think that the new methodology will help to enhance safety.

We gained responses from 112 flight crew members from the entire world. Most of the pilots - 79,5% are full time employment pilot, 16,1% of the respondents are still in training and 4,5% of the pilots fly as a hobby pilot (private pilots). Overall, they found out new system to be clearer compared to old SNOWTAM format (88,4% - 99 pilots) and about half of the respondents (57,1%) would choose new RWYCC as a single item to help them easily understand the runway situation. About 34,8% (39 pilots) would choose old braking action and the rest would either choose both, neither of these two or some other information in SNOWTAM report.

A part of the research project also to gained observations and feedbacks from airport operators. We addressed 5 operators in Slovak Republic and 4 operators in Czech Republic and gained answers from all of them. They found out new GRF system to be less precise compared to old one, mainly because of the absence of a braking action which is measured only for conformity of visual assessment and not even published in SNOWTAM report.

6. CONCLUSION

Contaminated movement areas cause irregular operations at airports, which represent losses for airlines. Inappropriate reporting of runway condition can lead to wrong airplane performance calculation and can turn into an incident.

Runway accidents and incidents are aviation's number one safety-related risk category. A primary factor contributing to this risk includes runway excursions during take-off or landing in adverse weather conditions; the runway surface may be contaminated by snow, ice, slush, or water, with a potentially negative impact on an aircraft's braking, acceleration, or controllability. ICAO therefore introduced a methodology to harmonize the assessment and reporting of runway surface conditions.

In 2016 has ICAO introduced new methodology for assessing and reporting runway conditions called Global Reporting Format (GRF). The new system includes new reports such as RCR and changes to format of a SNOWTAM report as well. The GRF methodology should be easier to understand and easier to use compared to old system.

Aerodrome operators will assess runway conditions by visual observations and publish RCR report which is later distributed in form of SNOWTAM to final users. Pilots found out new system to be clearer at the first glance, but it is harder to work with information in new SNOWTAM report in terms of performance calculations. Airport operators found new assessment process to be longer and not coherent and they stated that they found out a lot of differences in EASA, ICAO, and national authority legislative structures.

This creates question whether this worldwide unification actually created united system which is used in a same way all over the world.

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REVITALIZATION OF THE SEASONAL CHARTER PASSENGERS SEGMENT IN PERSONAL AIR TRANSPORT

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Abstract

The research focuses on charter passengers and their seasonal impact on charter air transportation. The relevance of the topic is supported by the events that occurred at airports during the summer season. The empirical part of the research is addressed through a questionnaire survey, which examines the behaviour of passengers who use charter air transportation, especially during the summer vacation season. In the final part of the article conclusions of the research are presented. The result of the practical part of the research is the summarization of data obtained from the questionnaire.

Keywords

charter traffic, passenger, seasonal impact

1. INTRODUCTION

Demand for air travel vacations is on the rise. The summer season of 2022 was the first sign of recovery for the aviation industry after a two-year crisis. During the Covid-19 pandemic, the entire airline industry was forced to lay off employees in all positions. Many of these jobs remained vacant even during the slow return of air travel to its former state. This was confirmed by the situation at airports during the summer season of 2022, when most airports suffered from a shortage of ground staff. In the summer of 2022, aviation began to revive again. However, the newly created jobs were difficult to fill, as there was a shortage of qualified personnel at the time for this type of work.

2. IDENTIFICATION OF PASSENGER BEHAVIOR IN AIR TRANSPORT

2.1. Charter Air Carrier

Some holidays destinations are far away from the main cities, and the time and cost of reaching them are unacceptable for tourists. Traditional carriers did not serve these destinations, which led to the emergence of charter carriers offering cheap flights to new vacation destinations. They are characterized by their flight schedules, which are not fixed or published [1].

2.1.1. History

Charter carriers were the main driver of leisure air transportation until the early 1990s. The seasonal or occasional nature of transport suited passengers who used this type of transport. Airlines behaved in many respects like low-cost carriers, emphasizing cost reductions through dense seating configurations, high load factors, use of secondary airports, or basic on-board service. All these factors led to low costs, allowing charter carriers to offer a satisfactory price for holiday travellers. After the 1990s, business models began to differentiate more. Traditional carriers focused on stable network coverage, low-cost carriers on point-to-point connections, and charter carriers were somewhere in the middle of these two models. However, strict model differentiation did not last long, and the defining elements of each group began to overlap.

The offered capacity by charter airlines corresponds to the demand, even despite high seasonality. They only fly at times or days when required by the customer, i.e., the tour operator. A tour operator is an entity that puts together tours and sells them to travel agencies or consumers. Travel agencies sell tours that were previously created by tour operators for consumers. When it's off-season, there's no reason to offer flights that wouldn't be occupied. Similarly, there's no reason to offer high flight frequencies during the day just to keep up with the competition. All flights are operated because the capacity was previously leased by one or more tour operators. This ensures a high load factor (percentage expression of the occupied aircraft capacity). Most of the capacity is sold to large tour operators.

The trend in charter aviation is to charge for individual parts of services rather than offering them together as a complete package. This offers passengers greater flexibility, whether in relation to the flight, accommodation, or travel duration. The goal is to offer a wide range of products from which passengers can choose any combination. This gives them the opportunity to compete with low-cost carriers, who, like charter airlines, focus on the price-sensitive segment of the market. These are passengers who have their own accommodation, students, or so-called backpackers.

2.1.2. Charter Passenger

For the purpose of this article, it is necessary to define who a charter passenger is. The profile of charter passengers is different from that of low-cost and traditional network airline passengers. In reference [2], charter passengers were compared to low-cost and traditional airline passengers. According to the

research, these passenger groups are not related to each other. Based on the variables, it was found that low-cost and traditional airline passengers are actually opposite groups of passengers. The study shows that charter passengers are more likely to be young people traveling in pairs, but not in large groups. The average income of this type of passenger is higher than in the other groups mentioned above, as there are fewer students and unemployed people. People most commonly choose charter airlines when they want to travel to more distant places outside Europe, especially to Latin America and exotic destinations in Asia for Europeans. If one of these destinations is the goal of these passengers, the probability of them choosing a charter airline for their transportation is 50% higher than for other types of airlines.

2.2. Methodology

Research in this paper is conducted through a questionnaire survey. The first questionnaire is addressed to charter passengers. By analysing the results of the questionnaire, we will synthesize the findings and identify recommendations for the research subjects. The target group consists of respondents who travel on vacation by air transportation. The questionnaire is processed using a quantitative method of data collection. Quantitative research works with numerical data. It measures, determines the frequency, range, or intensity of phenomena, and identifies their quantitative characteristics. The questionnaire was created using an online form through the Google Forms platform. The distribution of the questionnaire also took place online, via a link. In travel groups on Facebook, members of the group chose whether to participate in the survey by filling out the questionnaire after reading the invitation. The questionnaire consists of questions focused on experiences with air travel and possible choices of respondents related to air transportation and travel agencies.

The second questionnaire is focusing on travel agencies. In this part a qualitative method of data collection is used.

3. IMPACT OF AIRCRAFT AND PASSENGER GROUND HANDLING ON PERSONAL TRANSPORTATION

Personal air travel during the summer vacation season of 2022 was marked by strikes. They affected both the personnel at airports and the airline staff of individual airlines. In the summer of 2022, traveling in Europe was several times longer due to staff strikes on a daily occurrence. The series of strikes were initiated by Brussels Airlines employees on June 23. The following day, Ryanair workers from Italy, Portugal, and Belgium joined in. In Spain, the same airline's employees went on strike at the beginning of July, when another 12 strike days were announced for the entire month. At Paris Charles de Gaulle Airport, flights were cancelled due to striking firefighters and Air France pilots. The July strikes also affected Lufthansa, easyJet, and Scandinavian Airlines.

3.1. Reasons for strikes

3.1.1. Covid-19

The first cause of strikes is the global Covid-19 pandemic. After a series of lockdowns in early 2020 and the subsequent overall collapse of air travel, the entire airline industry was heavily impacted. Passengers were afraid to leave their homes or had great difficulty traveling due to restrictions. With a reduced number of flights, the number of required pilots also decreased. To survive, airlines offered pilots early retirement, voluntary departures, or unpaid leave to reduce wages. During the summer season, there was an increased demand for flights due to the easing of pandemic restrictions. However, airlines did not have their pre-pandemic levels of employees. Many pilots who were laid off did not return to their positions. The aviation personnel agency Goose Recruitment conducted a survey that found 43% of 2,600 pilots are doing jobs they were not trained for. 30% of pilots are unemployed, 17% are on leave, and the remaining 10% work in non-flying positions. A survey of unemployed pilots found that 84% of them lost their jobs due to the Covid-19 pandemic. [3]

3.1.2. Aviation Industry

The aviation industry has faced not only a shortage of pilots, but especially of trained personnel. Cabin crew, technical staff, and airport workers are hiding behind roughly 191,000 laid-off employees during the pandemic in Europe. This has put greater pressure on the remaining employees, who have had to handle greater workloads while their wages are being reduced. This has resulted in countless strikes targeting recruitment of new employees, among other things. Aviation is specific in its high demands on personnel qualifications. Specialized, time-consuming training and education are needed to ensure a qualified workforce. [3]

Although each airport had individual problems, the common feature was the inability to increase the number of employees to the level necessary to handle the intake of passengers. According to [4], the shortage of staff at airports is caused by:

- exhaustion of airport and ground handling resources due to the Covid-19 pandemic,
- tight labour market in Europe,
- training and security clearance requirements.

Airports and ground handling are emerging from the COVID-19 crisis with exhausted financial resources, as they were forced to lay off employees due to the decline in air traffic in 2020 and 2021. Jobs in security and ground handling are low-paid and involve working shifts 7 days a week, making it difficult to recruit new employees in times of inflation.

3.1.3. Security checks

Another factor is the training and security clearance requirements that make it difficult to quickly supply new staff. The time between staff recruitment and actual deployment can be up to 16 weeks [5]. Security clearances in France can slow down the recruitment of new employees by up to 5 months [6]. Airports require faster security clearance of airport and ground handling staff by competent authorities. However, the speed of verification depends not only on the authority, but also involves a number of other entities. Requirements for security checks of employees are becoming stricter. Standard security clearances are repeated at regular intervals of no more than 3 years (compared to the original 5 years). An increased security check is required within 12 months. This has further negative

implications for airport staff in the security section, where increased security clearance is mandatory.

3.1.4. War in Ukraine

Another significant factor behind the summer strikes is the ongoing Russian-Ukrainian conflict since February 24, 2022. Due to the current dispute, around 90 European commercial flights have to fly around Russian airspace each day for safety reasons. Commercial flights are also not allowed to operate in the airspace of Ukraine, Belarus, and Moldova for security reasons. Flights that would normally pass over these countries must now fly longer distances, consume more fuel, and incur higher costs to reach the same destination. IATA has issued a statement predicting a deepening of airline losses due to the increase in fuel prices caused by the war in Ukraine. Fuel costs are the biggest operational expense for airlines. The rise in fuel prices affects the amount of money that airlines have to pay for fuel, leaving less money to pay their employees. [3]

3.1.5. Rules for slots

On July 12, the European Commission proposed that the slot utilization rate should be 80%. Each slot at an airport, a reserved space for a particular airline, is retained by the airline if it uses it for at least 80% of the time. It is in the airlines' interest to keep their slots. In order to do so, smaller aircraft or so-called ghost flights were dispatched. These ghost flights were exclusively used to maintain slots using empty planes. During the pandemic, slot utilization was reduced to 64%.

The turn of the year 2022 and 2023 was again challenging for air travel. In October, the Heathrow Airport management increased the daily passenger limit and it should not be restricted even in the summer of 2023. Employees of this airport also protested in November before the World Cup held in Qatar. British Airways announced in August that it will reduce the number of flights in the winter schedule by 8%, affecting approximately 10,000 flights. Schiphol Airport reduced the number of passengers per day by about one-fifth until March 2023. This measure should contribute to solving the shortage of security workers. It is difficult to find workers for mostly mentally demanding work at airports relatively far from cities. During the beginning of 2023, companies should learn from the previous summer and ensure qualified personnel for the summer season. Schiphol Airport agreed to pay an additional 5.25 € per hour to 15,000 cleaners, baggage handlers, and security personnel during the summer. Salary conditions could be one of the motivating factors for recruiting new employees. [3]

4. ISSUE ADDRESSED FROM THE PERSPECTIVE OF TRAVEL AGENCIES

4.1. Package holidays

From the mid-20th century to the beginning of the 21st century, package holidays were the main form of holiday booking. However, independent travel became more popular than all-inclusive holidays. Just when people thought package holidays were a thing of the past, the trend of booking flights and accommodation with the same provider returned. Booking a package holiday is a very convenient form of travel purchasing because you can buy flights and accommodation from the same provider. The expansion of internet usage also had an impact on the travel agency industry. It saves time on purchasing because customers do not have to visit a travel agency office and can reserve services at any time, regardless of business hours. Direct online reservation allows for immediate receipt of confirmation and travel vouchers. Many websites and applications store credit card information, which also contributes to time savings and allows customers an easy reservation and payment process.

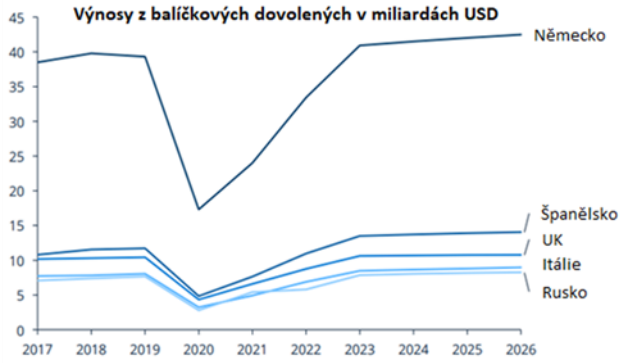

Figure 1 - Europe Package Holiday Revenue.

On the European market with package holidays, Germany clearly dominates. Given the growing interest in remote destinations all over the world, it is expected that providers of package holidays will continue to prosper due to this tourist behaviour trend. A total of 580 respondents from the travel group "EGYPT holidays - tips and advice for everyone!" completed the questionnaire. This group on the social network Facebook was selected based on two assumptions. Members travel or plan to travel to this destination, and therefore use air transport. Another assumption is that people will travel to this area more with travel agencies than on their own. The first part of the questionnaire gathered information about the respondents. This information includes gender, age, and information about who they usually travel with - whether alone, as a couple, or with children and family. The next part of the questionnaire focuses on travellers' preferences when purchasing vacations. The following section examines if respondents were influenced by delays and strikes at airports when traveling by air. Out of the total number of respondents, 488 were women and 92 were men. The majority of respondents were in the age range of 36 to 50 years, and the fewest were in the age range of 27 to 35 years.

5. QUESTIONNAIRE SURVEY

A total of 580 respondents from the travel group "EGYPT holidays - tips and advice for everyone!" completed the questionnaire. This group on the social network Facebook was selected based on two assumptions. Members travel or plan to travel to this destination, and therefore use air transport. Another assumption is that people will travel to this area more with travel agencies than on their own. The first part of the questionnaire gathered information about the respondents. This information includes gender, age, and information about who they usually travel with - whether alone, as a couple, or with children and family. The next part of the questionnaire focuses on travellers' preferences when purchasing vacations. The following section examines if respondents were influenced by delays and strikes at airports when traveling by air. Out of the

total number of respondents, 488 were women and 92 were men. The majority of respondents were in the age range of 36 to 50 years, and the fewest were in the age range of 27 to 35 years.

5.1. Conclusions from the travel survey

- The type of vacation (active or passive) is correlated with age. As age increases, the number of active vacations decreases and vice versa.
- The average amount respondents are willing to spend on air travel is between 15,000 and 30,000 CZK per person.
- There was no significant difference in the timing of air travel purchases between 2019 and 2023.
- 61% of respondents most often purchase tickets through travel agencies.
- Among the factors examined, COVID-19 and the availability of refreshments on the flight have the least impact on air travel purchases, while price has the greatest impact.
- 90% of respondents' flights were not affected by strikes in 2022.
- The average delay time for respondents affected by strikes in 2022 was 7.5 hours.
- Respondents are willing to sacrifice 2 hours and 24 minutes of travel time to get to the airport from their place of residence.
- When traveling for more than 7 hours and 8 minutes, respondents choose to travel by plane over other modes of transportation.
- The main reason for choosing a vacation with a travel agency is a feeling of security when traveling to riskier destinations.
- Passengers are most susceptible to waiting for baggage claim. The average maximum waiting time during the transportation process at the airport is recorded in table 1.

Table 1 - Average tolerated max waiting time.

Phase	Waiting time
Waiting in gate	54 minutes
Waiting for check-in	43 minutes
Luggage claim	25 minutes

5.2. Conclusions from the survey of travel agencies

Both companies observe a positive trend in the field of tourism in 2023. Koala Tours and Čedok report that demand is returning to pre-pandemic levels. Čedok has recorded a significant increase in demand and expects an excellent season if the situation with the pandemic or other global events remains stable. The demand for summer holidays in both travel agencies is already comparable to 2019. "Travel is booming like before the pandemic. At least that is confirmed by sales and economic results data for 2022 and the interest in first-minute trips for this season." [7].

Both surveyed companies report that they have not changed their sales strategy compared to last summer. The pandemic contributed to high online sales. However, customers are returning to direct contact with travel agencies. Thanks to this fact, Čedok, with its current 40 branches, can open new branches in Slovakia. Both companies plan and purchase the necessary capacity of airplanes and accommodation well in advance for the upcoming season.

6. AUTHOR'S EVALUATION

This chapter provides structured recommendations for airports and travel agencies.

Airports and ground handling are trying to overcome current challenges. Although there is no quick solution, there are steps that could help reduce operational disruption.

- Acquire new employees.
- Ensure faster approval of security checks for airport and ground handling personnel.
- Adjusting airline schedules to reduce traffic peaks and quickly return unused slots back to the slot pool.
- Not to allow further liberalization of ground handling.

For decades, ground handling companies have used a variety of operating procedures. It is necessary to enforce a solid legal framework that guarantees minimum service quality and supports and recognizes the skills of ground handling workers through initiatives such as widely recognized training passports. IATA is trying to standardize this through the IATA Ground Operations Manual (IGOM) and the IATA Safety Audit for Ground Operations (ISAGO) [8]. IGOM and ISAGO complement each other in harmonizing ground handling. The goal of both programs is to reduce risks, prevent damage to ground equipment, and enable standardized and sustainable operations. Setting an upper limit on the number of ground handling providers based on the size of the market or airport would also help solve social and operational problems [9].

- Airports should focus on the time-consuming processes in transportation.
- Introduction of modern technologies. New technologies will make travel easier or shorter for passengers. Airports will be relieved of the need to search for qualified personnel. The adoption of digital technologies is also recommended by ICAO.

E-tag

This is used for electronic labelling of baggage in air transport. E-tag is a small electronic device that attaches to luggage and contains information about the flight and passenger. E-tagging simplifies the check-in process and improves baggage tracking in air transport.

eGate

These are modern self-service gates that work on the principle of reading biometric data. Document recognition, face or fingerprint recognition technology is used to identify and compare with passport information. Passengers will spend less time on customs/immigration/passport control, which, as the data show, is desirable. Waiting times will be reduced and passengers can complete the control process in a few seconds.

For travel agencies, certain recommendations have emerged for securing the next season based on both questionnaires.

- Focus on flights outside traffic peaks. As we found out from the questionnaire, charter flights in our sample of respondents were not significantly affected by airport strikes. Nevertheless, travel agencies should aim for flights outside peak hours, when there is the greatest likelihood of a smooth process without unwanted delays.
- Utilize regional airports.
- Flexibility of charter carriers.
- Work on the online environment. Despite the post-pandemic return of travel agencies to direct customer contact and opening new branches, it is necessary to continue intensive work on online options for purchasing trips. Travel agencies should take advantage of the majority interest in online purchases, for example, by creating mobile applications for smartphones. Applications for booking trips, notifications of special offers, or easy display of recently searched options are already being used by Čedok. CK Blue Style offers an application focused more on the actual travel experience for customers.
- Emphasis on capacity planning for airlines and tour operators.

According to our findings, a large portion of charter flight capacity will be sold with a greater lead time than in the past two years. Despite the significant interest in first-minute purchases, we do not believe that this trend will eliminate the possibility of last-minute vacation purchases. Last-minute sales are an integral part of the sales strategy of travel agents and agencies. It is important to have agreements with airports to ensure capacity for passenger handling and ground handling. These agreements with airports could prevent long waits and delays in the air travel process.

7. CONCLUSION

The research provides a summary of the situation at airports during the summer vacation season. Recommendations are drawn based on the questionnaires addressed to passengers and travel agencies.

The 2022 season was very turbulent regarding the events at the airports. Airports and ground handling providers struggled with two main problems: a shortage of available staff and insufficient attractiveness of job positions for new applicants. As a result of the Covid-19 pandemic, airports and ground handling providers had to lay off employees during 2020 and 2021.

For the purposes of the thesis, a questionnaire was completed by 580 leisure travellers. Thanks to the large number of respondents, we are working with a relatively large sample of responses, which have a high informative value and can be a valuable source of opinions of leisure travellers. The application of the results is possible not only for travel agencies but also for airports. However, airports must take into account the segment of travellers for whom the questionnaire was intended. The time sensitivity of regular transport travellers will be different due to a different type of travel. Business travellers are more sensitive to departure time and less to price than other travellers.

Unfortunately, the results of the questionnaire were not as comprehensive for travel agencies. We therefore analysed responses from two travel agencies, one Slovak and one Czech. The answers of both agencies did not differ fundamentally. Demand is at least at pre-Covid standards, and this season should be even better according to initial sales.

The aim of the research was to define recommendations for travel agencies and airports. The main recommendation is to increase the use of modern technologies, both from the perspective of airports - eGates, E-tag, and from the perspective of travel agencies - focusing on online sales. Another recommendation is to pay attention to the harmonization of ground handling procedures. The key factor for the next season is employees. Ensuring qualified staff well in advance is essential at this stage.

Another goal was to identify problems at airports that led to strikes in 2022. The main reason was the consequences of the Covid-19 pandemic. Lengthy security checks are a significant obstacle to quickly recruiting new employees.

Although we found out from the survey that strikes did not have a significant impact on charter air transport (i.e., air transport with travel agencies), it is necessary to emphasize that strikes were not only a matter of the summer season, but also of the beginning of 2023, and are likely to continue in the following months. Rising living costs and overloaded employees are still a very relevant and persistent issue. Dissatisfaction among employees in the European airport environment and ground handling staff stems from inadequate payment conditions, workload, and high inflation. Nevertheless, travel agencies, airlines, and airports expect an extremely successful season that will undoubtedly bring the expected profits and renewed interest from travellers, whether within travel agencies or airlines.

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POSSIBILITIES OF IMPLEMENTATION REMOTE CONTROL TOWERS CONCEPT AT SLOVAK AIRPORTS

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Abstract

The aim of this article is to evaluate the feasibility of implementing virtual control towers at airports in Slovakia. The introduction provides an overview of virtual control towers, including their concept, usage, advantages, disadvantages, and existing implementations. The paper outlines the requirements for implementing such a system and presents a preliminary design and analysis of virtual control towers for Slovakian airports. The study covers the design and evaluation of the implementation, from a general perspective to specific airport analysis, and proposes a plan for implementing virtual towers in Slovakia based on available information. In conclusion, the author discusses the financial and technical aspects of implementation, as well as an assessment of the suitability of this concept for Slovakian airports. Remote towers have been proven to be a viable option for small and medium-sized airports, offering increased flexibility and cost reduction through centralized remote control of multiple airports. However, implementing virtual control towers in Slovakia would come with significant financial implications.

Keywords

virtual tower, remote tower, airport, r-TWR

1. INTRODUCTION

Traditionally, air traffic control near airports and airport surfaces is visually performed from ground control towers. With increasing air traffic, modern radar and other tracking systems have been introduced to assist in controlling flight operations. However, control towers still rely on visual observation, even though they are capable of controlling aircraft using modern technologies without optical contact with the controlled aircraft. The implementation of new technologies in the aviation industry, including airports and air transportation, has not been overlooked with the digital transformation. However, the need for safety places higher demands and standards on the implementation of new technologies, which slows down this process. Virtual control towers have emerged as a new concept in air traffic control, where airport control services are operated remotely from a distance. The aim of this work is to analyze the technical and economic feasibility of implementing virtual control towers at international airports in Slovakia and to describe the conditions for their potential implementation [1] [2].

2. CONCEPT OF VIRTUAL CONTROLL TOWER

Air traffic is expanding to smaller cities and airports with low traffic, necessitating the provision of ATS. However, air navigation service providers face pressure to reduce the operating costs of air traffic management, especially for smaller airports. The high fixed costs of a fully equipped and operational tower at a small airport can be an economic burden, overwhelming the capacity of a low-traffic airport. A remote virtual tower is a solution that can improve the profitability of such airports, enabling them to offer longer opening hours or avoid closure. The RVT system uses high-resolution visual and infrared cameras to replace the view of the airport, as seen from a local control tower, and allows air navigation service providers to provide services from a remote location with the same visibility [1] [2] [3].

2.1. Benefits of r-TWR system

The purpose of implementing remote ATS provision is to enhance safety and flexibility of services for smaller and medium-sized airports with lower frequency of flights. This can increase the airport's revenue by enabling them to handle more aircraft. The r-TWR system reduces costs as one RTC can manage multiple airports. Additionally, it can serve as a substitute for a traditional airport control tower or as a backup solution in case of its failure. The system can also function as a temporary or mobile airport control tower for an airport with higher traffic. The digital imaging and advanced tracking systems of r-TWR can improve operational safety by enabling controllers to monitor airport traffic more effectively and detect potential hazards such as birds, drones, and unknown objects on the runway. The use of r-TWR can also save the cost of constructing or refurbishing a traditional airport control tower, while enhancing controllers' awareness of airport operations and identifying potential hazards. [1] [2] [3].

2.2. Origin and development of r-TWR system

The first idea for RVT was proposed after 2000, and its development was supported by the SESAR JU program that aimed to modernize and develop ATM systems, financed by the European Union and private entities. From 2008 to 2016, the program focused on researching the possibilities of using RVT for a single airport, which led to the validation of the system and the launch of the first Remote Controlled Aerodrome (RCA) at Örnsköldsvik Airport in 2014 in cooperation with Saab AB and the Swedish air traffic service provider LFV operational services.

The PJ05 Remote Tower program investigated the use of RVT for providing ATS from one control station for several airports. The program report stated that it's possible to provide ATS to up to three airports simultaneously. Currently, the PJ05-W2 DTT program will run until 2022. RVT systems are also being developed by Searidge in Canada, FREQUENTIS in Austria, and Indra Sistemas in Spain. Each company has its own systems that differ in component design, software features, number of cameras and displays, and other factors. [1] [2] [3].

2.3. Parts of r-TWR system

The virtual control tower system consists of multiple parts and subsystems put together as one whole. It is necessary to ensure that individual subsystems and devices are mutually compatible and ensure reliable operation during operation. At the same time, these systems must meet the requirements for service provision and safety requirements [4] [5] [6].

2.3.1. Camera and voice system

In order for the camera system to meet the requirements for panoramic visualization of the airport that matches the view from the control tower of that airport (Out Tower Window - OTW), it is necessary to use different types of cameras, each of which is specific and adapted to particular purposes. It is also necessary to ensure a constant transmission of sound from the airport using microphones. Basic kinds of cameras using for RVT system is static camera that is installed to camera hub, usually there is used 2-6cameras. Next type of camera is PTZ – pan tilt zoom camera, it is camera that can move and supports zoom for long distances and tracking objects. Last one is infra-red camera that allows controller to better view in bad visibility conditions. The camera system also includes two directional microphones that are used to capture sounds at the airport. The general recommended placement of microphones is to direct them towards the ends of the take-off and landing runway. The sound recording is synchronized with the image, and the RTM allows controlling the volume and turning on or off the microphones [4] [5] [6].

2.3.2. Airport tower r-TWR

The camera system and camera housings can be installed on existing airport buildings or on a tower built for this purpose. The height of the tower depends on airport parameters, including runway length, topography, and layout. Due to the large area of the camera housing, approximately 1.5m2, which is exposed to wind and other natural influences, the tower structure must be attached to a solid foundation to ensure image stability even in strong winds. The tower is designed to withstand wind speeds of up to 210 km/h (depending on the manufacturer and requirements). Testing has shown that there was no distortion or image instability even during storms or Hurricane Ophelia (which hit Ireland in October 2017 during RVT testing). The tower has a service platform where the camera housing is located. Under the housing is a technical cabinet that must be accessible to the service technician [4] [5] [6].

2.3.3. Automatic meteorological station

The meteorological station is an integral part of air traffic control. For the purpose of transmitting current meteorological conditions, an automatic weather observation system (AWOS) was designed. AWOS is a flexible system and the station can be adapted to provide the required information. With the help of the MetObserver Reporting software, it can be integrated into the r-TWR system, where the information obtained is displayed, for example, in a weather head-up panel [4] [5] [6].

2.3.4. Signal light gun

The Signal Light Gun (SLG) is located on the same movable arm as the PTZ camera and is used for interaction with aircraft and vehicles. Saab AB designed and manufactures the signal light gun to meet the requirements of the International Civil Aviation Organization (ICAO). The light is equipped with LED bulbs with a long lifespan that can emit light with a minimum intensity of 6,000 cd20 at an angle of 3°, allowing the light to be visible from at least 4,600 meters in bright daylight. The SLG is manually controlled from the RTM, and its placement on the PTZ camera makes it easier to target [4] [5] [6].

2.3.5. Service room

Near the RVT tower at the airport, there is a service room. This room is a standard covered room with a concrete foundation. The building has standard dimensions of 3m x 7.5m (which may vary based on manufacturer requirements), and it is surrounded by a fenced area measuring 5m x 2m for handling. The interior of the room consists of two air-conditioned rooms with air filtration. The first room houses compressors that protect the external covers of the cameras from pollution and overheating, and provide moisture ventilation. The second room contains additional technical equipment such as RVT computers, backup battery power, and service monitors [4] [5] [6].

2.3.6. Control center and network architecture

Data from the RCA system is transmitted through data links and collected at the RTC, which can be located at any distance from the airport. The RTC may contain multiple RTMs, from where controllers at their CWP provide remote ATS. The RTC houses servers for all RCAs, with three servers used for one airport, two of which are backups. These servers gather and process all input data from RCA and supplement it with external data and supporting processes. The RTC also uses RAR servers that record and replay all data, including controller communication and work. The RCA is connected to the RTC through two independent networks, with the main requirement for real-time transmission of digital video with a response time of up to 30 ms and a recommended bandwidth of 200 Mbps for each line (main and redundant). The system is currently being upgraded to 5G to further speed up and optimize processes. The RTC also includes a monitoring center that oversees the proper functioning of the entire system and alerts to malfunctions or degradation [4] [5] [6].

2.3.7. Remote control module and visual presentation

The RTM receives all necessary data to provide Air Traffic Services, including information from monitors, equipment, and other support systems. The RCA image is displayed on a series of curved monitors that are easily accessible for maintenance. Backup monitors are also available in case of failure. The number and size of monitors are adapted to the number of

workstations, controlled airports, and other parameters. Possible configurations include up to 14 55-inch monitors capable of displaying a 255° view. This type of configuration occupies approximately 25 square meters. Depending on the required configuration, up to three airports can be remotely controlled from the RTM. "Overlay images" controlled from the context menu can be displayed on the main screens. This feature allows the controller to increase situational awareness without having to look at other monitors in the RTM. Various systems are available at the controller's workstation, such as the Radar Data Processing and Display (RDP), which displays data from various radar sources, enabling controllers to ensure proper spacing between aircraft. Additionally, the Electronic Strip (e-Strip) and Flight Data Processing system (FDP) process flight plans and other information. The r-TWR system also has several advanced features, such as automatic tracking of objects using visual means without radar. The system can detect flying objects such as planes, helicopters, and drones, as well as moving objects on the ground. Information obtained can be displayed on screens using picture-in-picture (PIP) to create overlays, such as highlighting runways, displaying meteorological information, or using infrared or PTZ cameras [4] [5] [6].

2.4. Configuration of RVT

The RVT system is flexible enough to be used in various configurations based on the options and requirements for providing ATS (Air Traffic Services) at the airport, its size, and operations [1] [7] [8].

The 1:1 configuration is suitable for large airports with high traffic volume or when there is no need to serve multiple airports simultaneously. Multiple RTMs can be active at once in one RTC. This configuration can also serve as a backup method for providing ATS in case of a standard airport tower outage [1] [7] [8].

The 1:n configuration allows for ATS to be provided to multiple less busy airports from one RTM simultaneously. If there is a standard airport tower in place, control between the RTM and the tower can be switched as needed [1] [7] [8].

The n:n configuration, also known as clustering, is characterized by greater flexibility compared to other configurations. One RTM can control one airport at a time, but airports can be switched between each other as needed and required for providing ATS. The disadvantage of this configuration is that the controlling personnel must have local knowledge of all the airports they may be linked to or remotely [1] [7] [8].

2.5. Comparsion of the r-TWR system and a convencial control tower

Conventional and remote towers do not differ significantly in operational aspects and overall safety. Remote towers can offer advanced features that can further enhance safety and quality of ATS, although they rely more on technology that may be vulnerable. However, these threats are carefully considered, and backup systems are designed to ensure that the service is safe and functional continuously. The concept of remote towers has been proven feasible at some airports, and many are currently attempting to incorporate them into operations. With the help of modern technology, both technical and operational feasibility have been achieved, allowing for the provision of ATS remotely using reliable and secure systems, almost the same way as conventional towers. Despite the limitations, especially in terms of operational procedures, remote towers are a feasible alternative at all airports. The advantages of remote towers, especially in terms of airport and airspace management, are various. These advantages include cost-effective air transport services with less required infrastructure and fewer human resources, greater efficiency in using human resources and infrastructure, improved operational safety and service quality through new technology, improved situational awareness, and reduced workload. Additionally, remote towers offer enhanced visibility and automated object detection, making them an attractive option for airport managers [1] [6].

2.6. Economical factors

The economic aspects of conventional and remote air traffic control towers have significant differences that drive the development of remote towers at airports seeking more cost-effective aviation services. Although specific values cannot be given due to various possible scenarios and peculiarities of each case, some general aspects can be analyzed.

The main source of revenue for airports is fees that are linearly dependent on air traffic. These fees are paid by aircraft operators for using the airport, usually referred to as landing fees and passenger fees. Therefore, higher levels of air traffic lead to higher revenues, and vice versa. On the other hand, airports have enormous costs, which include investments in buildings, management and maintenance of equipment, personnel, flight information systems, and other operating costs directly related to operations. Many of these costs are fixed costs and do not depend on the number of flights and passengers. For airports with high traffic, variable costs for providing air traffic services increase slowly, although this is offset by the growth of revenue from airport fees. Therefore, as seen in the figure, airports that want to provide aviation services such as ATC or AFIS need a minimum number of operations or passengers to reach the break-even point and achieve profit (or at least not incur losses). If there is little air traffic and landing and passenger fees do not cover the cost of providing ATS, the airport will not reach the break-even point. After a general description of the main economic issues of airport management, a study can be focused on specific aspects related to the development of the RVT system. From an economic feasibility standpoint, three different aspects can be considered: Revenue, Investment and Operating costs [2].

As previously mentioned, revenue is related to airport fees and will not be taken into account in this study, so it will be assumed to be the same for both types of airports with conventional and remote towers. However, it is worth noting that the implementation of a remote tower for air traffic control could lead to increased fees for an airport without prior ATC service due to the improved service. This will not be considered in order to compare remote and conventional towers, and revenue will be considered equal. Therefore, this study will focus on two main aspects influencing remote towers: investment and operating costs. For the purpose of this article, a general qualitative analysis will be conducted comparing remote and conventional towers, emphasizing the cost-saving aspects that each model offers in terms of investing in infrastructure and operating costs. Ultimately, the goal is to determine the

economic feasibility of implementing remote towers at airports and identify potential cost savings [2].

3. REQUIREMENTS AND SPECS OF THE IMPLEMENTATION OF THE R-TWR CONCEPT IN SLOVAK REPUBLIC

After analyzing the RVT concept and its feasibility, some requirements or criteria can be established to determine which airports are suitable for RVT implementation. Setting these qualification requirements will be based on existing research and recommendations from the system provider, taking into account the airport type, size, and operations [2] [9].

From a technical perspective, remote towers can be established on all types of infrastructure, airports, and heliports of all types and sizes. However, heliports rarely require a control tower, so they can be ignored for the purposes of this work. Remote towers are capable of operating all types of air traffic control services and are therefore suitable for airports that require air traffic control (ATC) or aerodrome flight information services (AFIS).

Infrastructure costs are significantly reduced with the implementation of the RVT system. Therefore, it is advantageous for newly established airports to implement this system from the beginning of operations. For existing airports, a deeper analysis is required, taking into account profit and operating costs depending on the type of infrastructure. The implementation of the RVT system is generally beneficial for smaller centrally controlled airports as part of a network of several airports.

Considering the above aspects, the following criteria can be established for the implementation of the RVT system to ensure a feasible solution:

Airports with commercial air transport and/or general aviation activity requiring air traffic services.

Airports with at least approximately 50,000 passengers handled or approximately 5,000 serviced aircraft per year.

All types of airports, from small and medium-sized (regional airports) to large international airports, even with different operating configurations, meaning a 1:1 configuration for large airports, where only one airport is controlled at a time, or a 1:n configuration, where multiple smaller airports are controlled at the same time.

At new airports or airports requiring a new tower, or existing airports where a remote tower is more cost-effective [9] [10].

As can be seen, only a few basic requirements are necessary for the implementation of the RVT system. However, in the next section of this article, some additional aspects will be considered for specific implementation scenarios [9] [10].

3.1.1. Implementation scenario 1

The first scenario corresponds to busy international airports that operate continuously with high traffic density. This type of infrastructure has the following common characteristics:

- 24/7 continuous operation
- Large airport infrastructure, usually with more than one runway and extensive movement areas
- High traffic intensity, more than 150,000 aircraft movements per year
- Mainly intended for commercial air transport, for the transportation of people and goods
- Prioritized airport for IFR flights, with the possibility of serving VFR flights as well [2] [9].

It is important to note that these scenarios are not fixed, and each airport has its own specificities. Therefore, airports can choose different scenarios depending on their own needs. This is especially true for airports that cannot be clearly classified into one of the mentioned categories. When considering the implementation of remote tower systems, it is also appropriate to distinguish between individual implementation at specific airports and global implementation across a network of airports. In the next section, the main aspects of these different scenarios will be discussed, to describe the conditions for the implementation of remote towers in Slovakia [2] [9].

3.1.2. Implementation scenario 2

The second scenario corresponds to medium-sized regional airports. In this case, there is greater diversity and therefore a unique model cannot be established. For larger regional airports that, although lower in level compared to international airports, require a larger amount of ATC services, Scenario 1 may be used. However, for most other regional airports, the following common characteristics can be established:

These airports usually operate only during certain time periods, during the day or at least only operated at certain times. Medium-sized infrastructure, usually with one runway

Medium density of traffic, less than 150,000 but more than 50,000 aircraft movements per year. The airport is used for commercial air transport, for the transport of passengers and cargo, as well as for general aviation purposes. Combination of IFR and VFR operations [2] [9].

3.1.3. Implementation scenario 3

Finally, the third scenario corresponds to small airports with low traffic density. For this type of airport, the following common characteristics can be established: no continuous operation. These airports usually operate only during certain time periods, during the day or at least only operated at certain times. Small infrastructure, one shorter runway, small movement areas. Most of these airports require only AFIS. Low intensity of traffic, usually up to 30,000 aircraft movements per year mainly used for general aviation purposes, but also for commercial air transport. Mostly VFR flight operations, with the possibility of IFR operations [2] [9].

4. PROPOSAL FOR THE IMPLEMENTATION OF THE R-TWR CONCEPT IN THE SR

4.1. Selection and assessment of airports

The main criterion for this work is to assess the possibility and benefits of implementing the RVT system at international airports in Slovakia. The following airports are considered as international airports in Slovakia: Bratislava Airport, Košice Airport, Poprad Airport, Žilina Airport, and Piešťany Airport. For the purpose of this article, Sliač Airport will not be taken into consideration due to the cessation of civil operations, when the airport serves exclusively for military purposes.

In this part of article will be proposed concept of implementation of RVT system on Slovak airports. Evaluation of both financial and technical aspects of implementing this system will be discussed. The proposal and possibilities of specific systems from Saab will be analyzed.

4.2. System design

The proposed system design will utilize elements and specifications from SAAB AB, a company known for their accessibility of information and willingness to assist with the development of the system. Based on these specifications, it is recommended to implement a simple configuration of a remote control tower for the airports in Bratislava and Košice, which would allow for the control of only one airport from one center at a time. As these airports operate 24/7, the implementation of the RVT system would shift air traffic controllers from a conventional tower to a virtual tower control center without reducing the costs of air traffic control. Although a virtual tower system proposal for Bratislava was rejected due to financial reasons, a study conducted by Eurocontrol found that the Advance Tower system was suitable for the airport [5] [8] [9].

The Advance Tower system aims to improve safety and efficiency by integrating information from various sources, such as electronic flight plans, air and ground surveillance, meteorological information, traffic information, and A-CDM, and providing a wide range of functions to support workflow and decision-making. This system unifies ATC services with new technologies in a single user interface, using a digital platform to harmonize system data into one operational display. Although the study mainly analyzed Bratislava airport, it concluded that any investment in the Advanced Digital Tower and RVT system would be financially unfeasible, except for some basic systems that are already being implemented.

The study also found that implementing the RVT system in Bratislava and Košice would be too costly and unnecessary. However, the airports in Poprad, Žilina, and Piešťany are suitable for implementing a virtual control tower system, and the RVT system can be configured to control all three airports from one center. To ensure the highest level of safety, additional features such as PTZ and IR cameras, as well as modified camera covers to protect against frost during the winter months, will be considered. The RTC will be established at Žilina airport, which is the busiest of the three airports and is home to the Department of Air Transport at Žilina University and a flight school.

To design the system, materials from SAAB AB and existing implementations at Linkoping, Sundsvall, and Örnsköldsvik airports will be utilized. A camera cover with 14 integrated static cameras, supplemented by a signal light and one PTZ camera, will be used to provide a basic view for the controller. Two additional Gap Filler cameras near the VPD will provide a better view of events at the airport, and one PTZ camera with night vision will be installed to facilitate ATC work in reduced visibility and to alert for foreign objects or animals in the area.

In summary, the proposed system design will utilize SAAB AB's elements and specifications to implement a simple configuration of a remote control tower for the airports in Poprad, Žilina, and Piešťany. The RVT system will be configured to control all three airports from one center, and additional features such as PTZ and IR cameras will be installed to ensure the highest level of safety. The RTC will be established at Žilina airport, and materials from existing SAAB AB implementations will be used to design the system [5] [8] [9] [11].

5. CONCLUSION

A virtual control tower system has been proposed for implementation in Slovakia, with the aim of reducing air traffic control (ATC) costs. The airports of Bratislava and Kosice were deemed unsuitable for long-term implementation due to the costs involved and were excluded from the proposed system. However, the airports of Poprad, Žilina, and Piešťany were found to be suitable due to their parameters and underutilization. An approximate budget of €9-11 million was created for the implementation of the system for all three airports connected to a single remote tower module (RTM).

The proposed system allows for air traffic control services to be provided at all three airports simultaneously, with the air traffic controller being able to switch between views to the airport currently being controlled. The system includes optional camera features that are already prepared for potential future extension of operating hours, including during the night. The implementation of the r-TWR system for three airports connected to a single RTM will help operators reduce ATC costs. The return on investment for r-TWR, as well as savings on ATC salaries, was calculated solely based on the procurement cost and the expected reduction in the number of air traffic controllers.

However, the procurement cost for the proposed system is high, at 11 million euros. This means that if airport revenues do not increase, and funding relies solely on savings in ATC salaries, the implementation of the system will be financially inefficient and increase the financial burden on individual airports. Therefore, a long-term plan to increase airport revenues is necessary.

In conclusion, the implementation of a virtual control tower system is feasible in Slovakia, but the suitability of individual airports needs to be carefully assessed. The proposed system can reduce ATC costs, but the high procurement cost means that a long-term plan to increase airport revenues is necessary. This study can serve as a supporting material for projects implementing the proposed concepts or for further in-depth studies on the implementation of virtual control towers at airports in Slovakia.

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FLIGHT CORRIDOR FOR HEMS AND NATIONAL CRISIS MANAGEMENT COMMITTEE WITH USAGE HTAWS DURING MINIMUM VISIBILITY CONDITIONS

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Abstract

This paper presents a new possibilities and methods of Helicopter emergency medical service operation in marginal adverse weather conditions with using the helicopter terrain awareness and warning system and impact on safety of crew and operation. It explains current operations in Slovakia, the principle of helicopter terrain awareness and warning system. Subsenquently, analyzed accidents with most common cause – controlled flight into terrain. Furthermore it analyze, design and verify the possibilities of increasing safety operations for helicopter emergency medical service also summaries designed so-called corridor with verify flights for proposes additions for next higher level of safe helicopter operations.

Keywords

Safety, helicopter emergency medical service, HTAWS, controlled flight into terrain, visibility

1. INTRODUCTION

The helicopter rescue medical rescue service has been used worldwide for several decades. More than 50 years have passed since the first rescue operation in Slovakia. From this time, aviation as such, as well as parts of aviation and individual types of operations using helicopters, developed at a rapid pace.

The technique was gradually developed in an effort to create a safe environment for the performance of this special operation. Several types of helicopters alternated and their equipment varied greatly. The environment and use of these systems also had to adapt to this trend

Despite the great effort to maintain the highest possible safety in aviation, precisely in Helicopter emergency medical service operation, dozens of incidents and accidents occurred which let to the implementation of safety measures and an increase in the level of safety

In the interest of high level of civil aviation safety in the Union, it is necessary to adjust all-weather operations in all relevant areas of helicopter operations, specifically in Anex 6, Part I,II and III.

And does it make sense to operate HEMS helicopters in all weather conditions? After all, so many accidents happened, and precisely in connection with bad weather situations. A pragmatic answer may be that it will be safer to operate helicopters at the current values defined by the regulations and another accident event will not happen. And they keep happening.

The topic of flying helicopters in the rescue system in low to borderline meteorological conditions under constant VFR flight using the Helicopter terrain awareness and warning system, hereinafter referred to as (HATWS), is revealed.

2. HEMS OPERATIONS

Despite the use of modern helicopters such as the Bell 429, the operations is carried out exclusively under VFR condition during day and at night. This means that the operation does not include any special low visibility procedures or IFR operation.

The annual report of company that provide HEMS operation in Slovakia itself confirms the need for implementation of new systems, which significantly contribute to the preservation and improvement of safety in connection with the increase in number of rescue missions.

In year 2022, a total of 2 186 patients were transported on board helicopters and airplanes in the territory of the Slovak Republic, which a 10% increase in the number of patients compared to the previous year 2021. Last year the rescue teams from the operation base in Banská Bystrica had the most rescue missions, which with their 418 flights they achieved a record number in one year in the history of company in Slovakia. They were followed by operation base in north part of Slovakia- Zilina with 373 rescue flights. On the third place was the base in Trencin with 345 rescue flights [2]

Currently, three types of helicopters are used in HEMS operation in Slovakia. Agusta A109K2, Bell 429 and Eurocopter EC135T2/T2+/P2+ [3]

Bell is at the forefront in providing multiple ways of satisfying evolving requirements in helicopter traffic management, flight following and terrain awareness safety.

The Bell 429 (figure 1) is the first helicopter in the light twin category to provide fully-coupled steep (9-degree) LPV WAAS (Localizer Precision with Vertical guidance Wide Area Augmentation System) approaches.

Figure 1 - Helicopter Bell 429

The Bell BasiX-Pro Integrated Avionics System concentrates on providing true operational capabilities and flexibility to our customers to address rapidly changing regulatory requirements and technologies, with an open architecture and flexible avionics systems solutions. The enhancements available for the Bell 429 through optional accessory kits and customizing include the Traffic Advisory System and Helicopter Terrain Awareness and Warning Systems / Enhanced Ground Proximity Warning System. [4]

3. HTAWS

ICAO introduced Ground Proximity Warning System (GPWS) carriage requirements in 1978 to alleviate the Controlled Flight Into Terrain (CFIT) problem. A significant decline in the number of incidents was observed after installation of GPWS. The CFIT, however, continued to be a critical flight safety problem. ICAO has, therefore, amended the GPWS provisions in Annex 6. System is designed to warn of dangerous terrain in the vicinity of the helicopter and avoid a collision with the terrain or obstacles on the ground in calculated current flight trajectory and other input data that the system evaluates. [5]

The success after the introduction and implementation of TAWS systems for aircraft pointed to the need to introduce these systems also for helicopters in the form of the HTAWS system. However, the implementation of the system alone does not guarantee the elimination of CFIT- type collisions. An understanding of the system and training to work with. Be able to recognize system displays independently and in a timely manner. [6] [7]

Helicopter Terrain Awareness and Warning System. HTAWS is a computer-based system that provides the flight crew with alerts, (both aural and visual) of pending collision of the rotorcraft with the terrain, considering such items as crew recognition and reaction times. Enhanced awareness is achieved by employing a look-ahead function that provides cautions, warnings, and terrain and obstacle display(s).

The individual displays of the systems are divided into basic colors for easy expression and understanding of the danger in the event of conflict. So that the warning display is clear and legible during the flight at lower altitudes and that the color markings do not interfere during the entire flight.

This display system work only below 2 000 ft above ground level. Individual colors represent a potential danger due to the position and height of the helicopter. In general the color according to picture No. 1 are red and yellow, the colors of heightened attention represent immediate danger.

The picture represent the view around the helicopter if we take into account the example that the helicopter hover with zero speed. The colors black and green do not represent an immediate risk, but the risk is potential. Both cases require the crew to react to given alert situation, which they mus evaluate as a potential risk or imminent danger.

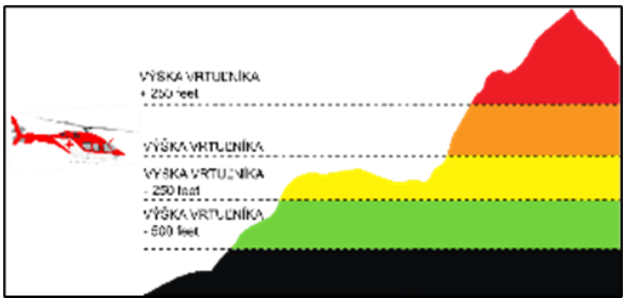

Figure 2 - HTAWS colour annunciation

The HTWAS should provide automatically, as a minimum, warnings under the following circumstances: [5]

- Excessive descent rate;
- Excessive terrain closure rate;
- Excessive altitude loss after take-off or go-around;
- Unsafe terrain clearance while not in landing configuration;
- Excessive downward deviation below the instrument glide path;
- Excessive banking angle;
- Excessive pitch angle; and
- Vortex ring danger [5]

The individual displays of the systems are divided into basic colors for easy expression and understanding of the danger in the event of a conflict. So that the warning display is clear and legible during the flight at lower altitudes and that the color markings do not interfere during the entire flight. This display system only works below 2000 ft AGL.

Individual colors in figure 2 represent a potential danger due to the position and height of the helicopter. In general, the colors according to figue number 1 are red and yellow, the colors of heightened attention represent immediate danger. The image represents the view around the helicopter if we take into account the example that the helicopter hangs in place with a speed of V=0 km/h. The colors black and green do not represent an immediate risk, but the risk is potential. Both cases require the crew to react to the given situation, which they must evaluate as a potential risk or imminent danger.

4. CFIT

CFIT (controlled flight into terrain) occurs when an aircraft or helicopter is fully capable of flight under control and the pilot

flies unintentionally and without prior awareness of the terrain, water or obstacle. It is the second most common consequence of commercial helicopter air transport accidents. [8]

It is very important for pilots to understand what conditions lead to CFIT in order to be able to recognize these dangers, avoid them in time and prevent an accident. More than 80% of accidents due to CFIT in the operation of HEMS happened at night. 60% of accidents are fatal. [9]

A pilot should and must:

- expect that the conditions may be worse than predicted by the weather forecast, recognize the signs and dynamics of deteriorating weather,
- check and evaluate the current actual conditions compared to the forecast,
- identify route alternatives and suitable backup airports or safety areas,
- have a sufficient reserve of fuel for unexpected situations,
- listen to ATIS reports during the flight to verify the airport's current weather conditions (if the airport has such reports),
- be ready to divert, turn or land within the framework of maintaining the safety of the flight even at the cost of not reaching the planned landing place,
- and last but not least on the basis of the implementing regulation EU 923/2012 in the SERA.2015 section "Authority of the aircraft commander: The aircraft commander has the right to make a final decision on the execution of the flight". 10 [30]

New technologies help to raise situational awareness to a much higher level than without the introduction of these technologies. Systems that are introduced into modern aviation technology, which is also used in the operation of HEMS in Slovakia, have systems such as EGPWS or HTAWS.

These systems present displays and warnings to pilots within the terrain that creates a dangerous collision situation. These advances in avionics can help to increase safety, but the pilot-in-command is the element that prevents him from getting into situations that would be dangerous if he evaluates them in time. 8 [19]

5. DESIGN OF CORRIDOR

From the annual report of the Air Transport Europe company, it follows that of all the hospitals in Slovakia, in 2022, the rescue helicopter was most often seen at the Kysucka hospital and polyclinic in Čadca, where the pilots landed exactly 70 times, and this is the reason why the design and its experimental measurement are carried out for the flight from Žilina – Čadca or backward. [1]

flight corridor is the name behind which the flown route is taken into account, which is tested in advance under satisfactory conditions. Corridor because the track and its control points are led in a corridor that ensures a sufficient distance from the nearest and most critical obstacles from the point of view of the terrain and other obstacles such as e.g. BTS antennas, Chimneys, Power lines, etc.

The selected corridor was designed to meet the minimum requirement of a minimum height above the ground of 500 ft AGL within a radius of 150 m from the helicopter. In this way, a sufficient safe distance from obstacles, especially off-road ones, will be achieved in individual critical points of the track.

In figure 2 is the line shown in blue, which is mainly used by the crews of HEMS Krištof 06 for the direct flight to the hospital in Cadca and also back to Žilina. The red color shows the route that would ensure a safe flight even under the minimum limit values for VFR or SVFR flight, namely 600 ft AGL with a minimum flight visibility of 800 meters. Individual control critical points are shown in yellow.

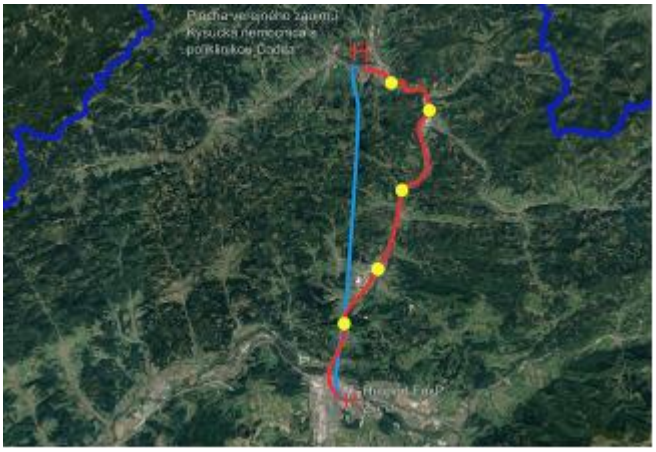

Figure 3 - Designed route for corridor compared with direct flight route

VI. RESEARCH

A part of the paper is also research which aims to enhance helicopter emergency medical service safety during marginal adverse weather through experimental flights with helicopter Bell 429 from one of operational bases in Zilina. A total of 7 flights were made, of which 4 were designed corridors and 3 were direct flights.

For experimental purposes was used calibrated recording device Nano 4 was used for recording the flight, which was subsequently evaluated in the Seeyou Cloud program, additional devices for photo documentation of the dashboard with a Garmin 750 display in Terrain and Map mode and Garmin D2 Bravo watches.

The main criteria include following:

a) Compliance with the minimum set parameters according to regulation Annex 2 – Rules of the air. Minimum visibility 800 m.

b) Observing the availability of the helicopter with regard to road traffic or selected safety areas.

c) Adherence to the flight at a flight height of at least 500 to 1,000 ft above the terrain specified by regulation Annex 2 Rules of the air.

d) Adherence to the time benefit and thus the time deviation of the measured route must not be higher than 25% compared to the flight as the crow flies.

e) Recognition of terrain and other significant obstacles by the onboard HTAWS system and comparison with visual contact, (figure 4) or evaluation of deviations or changes in the underlying maps of the system.

Figure 4 - Detailed HTAWS screen on Garmin G750 during test flight.

a) The flights for the purpose of measurement ranged from 530 to 1,046 ft AGL, which fulfilled the requirement for a min height of 500 ft and also verified the signaling of the system at heights higher than 500 ft AGL.

b) The speed during flight measurement was set to a range of 100-120 kt, for which a minimum visibility of 1,500 m and maintaining visual contact with the ground is established. The required parameters were partially met with the exception of the first control point in two flights when the speed exceeded 130 kt. Speeds ranged from 75 to 135 kt. The times required to fly through the corridor were calculated for the limiting speeds at a visibility of 800 m 50 kt.

c) Maintaining the availability of the helicopter with regard to road traffic or selected safety areas. The intended track replicates the 1st class road E75 in the off-road valley. This road is suitable for coverage by a ground ambulance in case of worsening weather conditions or due to technical reasons of the equipment used. The required parameters were met, the flights were always conducted along the road.

d) Compliance with the time benefit. The time deviation of the measured track ranges from 13.4-28%. It represents potentially good time benefits, but on the contrary, when flying at a speed of 50 kt, the benefit disappears. For individual flights, it was found that the differences in the time needed to fly this route are minimal compared to the time needed to move an ambulance on the road.

e) During the measurement flights, terrain obstacles were recognized on a large scale during the flight at 500-600 ft AGL, where colored warnings and also the voice warning "TERRAIN" were marked. Only one chimney was recognized in Kysucké Nové Mesto, it is the only obstacle that can be found in the database of obstacles in this area. The compliance of the map background with the real terrain in the area of the intended line was fulfilled by a sufficient map background, which included the representation of a part of the railway line and the power line. Identification of obstacles along the flight path. These were not observed in the system. However, not every obstacle is within tight horizontal and vertical boundaries.

6. CONCLUSION

The results of the work show that the use of the HTAWS system during such low flights notifies the pilot and the crew sufficiently in advance of obstacles near the flight trajectory and also of the warning near the terrain. It presents the pilot with a graphic display of the position relative to the terrain to the required extent, which helps to recognize known terrain in the case of reduced visibility.

The route can be used in real operation with minimal time deviations from the flown route by direct flight only under the conditions that there will be no flight with the minimum limiting meteorological visibility at 800 m.

Then the flight speed is very limited to 50 kt. flight is highly marginal and the time benefit compared to ground transportation is slowly but surely being lost, which is not the goal of flights. Flights at such a low speed with minimal visibility are time disadvantageous even with the use of the HTWAS system.

Individual flights confirmed the completeness of the map base of the system. It displayed the terrain relief, the railway line and in some places even the power lines correctly every time it was flown. However, what turned out to be insufficient is the number of obstacles on the flight path from the point of view of low flight. It is only an obstacle that is also marked on the ICAO map, namely the factory chimney in Kysucké Nové Mesto. No other obstacles are sufficiently shown in the map base. This can represent a potential risk for a pilot who does not know the terrain and obstacles well enough, but also for a pilot who performs flights in the space regularly.

After evaluating all the results, we also get to evaluate the status and availability of meteorological data from meteorological stations and web cameras, which are insufficient for this area. It would be necessary to ensure the addition of web cameras and stations, with basic data for pilots, which would greatly help in the decision-making process on the execution of the flight.

The obtained results can help in the future process of developing innovative procedures for VZZS to analyze the options for creating a network of flight procedures for VZZS crews.

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DIGITAL MEDIA AIRLINE CRISIS COMMUNICATION

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Abstract

This article explains what social media is and how influential can social media be. Focus of this paper is on usage of digital media by airlines during times of crisis. This article explains what digital media and Twitter are, how airline use Twitter as a social media platform to communicate with its stakeholders, customers and employees during crisis and how digital media can be used by airlines to efficiently communicate with interested parties. Furthermore, examples of inadequate crisis communication made by airlines during major crisis incidents will be shown as an example of what consequences can incorrect crisis communication cause.

Keywords

crisis management, crisis communication, social media, online user-generated content

1. INTRODUCTION

Digital media airline crisis communication refers to the strategies and tactics used by airlines to manage their reputation during a crisis that has spread through social media platforms. The airline sector has recently gone through several crises that have seriously impacted both its operations and reputation. Airlines are a unique kind of business that offer perishable products which is very vulnerable to economic instability, political unpredictability, and crises. Airlines need to be ready to respond swiftly and effectively to crisis events, including natural catastrophes, technological malfunctions, and human errors, particularly in the digital era. Considering the continuous increase in popularity of social media sites like Twitter, Facebook, and Instagram, airlines need to be ready to react immediately and effectively to any potential negative publicity. Effective crisis communication strategies through social media may have a significant impact on a company's reputation, brand loyalty, and customer retention.

Over the past years, social media influenced our everyday lives. More than half of the Earth's population currently uses at least one social media platform. The growing influence of social media offers more opportunities for companies' advertisements, brand promotion, the easily accessible reach of customers to companies and vice versa, receiving customers' feedback, and crisis communication.

The purpose of this thesis is to provide an in-depth content analysis of crisis communication strategies used by airlines and whether the provided information was appropriate, using correct SCCT strategies, and if the shared content based on the key performance indicators for social media has been effective during and after the crisis. This thesis will focus on a social media platform called Twitter. Twitter as one of the biggest social media websites offers a perfect platform to share straight-to-the-point messages (tweets) that suites crisis communication perfectly. On average, around 6000 tweets per second and around 500 million tweets per day are posted on this social media platform. Given the amount of information being shared among users every day companies must always stay on top to be ready to respond anytime

RQ1. How effective the crisis communication of an airline is?

RQ2. What are the crisis communication strategies used by a selected airline during a crisis?

2. DIGITAL MEDIA

All forms of media that are produced, viewed, and shared utilizing digital technologies are referred to as digital media. Anything that may be sent via a computer network or the Internet, such as text, photos, audio, and video, is included in this. The way we communicate, learn, and consume information has been completely changed by digital media, which has integrated itself into every aspect of our everyday life. Social media is used by billions of people worldwide and has quickly emerged as one of the technologies that defines our age. As of March 31, 2019, Facebook as one of the most popular social media websites, for instance, claimed having 2.38 billion monthly active users and 1.56 billion daily active users. It is not surprising that marketers have embraced social media as a marketing medium given the sizable potential audience accessible who spend several hours a day using social media across the many platforms. According to Statista the number of social media users worldwide in 2022 was 4.59 billion and this number is projected to grow in upcoming years [1] [2].

Digital media's interaction is one of its most important features. Digital media, as opposed to traditional media like print or broadcast, allows for two-way communication between the sender and the receiver. By commenting, sharing, and responding to the content they consume, individuals can engage with it. Social media sites like Facebook, Twitter, and Instagram are great examples of interactive digital media that have completely changed how we communicate with one another. The accessibility of digital media is another crucial aspect. We can access information and content at any time and from anywhere thanks to digital technologies. Because of this, we are

now able to entertain ourselves, acquire new skills, and keep informed all from the convenience of our own homes. Furthermore, the availability of several platforms, such as websites, social media, and email marketing, has made it simpler for companies and organizations to contact their target audience.

Also, the manner in which we receive news and information has changed thanks to digital media. We now have access to a wide range of internet news sources, including both conventional news organizations and alternative media platforms. This has made it possible for us to access a variety of viewpoints and keep up with events taking place around the world in real time. The development of digital media has raised questions about the reliability and validity of information as well as the influence of false information and fake news on public discourse.

3. METHODOLOGY

For the purpose of this paper, content analysis was selected as the best approach to respond to the research questions. A dataset of information was gathered during several crises in different regions of the World. A dataset of tweets from the past was acquired from the Twitter platform using the Python program- snscrape. Using social media metrics proposed by Bonsón and Ratkai (2013) in Table 2 to evaluate stakeholders' engagement and social legitimacy on a company's social media page. To make data as relevant as possible to the date of crisis occurrence we have used an internet archive database called "wayback machine" which allows you to look at the chosen page's available "snapshots" in time. This proved to be useful in acquiring the number of followers at the time of crisis. Selected airlines that receive the best results in social media metrics of popularity, virality, and customer brand engagement will be evaluated based on the crisis response strategies used in their tweets.

Table 1 - Social media metrics Source [3].

Construct	Measure	Formula
Popularity	Percentage of posts with "like"	Number of posts with likes/total posts
	Average number of "likes" per post	Total likes/total number of posts
	Popularity of messages among followers	(Total likes/total number of posts/ number of followers) x 100
Virality	Percentage of posts with "retweet"	Number of posts with retweets/total posts
	Average number of "retweets" per post	Total retweets/total posts
	Virality of messages among followers	(Total retweets/total posts/ number of followers) x100
Customer Brand Engagement	Percentage of posts with "comment"	Number of posts with comments/total posts
	Average number of "comments"per post	Total comments/total posts
	Customer brand engagement of followers	(Total comments/total posts/number of followers) x100

4. USE OF DIGITAL MEDIA BY AIRLINES

The airline industry has been one of the early adopters of digital media. Airlines have benefited from the growth of the internet and mobile technologies by utilizing these digital media to provide clients a smooth and personalized travel experience. In their marketing and advertising activities, airlines utilize digital media in a very direct manner. Airlines market their brands and interact with their customers on social media sites like Facebook, Twitter, and Instagram.

4.1. Attracting customers

Airlines can draw in new business and keep their current clientele by developing aesthetically appealing content and engaging in marketing initiatives. As for an instance, airlines frequently employ influencer marketing to promote their offerings to a larger audience. They work together with social media influencers to produce interesting material, including photographs and videos, that showcase the distinctive qualities of their airline. Another tool used by organizations is target marketing. For instance, Facebook service Dynamic Advertising for Travel, which was introduced in April 2017 is a great example. This service is intended exclusively for airlines and is made to assist them in efficiently and personally promoting their campaigns and announcing their flights and destinations via Facebook. The platform provides airlines the ability to create dynamic, personalized marketing based on Facebook users' searches and interests [4].

4.2. Online check-in and booking options

Offering online check-in and booking options to clients is another way airlines leverage digital media. Nowadays, customers may use airline websites or mobile applications to book tickets, select seats, and even pay for supplementary services like extra luggage. Customers now find the booking procedure to be more convenient, while airline employees now have less work to do. Customers who use online check-in services may skip the lengthy airport lines and get right to the boarding gate.

4.3. Notifications regarding flight information

Airlines also use digital media to give consumers up-to-the-minute flight information. Consumers may now sign up to get push, SMS, or email notifications for information on gate changes, flight delays, and cancellations. This makes it easier for passengers to plan their journey and less stressful when a flight gets delayed.

4.4. Customer's feedback

To get client input and enhance their services, airlines utilize digital media. Airlines collect information about consumer preferences and identify areas for improvement through online surveys and feedback forms. This has made it possible for airlines to improve their services and adapt to the changing needs of their customers.

5. ROLE OF SOCIAL MEDIA DURING AVIATION CRISIS

Social media has a significant influence on how we react to and interpret crisis situations. Social media gives people a platform to communicate, share information, and offer support during emergencies like natural disasters, terrorist attacks, or public health crises. On the one hand social media enables the quick broadcast of information, such as government updates and

eyewitness accounts. This can be especially helpful when traditional news sources are unavailable or sluggish to reply. Furthermore, social media gives people a platform to express their feelings and experiences with others, forging bonds of support during difficult times. However, there are limitations to the quickness and scope of social media. False reports and rumors have potential to spread swiftly and inflict undue anxiety and confusion. Due to the enormous volume of frequently upsetting content that users are exposed to, social media can also intensify dread and anxiety. Additionally, particularly during times of crisis when people are looking for explanations and answers, it may also be a source of false information, hoaxes, and conspiracy theories. Sharing graphic photos and videos can violate people's right to privacy and traumatize others who view the content. Social media companies have occasionally come under fire for how they handle sensitive content, particularly when it comes to censorship and algorithms that amplify or repress sorts of content.

So far social media has played a dual role in how we react to and interpret crisis situations. While technology has numerous advantages, such as the capacity for information sharing and social interaction, it also has drawbacks, including the propagation of incorrect information, ethical issues, and the exaggeration of anxiety and terror. People should therefore view social media content during times of crises with care and critical thought. It is essential for social media companies to handle sensitive content responsibly and openly when there is a crisis. This can entail taking measures to confirm information, eliminating harmful or inaccurate content, and working with trusted organizations to give users correct information. When absorbing information from social media during crisis situations, governments and other organizations can also play a role in developing media literacy and encouraging critical thinking [4][5][6].

5.1. What is Twitter

Twitter is a well-known social media network that has affected modern day conversation. It has revolutionized the way we share and consume information because to its straightforward design and stringent character restriction of 280 characters. Posts on Twitter called “tweets” can possibly contain photos, videos, and links to other websites. Tweets may be retweeted(shared), liked and commented on by other Twitter users. Twitter is a helpful instrument for networking and being informed since it enables users to search for particular topics and participate in conversations about them. Hashtags are a type of user-generated tagging that are used on social media platforms like Twitter to facilitate cross-referencing of material by topic or theme. For instance, a search for the hashtag #aircraft on Twitter or other social media network finds all posts that have been tagged with that phrase. With more than 330 million active users today, Twitter has developed into an essential network for people, businesses, and organizations to interact with their audiences. The majority of Twitter users come from the United States, where political and government figures often utilize it for their campaigns.

5.1.1. History of Twitter

In 2006, Jack Dorsey, Biz Stone, and Evan Williams founded Twitter. The website was initially intended to serve as a message tool for a limited group of friends, but it soon acquired popularity and developed into a platform for the general public to communicate their views and thoughts.

In 2022 Elon Musk acquired Twitter, Inc. for US$44 billion, gaining control of the platform and fired the majority of the management team, disbanded the board, and took the company private. On December 20, 2022, Musk announced he would step down as CEO once a replacement had been found. He is currently Twitter's chairman and CEO, in charge of all business operations.

5.1.2. Use of Twitter by airlines

Airlines utilize Twitter to interact with passengers and offer customer service. Customers can reach airlines on Twitter quickly and easily, and they'll get a response right away. The majority of airlines have social media staff who constantly check their Twitter feeds, which enables them to spot issues early and offer consumers prompt solutions. Customers can tweet the airline using the airline's Twitter name to voice their opinions or inquire about a specific issue. Then, airlines can reply to the tweet and provide support. By keeping users on their platform, Twitter also enables airlines to manage their brand identity and experience.

By retweeting customers comments and attaching a brand message, airlines may utilize Twitter to encourage favorable experiences. In order to keep its clients informed about their flights and find solutions to any of their issues, Jet Airways uses the hashtag #JetInstant. American Airlines strengthens their relationship with customers by using the hashtag #AATeam to refer to its social media team.

Customers who want to feel like a real person is paying attention to their issues might benefit from Twitter. Customers can tweet about their problems in the public Twitter feed to receive replies in a confidential, private message format. In a poll conducted by Millward Brown and Twitter, 73% of respondents reported feeling happier after receiving a response from a travel organization [7].

Figure 1 represents twelve different airlines with the most amounts of followers on Twitter platform. This graph's follower count was updated on March 25, 2023, using data from the previously mentioned airlines' Twitter accounts.

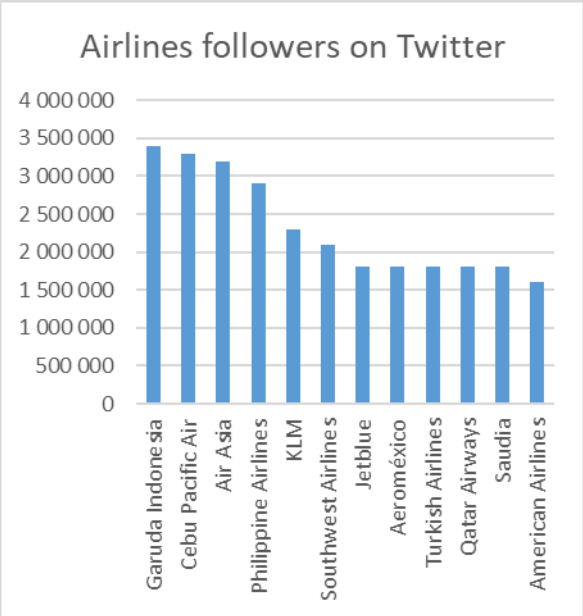

Figure I - Airlines with highest amounts of followers on Twitter Source [Author]

5.2. *Social media used as a tool for public public reporting Aviation accidents*

In recent years, social media has developed into a potent instrument for the public reporting of aviation accidents. While an aviation catastrophe unfolds, observers and passengers can immediately post images, videos, and updates because of the widespread usage of smartphones and social media platforms. Social media has proved crucial in giving real-time updates and information regarding aviation catastrophes, especially when traditional media channels are slow to react. However, it's crucial to remember that not all information shared on social media is correct or trustworthy. On social media, incorrect information or rumours can sometimes spread quickly, confusing people and impeding the operations of the investigation and reaction teams. As a result, while using social media as a source of information regarding aircraft accidents, it's crucial to double-check the information. Despite these drawbacks, social media has developed into a crucial instrument for the public reporting of aircraft accidents, giving passengers and eyewitnesses a platform to tell their stories and promoting awareness of issues related to aviation safety [5][9].

In each of following situations, social media significantly influenced how the general public perceived the events and exerted pressure on the airlines to act more promptly and effectively.

5.2.1. *Asiana Airlines flight 214*

When attempting to arrive at San Francisco International Airport, Boeing 777 Asiana Airlines Flight 214 on the 6th of July 2013 crashed. While the airline was still having trouble informing the public, images, and videos of the smoking wreckage were posted within 20–30 seconds of the aircraft touching down, the first tweet and photo of the disaster were sent out to the public, before anybody had even had time to process what had just happened [10].

Figure 2 - Asiana Airlines flight 214 Twitter report Source

The incident occurred at SFO at 11:28 a.m. on the 6th of July. The initial response from Asiana Airlines was posted on their Twitter account @AsianaAirlines at 4:39 p.m. “Our thoughts and prayers are with all the passengers, and flight crew on the flight. We hope to provide you with further info asap.”

Seven hours after the crash, Asiana finally released its first press release on Twitter, Facebook, Google+, and Asiana’s official website. The press release stated that Asiana Airlines is cooperating with the ongoing investigations.

Yoon Young-doo, CEO of Asiana Airlines, stated his company has excluded mechanical failure as the reason for the crash in the first hours following the incident. Afterwards, he supported the pilots, calling them "extremely experienced and skilled pilots". Yoon personally apologized to the families of the three deaths on July 9 before boarding Flight 214 and travelling the same route as the downed plane to San Francisco to meet with NTSB investigators.

Furthermore, The U.S. Department of Transportation fined Asiana Airlines $500,000 on February 25, 2014, for failing to promptly and appropriately assist crash victims and their families. Some families weren't contacted by the airline until five days after the crash [10] [11].

5.2.2. *Malaysia Airlines Flight MH370*

In 2014, a scheduled flight from Kuala Lumpur International Airport to Beijing Capital International Airport operated by Malaysian Airlines Flight MH370 vanished with 227 passengers and 12 crew members. The crew of the Boeing 777-200ER, last communicated with air traffic control (ATC) around 38 minutes after take-off when the flight was over the South China Sea. Malaysian Airlines Flight MH370 took off from the Malaysian capital of Kuala Lumpur, headed for Beijing at 12:41 a.m. At 2:40 a.m. Malaysian air traffic controllers told Malaysia Airlines that Flight 370 was missing from the radar. At 3:45 a.m. Malaysia Airlines said it issued a “code red” alert that the plane was

missing from the radar. Malaysia Airlines Flight 370 should have landed in China's capital at 6:30 a.m.

At 7:24 a.m. Malaysia Airlines announced the plane's disappearance on its Facebook page. The first official statement was posted on their Twitter account @MSA at 8:13 a.m.: "MEDIA STATEMENT released at 7.24 am/8 Mar 2014 - MH370 Incident - http://bit.ly/1kDkjiS"

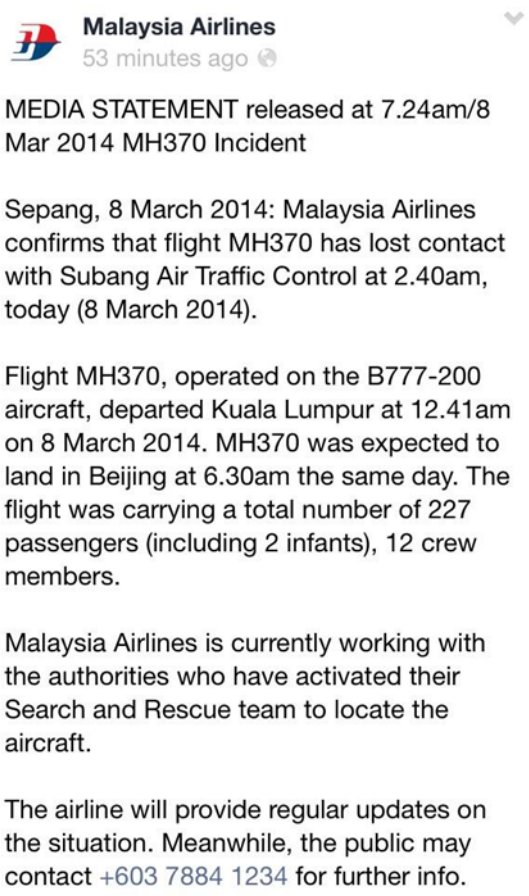

Figure 3 - Malaysian Airlines media statement on MH370 incident
Source: [Twitter]

Users of social media circulated theories, rumours, and conspiracy theories over what transpired to the plane while the search for it stretched on for weeks. Meanwhile, the airline came under fire for its patchy and sluggish contact with both the public and the families of the passengers. Public communication from Malaysian officials has been criticized: people say the airline consistently released imprecise, incomplete, and sometimes inaccurate information [12].

5.2.3. Southwest Airlines Flight 1380

Twenty minutes after take-off from New York-LaGuardia Airport to Dallas Love Field Boeing 737-700 experienced a left engine containment failure on 17th of April 2018. Explosive depressurization resulted from the engine cowl being shattered during the failure, and cowl pieces damaging the fuselage. Other fragments caused damage to the wing. One passenger died after being partially ejected from the airplane. Eight more passengers had minor injuries. On-board passengers soon turned to social media to share pictures and videos of the occurrence, which generated a lot of online discussion and sharing [13].

Incident reportedly happened at 11:03 a.m. On Facebook, a passenger by the name of Marty Martinez chronicles the terrifying experience. At 11:12 a.m. cabin reached 10 000ft. Flight 1380 landed in PHL at 11:23. First statement regarding this accident from Southwest Airlines Twitter account @SouthwestAir was posted at 12:39 p.m.:

" We are aware that Southwest Flight #1380 from New York LaGuardia (LGA) to Dallas Love Field (DAL) has diverted to Philadelphia International Airport (PHL). We are in the process of transporting Customers and Crew into the terminal. The aircraft, a Boeing 737-700, has 143 Customers and five Crewmembers onboard. We are in the process of gathering more information. Safety is always our top priority at Southwest Airlines, and we are working diligently to support our Customers and Crews at this time. We will share updates to the flight as they are confirmed."

The airline was criticized on social media for its delayed and insufficient initial response.

At 05:21 p.m. Southwest CEO Gary Kelly issued a video message expressing his condolences on Twitter.

In each of these situations, social media significantly influenced how the public perceived the events and exerted pressure on the airlines to act more promptly and effectively.

6. DATA COLLECTION

Obtaining data from Twitter is difficult without the help of a program. Multiple sites offer to obtain data from tweets on Twitter but they have limitations in terms of the amount of data that can be collected as well as their design doesn't allow them to reach further in time than a couple of days or weeks. Twitter itself offers an application called Twitter API which stands for an application programming interface. Using a set of definitions and protocols, APIs are mechanisms that allow two software components to interact with one another. With Twitter API users can retrieve posts from the past with a limitation of 3200 tweets. Similar to Twitter API for scraping Twitter data is an alternative program called snscrape. Opposed to Twitter API, snscrape is free and can retrieve more data, and can be used anonymously. Snscrape uses Twitter's advanced search options to look for specific data which can be: tweets from or to a user, exact time intervals, use of hashtags filter for replies, etc.

An important step is to turn on the Hyper-V function in Windows features. Hardware virtualization is provided by Hyper-V particularly. This implies that each virtual computer uses virtual hardware to execute. Virtual switches, virtual hard drives, and a variety of other virtual devices can all be added to virtual machines thanks to Hyper-V.

6.1. Snscrape

To receive tweets using the snscrape program, Windows users must first install the Linux subsystem for Windows. With the help of Windows Subsystem for Linux, programmers can operate a Linux environment without the need for dual booting or a separate virtual machine. Windows Subsystem for Linux

(WSL) is a freeware program that is available to all Windows users from Windows Store. After downloading the Windows subsystem through Windows features WSL must be turned on to enable the functionality of Linux OS. The next step is installing the current Python version which is Python 3.11 (snscrape requires Python 3.8 or higher). The Python language is a collection of C libraries that you obtain when you download Python. You must have access to the Python compiler and language libraries to build your Python code. Lastly, the user needs a terminal environment to make a cross-platform application without leaving Windows, in my case I used Visual Studio Code. In the terminal environment user can download the snscrape package using the command line:

pip3 install snscrape:

7. ANALYSIS OF SELECTED AIRLINE CRISIS COMMUNICATION

In this section, we will examine how selected airlines have handled crisis communication in the past, with a focus on their response to the crisis and the effectiveness of their communication strategy on social media platform Twitter. This section will analyse three different crisis scenarios and airlines that were impacted by them.

7.1. Malaysian Airlines

The first accident is Malaysian Airlines Flight 17 (MH17), it was a scheduled passenger flight from Amsterdam to Kuala Lumpur that was shot down on 17th of July 2014, over eastern Ukraine (Donbas region), by pro-Russian separatists. All 15 crew members and 283 passengers on board of Boeing 777-200 died. The flight route was at the time declared safe and unrestricted by ICAO and IATA. At the time of the accident, Malaysian Airlines had approximately 515 700 followers on Twitter [14].

7.1.1. Crisis stage

Malaysian Airlines Flight 17 departed from Amsterdam at 12:15 CET. At 16:15 CET Ukrainian aviation authorities reported to Malaysian Airlines that they lost contact with the MH17 30 miles from the Russia-Ukraine border. During the crisis stage airline dealt with two major issues. The first issue was the crash of flight MH17 itself which immediately obtained a lot of worldwide attention. The second one was negotiating with pro-Russian separatists to obtain the remains and flight recorders from Malaysia Airlines Flight 17's crash site in eastern Ukraine.

Figure 4 - Initial response from Malaysian Airlines on MH17 accident Source: [Twitter]

The first tweet (Figure 4) was posted by Malaysian Airlines at 17:36 CET hour and 21 minutes after the Ukrainian aviation authorities report. The initial response from Malaysian Airlines was stating facts that Malaysian Airlines lost contact with MH17. The airline's response did not show any emotion or remorse while waiting for more information.

Figure 5 - Media statement 1 of MH17 accident Source: [Twitter]

AT 18:43 CET Malaysian Airlines released their first media statement (Figure 5) containing a link to their Facebook page with the message:

"Malaysia Airlines confirms it received notification from Ukrainian ATC that it had lost contact with flight MH17 at 14:15 (GMT) at 30km from Tamak waypoint, approximately 50km from the Russia-Ukraine border. Flight MH17 operated on a Boeing 777 departed Amsterdam at 12:15 pm (Amsterdam local time) and was estimated to arrive at Kuala Lumpur International Airport at 6:10 am (Malaysia local time) the next day. The flight was carrying 280 passengers and 15 crew onboard. More details to follow."

In the first media statement, Malaysian Airlines informed the public about information provided by Ukrainian aviation authorities and details about the flight and souls on board.

Figure 6 - Statement of Prime Minister of Malaysia Source: [Twitter]

At 23:24 CET Malaysian Airlines tweeted (Figure 6) a Statement by Prime Minister of Malaysia, Dato' Seri Najib Razak, who was in charge of negotiating with the leader of pro-Russian separatists – Alexander Borodai over recovering of remains and flight recorders of the MH17 flight. In this statement, the Malaysian Prime Minister stated that s all remains of bodies will be moved by train to Kharkiv where they will be handed over to representatives from the Netherlands responsible for additional transfer to Amsterdam on board of Dutch C130 Hercules. After the necessary forensic work is done, the remains of Malaysian citizens will be flown to Malaysia.

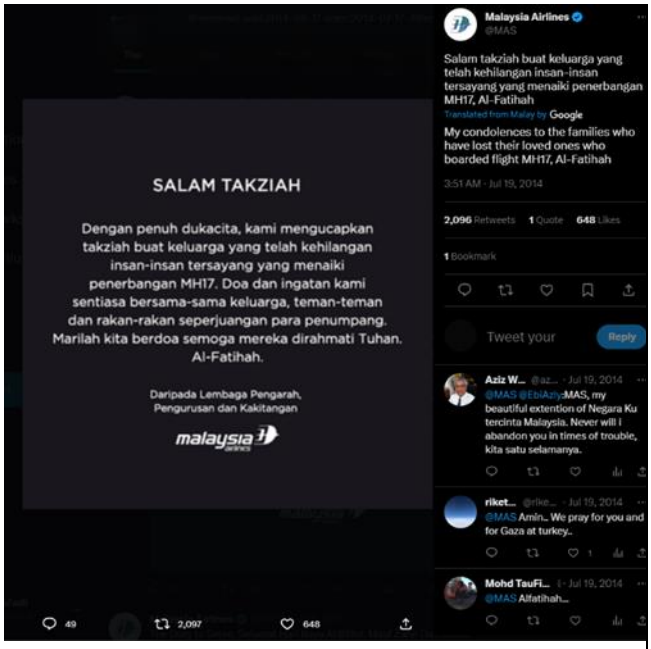

Figure 7 - Malaysian Airlines tweet towards victim's relatives Source: [Twitter]

The first tweet addressed to the victim's families was posted on 19th of July 2014 at 3:51 AM CET 35 hours after the accident (Figure 7). The tweet was written and posted in Malay, translation of the tweet is as:

"OUR SINCERE CONDOLENCES

With sadness in our hearts, we express our sincere condolences to the families of the occupants of Flight MH17. Our thoughts are with the relatives, friends, and colleagues of all 298 passengers. Let us pray together for the precious lives lost.

The Board of Directors, management, and staff of Malaysia Airlines"

The post showed compassion and condolences towards the families that lost their loved ones on flight MH17. Expressing compassion shows the company as a powerless victim, which makes stakeholders less critical and increases the likelihood that the company will be viewed favourably. However, Malaysian Airlines should have used English when they posted on their social media considering that the majority of victims on board MH17 were not Malaysians.

7.1.2. Post-crisis stage of MH17

The post-crisis period is when an organization begins to rebound back and return to business activities as usual. According to (Coombs, 2011 cited in Andreas, 2015) The time to fulfil any responsibilities made during the crisis communication phase, such as victim compensation and follow-up communication, is during the post-crisis period.

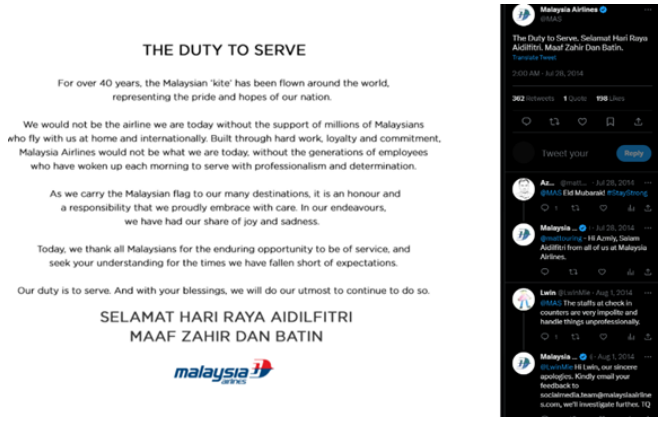

Figure 8 - Malaysian Airlines post crisis stage tweet Source: [Twitter]

As one of the first post-crisis stages of MH17 tweets, we can consider the post (Figure 8) from the 28th of July 2014 which is eleven days after the accident. The content of the tweet was reminding readers that Malaysian Airlines has a long history of 40 years. Airline appreciates their customers as well as their hard-working employees without whom they would not be where they are today. The airline seeks forgiveness for disappointing its customers and wants to keep improving in the future.

Figure 9 - Malaysian Airlines post crisis bolstering tweet Source: [Twitter]

Figure 9 is an example of tweets posted in the post-crisis stage by Malaysian Airlines. The catastrophic accident of MH17 left victims' relatives grieving over the loss of their loved ones. The airline used a bolstering crisis management strategy to create bonds and uplift or perhaps motivate the stakeholders.

"Tough times do not last, tough people do #staystrong"

Figure 10 - Malaysian Airlines tweets content Source: [Author]

Figure 10 shows that Malaysian Airlines during 1 month posted a total of 43 tweets. Malaysian Airlines chose to keep stakeholders informed about the crisis and posted 29(67%) of their tweets addressing the crisis. Brand engagement- 11 (26%) of tweets were the company's supportive and empowering thoughts addressed to stakeholders and victims of the accident. The company in this situation chose an adequate bolstering crisis response strategy to forge bonds in difficult times. The rest of the tweets were informational -3 (7%).

Table 2 - Social media metrics Malaysian Airlines Flight MH17 Source: [Author]

Airline	Malaysian Airlines
Percentage of posts with "like"	100%
Average number of "likes" per post	610.16
Popularity of messages among followers	11.8%
Percentage of posts with "retweet"	100%
Average number of "retweets" per post	2360.09
Virality of messages among followers	45.76%
Percentage of posts with "comment"	100%
Average number of comments per post	90.74
Customer brand engagement of followers	1.76%

8. CONLUSION

This paper aims on the use of digital media as a medium for crisis communication by airlines. Nowadays businesses have variety of options when it comes down to social media websites. Amongst the most popular social media platforms are Facebook, Instagram, Twitter and TikTok. All of above-mentioned social media sites have its advantages in different fields. When it comes down to product promotion businesses tent to use mostly Instagram or Facebook because of their reach, amounts of traffic on websites and their overall design. On the other hand, businesses tend to use Twitter as a platform to post quick, short but relevant information. These characteristics make Twitter ideal platform to inform stakeholders, customers and employees about situations that have recently occurred.

Twitter's design allows organizations to use their platform as their main tool for providing information during crisis. In this paper three different examples of accidents that followed with incorrect use social media are shown. All of these examples have one crucial mistake in common and that is a slow response time. In order to avoid criticism of public companies should improve their usage of social media and adapt to the fast paced social media environment.

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UNIVERSITY OF ŽILINA

PROPOSAL AND REALISATION OF A MODIFICATION TO AL-9 ENGINE FOR INSTALLING A FREE GAS TURBINE

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Abstract

This paper focuses on the creation of a prototype connection of the AI-9 engine with a free turbine for creation of an experimental turboshaft engine. We go through theoretical knowledge about the issue in which we work on the basis of which we created solutions. We worked with the teaching aids of the Department of Aviation at the airport in Žilina. We prepared these tools for work in the workshop and we made minor adjustments to the engine to make it possible to carry out our work. In our work, we used a procedure called high-fidelity prototyping. This means that we created a digital model on which we applied solutions. We decided to transfer our prototype to the digital environment due to low financial and time costs. We faced several design problems, including the need for a stator, the gap between the guide tunnel and the rotor, or how to connect to other components. We managed to find preliminary solutions for these problems and created a digital prototype of the resulting assembly. Subsequently, we presented the positives of our results and the method of their application in practice.

Keywords

turboshaft engine, free turbine, modification, proposal, connector

1. INTRODUCTION

This paper presents a solution for attaching a free turbine to an AI-9 engine. The AI-9 is an auxilary power unit used in the former Warsaw pact military helicopters like Mi-8 and Mi-24 and Jak-40 aircraft. It is a turboshaft type gas turbine engine with a power of 56 kW. It is manufactured by Ivchenko Progress and Motor Sich, corporations of Ukrainian origin, in three different variations. The base model and AI9-3B are used as starters by supplying compressed air to the main engines for startup. The AI-9V variant is used as an electrical generator to supply electricity to onboard systems.[1][2]

Figure 1 - AI-9 Engine

2. ENGINE CHARACTERISTICS

Table 1: General characteristics [1][2]

Type	Auxiliary power unit
Lenght	740 mm
Diameter	500 mm
Dry weight	45 kg

Table 2: Components [1][2]

Compressor	1-stage centrifugal
Combustors	Annular combustion chamber with 6 fuel injectors
Turbine	1-stage axial
Fuel type	JP-4

Table 3: Performance [1][2]

Maximum power output	56 kW
Overall presure ratio	2:8:1
Air mass flow	1.5 kg/s
Fuel consumption	120 kg/h max
Power to weight ratio	1.23 kW/kg

3. TURBOSHAFT ENGINES

A turboshaft engine is a variant of a jet engine that has been optimized to produce shaft power to drive machinery instead of creating thrust. Turboshaft engines are most commonly used in applications that require a small but powerful engine with low weight, including helicopters and auxiliary propulsion units. A turboshaft engine uses the same principles as a jet engine to produce power, that is, it contains a compressor, a combustion chamber and a turbine in the engine's gas generator. The main difference between a turboshaft and jet engine is that an additional power part consisting of turbines and an output shaft has been incorporated into the design. In most cases, the power turbine is not mechanically connected to the gas generator. Referred to as a 'free turbine', this design allows the power turbine speed to be optimized for the machinery it will power without the need for an additional reduction gearbox within the engine. The power turbine takes almost all the energy from the exhaust gas stream and transfers it through the output shaft to the machinery it is supposed to drive.A turboshaft engine is very similar to a turboprop, and many engines are available in both variants. The main difference between the two is that the turboprop version must be designed to support the load of the attached propeller, while the turboshaft engine does not need to be as robust as it normally drives a gearbox that is structurally supported by the vehicle rather than the engine itself. [5][6][7][10]

4. FREE TURBINES

In a free turbine engine, the propeller is driven by a separate turbine through a reducer. The blower is not on the same shaft as the basic engine turbine and compressor. Unlike a fixed shaft motor, with a split shaft motor we can change the pitch angle of the fan blades in flight or on the ground while the motor is on. The free turbine design allows the pilot to select blower speed regardless of engine speed. A typical free turbine engine design has two independent turbines that rotate in opposite directions. One turbine drives the compressor, while the other drives the blower through a reducer. In the diagram [Figure 2], the compressor is composed of three axial stages combined with one centrifugal stage. Axial and centrifugal stages are assembled on one shaft and work as one machine. Intake air enters the engine through the intake system at the rear of the engine and flows forward through the compressor. The flow is directed to the engine periphery by the centrifugal compressor stage through radial diffusers before entering the combustion chamber where the flow direction is reversed. The gases produced by combustion are reversed again and expand through the stages of the turbine. After exiting the turbine, the gases exit the engine to the atmosphere through an outlet at the front of the engine. Unlike conventional jet engines, exhaust gases are not used to create additional thrust. A pneumatic fuel control system adjusts the fuel flow to provide the desired power level. The speed of the blower remains constant at any position of the control lever using the propeller governor. The accessory drive at the rear of the engine supplies electrical current to the fuel pumps, fuel valves, oil pumps, starter/generator, and tachometer transmitter. [4][7]

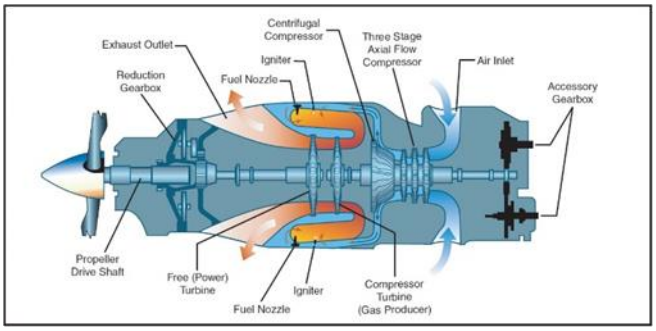

Figure 2 - Free turbine design

5. FREE TURBINE USAGE

Helicopters are a big market for turboshaft engines. When turboshaft engines became available in the 1950s, they were quickly adapted to new designs as a replacement for piston engines. They offered more power and much better power-to-weight ratios. The piston helicopters of that time barely had enough power. The transition to turbine engines made it possible to reduce engine weight and increase cargo capacity. Free turbine engines have proven to be a very good choice for helicopters. They do not need a clutch because the generator can be started while the drive shaft remains stationary. The resulting advantage is a quick start and take-off with a cold engine. By locking the main rotor with the rotor brake, the engine can be started and then, with the gas generator running at 10,500 rpm, the brake is released allowing the turbine to drive the rotor and reach its operating speed in 15 seconds and the time from engine start to take-off is 30 seconds.Another advantage of free turbine designs is the ease with which an opposing engine can be constructed, just turn the drive turbine. This made it possible to construct engines in pairs if necessary. It also allowed opposed engines, where having the turbine rotate in the opposite direction caused a reduction in overall torque and increased stability of the helicopter in flight. The flexibility of these engines allowed easy replacement of piston engines in existing designs where no emphasis was placed on engine layout. However, over time, a parallel horizontal layout placed above the cab became standard. Turboprop aircraft are also powered by a range of free or fixed turbine engines. Larger engines have mostly retained the fixed turbine design, although in many cases this is a twin-shaft arrangement where the main turbine drives the blower and low-pressure compressor, and the high-pressure compressor has its own turbine. Some large turboprops such as the Bristol Proteus or the more modern TP400 have free turbines. The TP400 is a three-shaft design, with two compressor turbines and a separate drive turbine. When the turbine is located at the rear of the engine, the turboprop engine requires a long shaft that leads to the front of the reducer to drive the blower. Such long shafts often pose a problem for designers, as it is necessary to pay close attention to limiting the removal of this shaft.For small turboprops, the free-turbine design has become dominant in modern times, and these designs are essentially all-round, where the intake is located on the front of the engine, driving air forward through the compressor to the combustor and then to the turbine at the front of the engine. This enables a substantial shortening of the shaft driving the propeller, as the turbine is placed much closer to the reducer. Such engines are easily recognizable due to their curved output gear. [4]

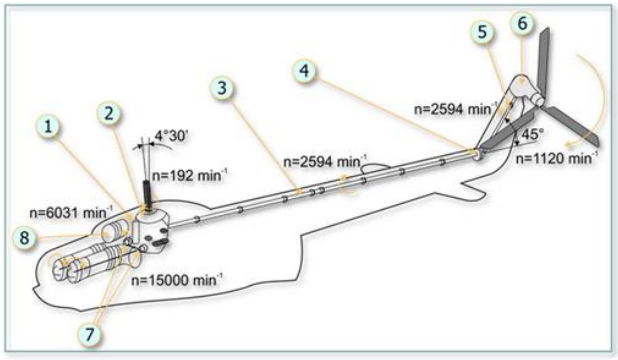

Figure 3: Engine placement in a helicopter

6. HIGH FIDELITY PROTOTYPING

Prototyping is an experimental process where design teams implement ideas into tangible forms from paper to digital. Teams create prototypes of varying degrees of fidelity to capture design concepts and test them.As the main goal of the paper, we set the creation of a digital prototype of the intermediate part that will connect the AI-9 engine and the free gas turbine. The essence of this goal determined the work techniques that we subsequently used in our work [11]

Advantages of prototyping:

- The existence of a solid foundation on which to test ideas and improvements.
- The possibility of rapid adaptation - it is possible to avoid investing too much in one idea, which, if it turns out to be wrong, can slow down or completely stop the development process and cause large expenses.
- Sample target product can be discussed with experts and target customers who can give us feedback
- The prototype is an ideal target for the application of new technologies and procedures that are not established in practice
- Reducing the time required to eliminate errors

Fidelity refers to the level of detail and functionality incorporated into the prototype. It may depend on the level of development in which the product is located and also on the purposes for which we are creating this prototype.

Low fidelity – An example of low fidelity prototypes are paper prototypes. They are fast and cheap, they are expendable, while allowing the rapid application of changes and new designs. However, the downside is the lack of realism, which can make delivering feedback problematic. We must also not forget that complex problems can look simple on paper and will not be given enough attention.

High accuracy – Examples of high-fidelity prototypes are digital models created using software such as SketchUp or Adobe XD. The advantage of digital models is that working with them is more reliable and the development team can better focus on the problems that need to be solved. Testing on these prototypes will produce more accurate results. The disadvantage is that they may take longer to produce and after a long production process the design team may look negatively at the need to make major changes to the prototype and choose a shorter but less perfect solution

When dealing with the creation of a new solution in a field such as aviation or other similar field, as well as for example rocket engineering, space engineering and aerospace technology, it is a common procedure to create several successive physical prototypes, which subsequently improve the errors of the previous prototype. For our situation, however, this is an unattractive approach, because creating individual prototypes is time- and material-consuming. It would also be financially demanding, because we would need the assistance of a third party, as we did not have the capacity to create such parts in the workshop at Žilina Airport. That's why we decided to transfer the entire problem to the digital environment. We achieved this by creating a 3D model, on which we applied solutions from a theoretical environment and evaluated their applicability and discussed the necessary adjustments without the time and material demands of classic prototyping. [11]

7. PART PREPARATION

Both the engine and the free turbine were available in storage at the Žilina Aerodrome, but they had to undergo a preparation before a solution could be contemplated. The free turbine did not require a mechanical adjustment, although the same could not be said about the engine. Free turbines are mounted after the propulsion turbine without being mechanically bound to it. However, this space was occupied by the exhaust apparatus, which neccesitated it´s removal, before anything could be attached. The removal of the engine exhaust did not neccesitate any special equipment and was succesfully removed with basic tools. After the exhaust was removed, the power turbine was exposed and the next phase of the preparation could begin.

Figure 4 - Exposed power turbine of the AI-9 engine

The next phase of the preparation consisted of taking measurements and considering possible theoretical problems and solutions. The flanges on both ends of the future conection part were very similar in size, being only 1cm different in diameter, however the number of holes on each side was different and incompatible with each other, meaning that it was impossible to create a connector with only a single flange,

neccesitating a desing with two flanges, which meant that the connector design had to be longer to allow acces to screws during assembly process.

Figure 5 -Free turbine with flange

8. CONNECTOR PART REQUIREMENTS AND DESIGN

One of the questions we encountered during the theoretical part of the design was the need for the static vanes. The rotors of the turbines rotate in opposite directions, which under normal conditions, would eliminate a need for static vanes in the flow of air before the free turbine rotor, but the distance between both rotors proved a challenge as the counter rotating turbine rotors need to be close to each other to provide the functionality of static vanes. The distance between the rotors would at best be 95 mm apart and that is if the two main components would be directly attached to each other, which, as was established earlier, was not possible due to the incompatibility of the flanges. This distance would be increased further by reasons of the flange desing, wich required both engine and free turbine to have it´s own attachment flange and because access directions to both flanges were opposite to each other, distance between both flanges had to be sufficient to grant access to tool required to securely attach both flanges to it´s counterparts. It was deemed that the theoretical distance was too great, and the connector part had to include static vanes on the side that would be attached to the free turbine. This had positive sideffect of providing structural support for a tunnel shaped connector and providing means of attaching a core of the tunnel to the outer shell. The next design requirement for the connector part was it´s abillity to direct the flow of air between the two main components without creating vortexes wich would radically diminsh efficiency and thus viability of the design. One side of the directive apparatus would be the central core in the tunnel between the rotors. It´s need arose from the fact that turbine rotors consist of a wheel surrounded by vanes, thus air flows only on the edges of the tunnel. This needs to be maintained in the tunnel as air flow impacting thecenter part of the free turbine rotor, which you can see in [Figure 5], would diminish the amount of energy the air flow would be able to transfer on to the rotor itself. Thus, the connector part would contain a central core of a conical shape with the top of the cone cut off to match the diameter of the central wheel of the free turbine. The base of the cone would match the diameter of the central wheel of the power turbine. Conical shape of the central core would be a result of a different diameter of the two rotors, the power turbine diameter being bigger, thus the conical core would be pointing from the power turbine to the free turbine. The second part of the flow directing shape would be the outer shell. It also would be of a similar shape as a core, the difference being the shell would be hollow. It would be dirrectly attached to the flanges and connected with the core through the static vanes. Both the core and the shell would pertrude beyound the flanges connecting them to the two main components of the assembly because the flow direction needs to be performed as close to the rotor of the free turbine as possible, the outer shell even petruding beyond the rotor of the free turbine. This is allowed by a gap bethween the rotor and the shell of a free turbine, which could be seen in [Figure 5]. This gap was measured to be between 7 mm and 8 mm, which is sufficient to insert a steel outer shell which could be thick enough to contain hot expanding gases powering the turbines. The flow directing core would need to be as close to the rotors as possible without touching them, ideally no more than one millimeter, to minimize efficiency losses. This however runs into a problem on the side of the engine, as the power turbine is attached by the means of four screws, as seen in [Figure 4]. Theese screws pertrude around 15 mm beyond the rotor. This means that the base of the core needs to have a dip in its center wich would be more than 15 mm deep and its outer diameter would be 30 mm or less smaller than the outer diameter of the cone base, thus allowing the power turbine rotor to rotate freely without being obstructed by the connetor part, yet thou outer diameter of the cone base would still be as little as 1 mm from the power turbine rotor, minizing efficiency loses due to air escaping into the gap. Attachment of the outer shell to the engine side is problematic a s the transition on this side has to be smooth to prevent interuptions to the flow of the air and vortex formations. Problem arises in the fact that the width of the shell cannot decrease indefinitely to allow for a completely smooth transition, as material too thin would be susceptible to melting by hot gases passing through the turbine. Also, some losses are expected due to a small gap between the engine flange and the outer shell of the tunnel. It could not be filled by insulating materials as those are also susceptible to the high temperatures present.

9. VISUALISING THE PROBLEM AND SOLUTION

For visualising all the components in a framework where we could apply theoretical solutions, we chose to create a 3D model of individual components and the assembly as a whole in a 3d modeling software. This method of creating results is preferrable, as creating physical prototypes would be costly and time consuming, since we are working with heavy materials such as steel. It would not only take a long time to make changes and apply them, it would also prove costly. For theese purposes, software chosen was Google SketchUp. Reasons for this choice of software in face of existence of more advanced 3D modeling tools were ease of access and ease of use, while being more than adequate for our purposes. First, we started by modeling the free turbine. It consisted of two comnponents in itself, which were the shell in which the turbine was placed, and the rotor.

The shell is a big cavity through which hot gasses travel to spin the rotor and then are directed outwards. The rotor consists of a metal wheel with 26 blades.

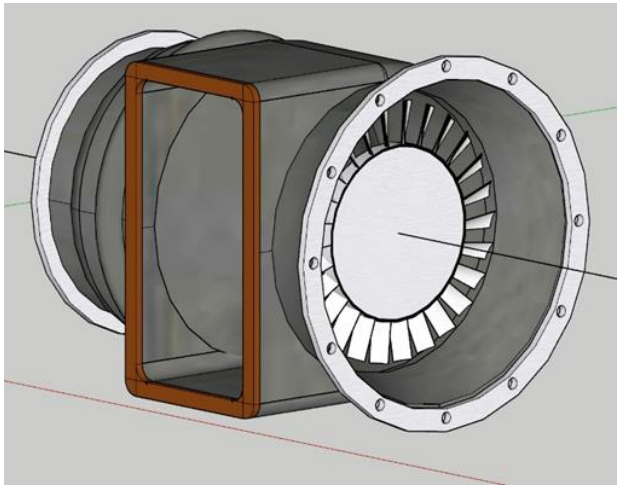

Figure 6 - 3D model of free turbine

Next up was the engine, we decided to model the outer shell and the contour, leaving out all the exterior accessories as it would only clutter the model. However, it was decided to model the most importand interior components for purposes of visualising flows of air in the engine.

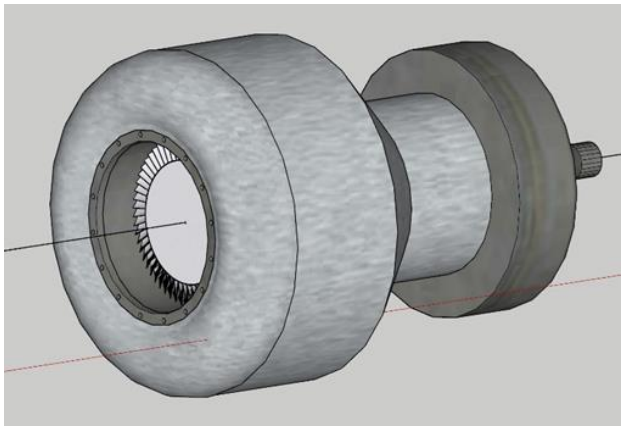

Figure 7 - 3D model of engine

10. RESULTS

The result of our effort was a model of a connector able to be attached to both engine and the free turbine, providing an abillity to use hot gasses that exit the engine for generating power with a free turbine. Connector part is of a peculiar shape as it´s inner parts pertrude beyond and into other parts. It consists of two flanges, one 5mm in lenght, second 10 mm lenght, connected with 50 mm long metal ring. In this ring, an air flow directing tunnel is located. This tunnel is of a conical shape, it´s base being on the side of the engine with a cutout to allow for rotation of the screws that attach the power turbine. The shape of the cone is cut off at the point where it´s diameter matches that of the rotor wheel seen in [figure 6]. On that side, the stator is located, consisting of 16 individual blades to guide hot gasses onto the blades of the rotor.

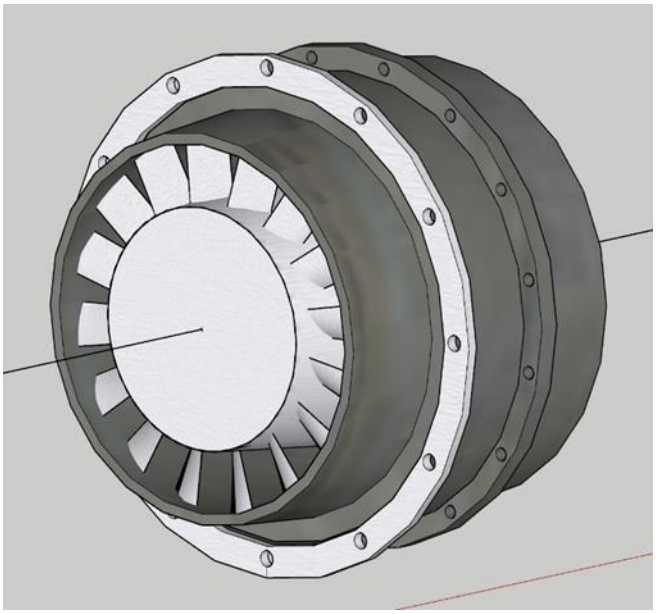

Figure 8 - Connetor part

11. ASSEMBLY

After the connector part was modelled, it was decidet to add all three pieces together and make an interior point of view to visualise how individual parts connect together on the inside and to help visualise how hot gasses flow through the resulting assembly

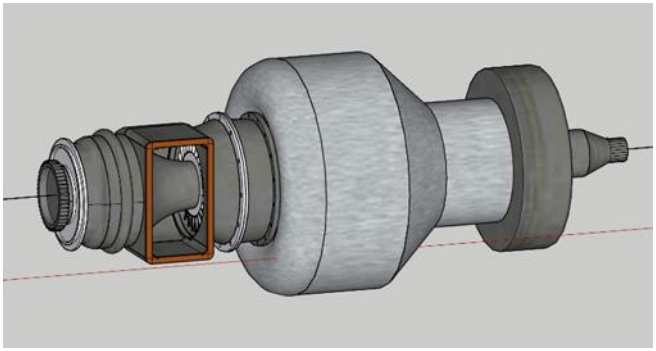

Figure 9 - Assembly

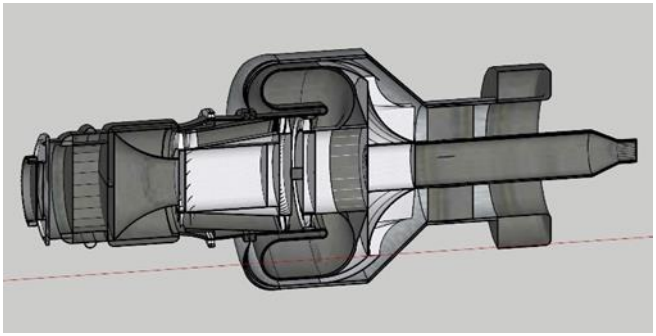

Figure 10 - Assembly interior

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UNIVERSITY OF ŽILINA

CONSTRUCTION OF A METEOROLOGICAL STATION FOR THE NEEDS OF SPORTS AVIATION

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Abstract

In this research, we are dedicated to the design and construction of our own meteorological station and its use in sports aviation. In the first part of the research, we deal with meteorological elements that occur in the atmosphere and their measurement by instruments. In the next part, we focus on the importance of observing and measuring weather in aviation and we point out situations that may arise due to adverse weather. Subsequently, we describe the devices that we use at our meteorological station. We mention the ranges in which they measure and the ways in which the devices work. Towards the end, we devote ourselves to the design of the prototype of our weather station and its construction and programming for proper functioning. Finally, we compare the measured results of our meteorological station and the meteorological station at the selected airport.

Keywords

meteorogical station, meteorogical senzors, programming

1. INTRODUCTION

Weather monitoring and forecasting is one of the most important activities in aviation. Its monitoring allows us to create an overview of the phenomena that occur in the given area. Especially at airports. Changes in the weather can lead to situations that can adversely affect the smooth running of air traffic at the airport. The information needed to create an overview of the current weather is obtained from professional weather stations located at airports. Weather reports in the form of METAR and TAF are further created from the measured values, which are used in flight planning or even during the flight to provide pilots with an overview of the weather in the given areas. These reports are generated at designated airports. Smaller airports located in the vicinity of designated airports use the METAR reports that were created for those airports.

Our goal is to create a prototype meteorological station using freely available sensors and devices. In the work, we will focus on the used sensors and devices, where we will discuss their characteristic features. We will discuss the ranges in which they provide the data, their connection to the Arduino microprocessor, and then their programming in the Arduino software.

During the acquisition of the necessary data, the station prototype will be located near the Žilina airport in the village of Kotešová for 14 days. With the use of sensors and their correct coding, we will be able to measure meteorological variables in the required formats. After the specified test period, we will subsequently compare and validate the obtained values in comparison with the values in the METAR reports issued at the given airport from the same period. By validating our values, we point out the overall accuracy of the devices and sensors used.

Finally, we will propose possible optimizations based on the information obtained during testing.

2. METEOROLOGICAL ELEMENTS AND HOW THEY FORM

2.1. Air pressure

The air around us has a certain weight and thus exerts a given pressure on everything it touches. The pressure it acts on is called atmospheric pressure or air pressure. Air pressure is the force exerted by the air from above on the surface due to gravity [1].

If the air reaches a high density, its weight also increases and, as a result, it exerts a greater force on the surface. It is also the fact that air pressure (mass by which air acts) decreases with increasing altitude, therefore the highest air pressure is observed at the earth's surface [1] [2].

Air pressure is one of the most important meteorological elements. Each of its changes causes a change in the atmosphere. Other meteorological elements such as temperature, solar radiation and wind are also associated with changes in air pressure. Changes in pressure occur constantly, so it is not possible to define a pressure standard for any area [2].

2.2. Wind

Winds are caused by different values of air pressure. The wind balances the pressure values by means of flow from high pressure to low pressure. Thanks to this, we observe cloudless and windless weather at the pressure level. On the other hand, in the pressure trough, we observe increased wind and accumulated clouds. In addition to equalizing pressure, wind generally moves energy, water, and the like in the atmosphere [2].

2.3. Sun radiation

In meteorology, an interesting part of solar radiation is electromagnetic radiation with wavelengths from 100 to 10,000 nm (nanometers).

- Ultraviolet radiation (UV) 100-400 nm
- Visible radiation (VIS) 400-700 nm
- Infrared radiation (IR) 700-1000 nm [3]

Solar radiation falling on the Earth warms the Earth's surface by absorbing the radiation and subsequently convection occurs. It is the conversion of solar radiation into heat, which causes the surrounding air to warm. Convection is the vertical upward movement of warm air. With its expansion, the warm air reaches a lower density than the surrounding colder air and begins to rise upwards, and the cooler air flows downwards and replaces its place, and the whole procedure is repeated. Such movement of warm air, gradually cooling through the atmosphere, creates clouds, which later contribute to precipitation [4].

2.4. Temperature

Air temperature or the overall temperature regime of the atmosphere is included among the meteorological elements, on the basis of which we are able to monitor temperature differences in a specific area or in the atmosphere as a whole. Using the average of the measured temperatures in a certain period and the amount of precipitation, we further determine the type of climate in the area. The device used to measure the temperature is a thermometer, located in the meteorological booth. We will discuss its exact location in the meteorological station later in the work [2].

2.5. Moisture/Precipitation

In the atmosphere, water occurs in all its states. The presence of water, humidity, in the atmosphere affects the weather to a very large extent. We observe water in the atmosphere in the form of clouds and precipitation that is produced from clouds (rain, frost, snow, fog, etc.) [2].

3. IMPORTANCE OF WEATHER FORECASTING IN AVIATION

Acquaintance with weather information is a basic duty of pilots before the flight, before departure and also during the flight. Adverse weather conditions can create situations where even experienced pilots have a problem with managing it during the flight. Safety always comes first, so it is very important to be familiar with weather information. In addition to the safety of the flight, great emphasis is also placed on the economy of the flight itself, which can also be adversely affected by the weather [6].

Aspects such as:

- Wind – Wind in general can cause major problems during flight. A headwind causes the aircraft to slow down in flight relative to the ground, but helps create a greater amount of lift during takeoff (a favorable aspect). In areas where there are mountains, it causes turbulence. Another adverse effect that the wind creates is crosswind. It causes difficulties especially when landing
- Precipitation – Heavy rain or other forms of precipitation affect the flight in ways such as aquaplaning, i.e. it lengthens the braking distance, the presence of clouds can reduce visibility
- Turbulence – Meteorological forecasts can indicate areas of turbulence so that pilots can safely avoid them
- Temperature – Low temperatures create dangerous situations at airports and airplanes (ice, frost, snow, etc.), but high temperatures also have an adverse effect (reduces the performance of airplanes).
- Visibility – Reduced visibility hinders the pilot's visual navigation. VFR flights are limited [6] [7].

3.1. Weather reports

On the ground, during planning, the briefing includes weather information, possible adverse conditions, current weather and conditions, in-flight weather, forecast and current weather at the destination, wind direction and speed at altitudes at which the flight will be carried out, airport forecasts (TAF) and meteorological reports (METAR) [6].

Efficiency and simplicity are some of the key factors that apply to aviation weather reporting. In aviation, we encounter weather reports mainly in the form of METARs and also TAFs. METAR is issued at designated airports of each country at an interval of 30 minutes. TAF is issued at airports with controlled air traffic at an interval of every 6 hours with a validity of 24 hours or 3 hours with a validity of 9 hours. The reports provide the flight crew with the most important information about the current weather at the airport and its surroundings [8] [9].

3.2. Impact of weather on air operations

We mentioned that weather changes or adverse weather conditions can create challenging situations for pilots. However, these conditions are equally demanding for employees who work at the airport, manage flight operations in the air or on the ground on airport areas, or even for the airport operators themselves [10].

3.2.1. Airport closure/diversion of flights

There may be a situation where very adverse weather conditions inevitably lead to the closure of the airport, as the safety of transportation would be greatly compromised. Flights are diverted to other airports and operations at a specific airport are suspended until the weather clears. Such situations also occur in our territory of Slovakia. For example, flight FR2366 from London Stansted Airport to Košice Airport on 13/11/2022 had to be diverted to Vienna Airport due to the fog created and accumulated at Košice Airport [10] [11].

3.2.2. Selection of take-off and landing runway

Wind speed and wind direction are the most important factors in deciding which take-off and landing runway will be used (if

the airport has two or more such runways). It is also decided in which direction the planes will take off and land [10].

There is a wind that does not flow in the direction of the runways, but its direction is across the runways. We refer to such wind as cross wind or side wind. Airplanes can generally take off or land only when there is no or minimal crosswind. Usually up to 25 km/h. As soon as the crosswind reaches a higher value, the aircraft is forced to use another runway or divert to an alternate airport [10].

3.2.3. Wind shear

This is a sudden change in wind direction or wind speed. It usually occurs during thunderstorms. Wind shear can be in the horizontal direction, but also in the vertical direction, which can lead to considerable complications in controlling the aircraft during takeoff or landing [10].

4. METEOROLOGICAL INSTRUMENTS

4.1. Thermometer

A thermometer, as a meteorological instrument, is used to measure air temperature. It is placed in a meteorological booth approximately two meters from the earth's surface. A second thermometer is often placed at the meteorological station, which is placed closer to the earth's surface. The temperature at the earth's surface has a different value than the temperature two meters above the surface. A suitably placed thermometer near the earth's surface will make it possible to better measure these temperature deviations and thus create a temperature image in the measured area [12].

4.2. Hygrometer

A device for measuring air humidity gives us data such as the air humidity itself in percent and the dew point temperature. The measurement of air humidity is often combined with the measurement of temperature due to the recalculation of the dew point, where it is necessary to know the relative humidity and temperature of the surrounding air [13].

In our case, as mentioned, we equipped the weather station with a sensor that detects air temperature and air humidity. By merging the sensors into one, we gain an advantage in our favor. The basic code that the sensor uses allows us to directly calculate the dew point values by defining the calculation in the sensor code. This way we get the data we need exactly [14].

4.2.1. SHT31

The sensor for measuring temperature, which we used in the construction of the weather station, has the designation SHT31. It is made of polymer. The sensor itself has a digital output and allows customization according to the user's needs (we can adjust the changes when coding the sensor). In addition to measuring air temperature, the sensor also has a sensor for measuring air humidity [14].

The SHT31 sensor ranks among the highest quality and most accurate sensors available at an affordable price. Air humidity measurement measures in the full range from 0 to 100% with an accuracy of ±2% and in the range from 20% to 80% with an accuracy of 0.01%. Air temperature measurement measures in the range from -40 °C to 125 °C with an accuracy of ±0.3 °C at 25 °C [14].

4.3. Anemometer + wind direction

An anemometer is a meteorological instrument used to measure wind speed. This instrument is one of the most important instruments that every weather station must have. This device allows meteorologists to monitor the wind speed and its changes in real time. Changes in wind speed represent very important information at airports due to aircraft taking off and arriving [15] [16].

Wind direction is used to determine the direction of wind flow. A horizontal rod, with a vertical vane at one end and a balancing body at the other, is mounted on a freely rotating shaft that allows the compass to rotate against the direction of the wind [16].

4.3.1. WH-SP-WS01 and WH-SP-WD

For the needs of measuring wind speed, we have chosen a suitable device with the designation WH-SP-WS01, which enables such measurement. It is made of plastic. The principle of operation of the device is based on sensing the revolutions of the sensor using a magnetic reed contact. The device uses a specified constant for calculating the wind speed (1 pulse = 0.33 m/s) [17].

The instrument for determining the direction of the wind that we decided to use has the designation WH-SP-WD. Specifically, this type of device is capable of direct connection to the already mentioned anemometer, which enables simple communication between the devices. It also works on a mechanical principle. The sensor has 8 magnetic switches which are connected to a resistor of different value. The rotating part of the device can touch up to two switches at the same time, which enables the indication of up to 16 different positions [18].

4.4. Barometer

A barometer is an instrument used to measure air pressure. As mentioned, the air exerts a certain force on the earth's surface and on everything it touches. We call this force pressure.

Atmospheric pressure tells us what the weather is like in a given area. Atmospheric fluctuations, including changes in air pressure, have a direct effect on the current weather in the area. The device measures air pressure in bars/hectopascals [bar/hPa] or atmospheres [19].

4.4.1. BMP 180

In our meteorological station, we used the BMP 180 sensor for measuring air pressure. It is a digital barometer that, in addition to measuring air pressure, also provides measurements of air temperature. As we know, with increasing altitude, air pressure decreases. The sensor has this information written in the code, and the sensor thus recalculates the height of its location according to the air pressure. Thanks to this, it can be used as an altimeter for aircraft models. It can determine the calculated

height with an accuracy of 17 cm to 50 cm according to the noise that arises between the communication of the airplane and the control device [20].

The range in which the sensor is able to measure air pressure values is from 300 hPa to 1,100 hPa, which actually represents 9,000 meters above sea level (300 hPa) and -500 meters converted from sea level (1,100 hPa) [20].

The sensor can measure the temperature in the range from -40 °C to 85 °C with a deviation of ±1 °C [20].

5. PROTOTYPE DESIGN OF OUR OWN METEOROLOGICAL STATION

5.1. Siting weather station

The correct location of the weather station is one of the most important things for the weather station to function properly and to provide the most accurate measurement results [21] [22].

5.1.1. Sunlight

Due to solar radiation, it is important to place the weather station in a place where there is no risk of shadow from surrounding obstacles (trees, buildings, etc.). It is also important to take into account the change of seasons, due to the change in the angle of incidence of solar radiation on the earth's surface, and thus the change in the lengths of the shadows of surrounding obstacles [21] [22].

5.1.2. Wind

An open space is also essential for the correct measurement of wind speed. A weather station that would be downwind of buildings or other obstacles will not provide relevant data on wind speed. To avoid adverse effects and deviations in measurements, it is recommended to place the weather station at a distance of 7-10 times the height of the highest obstacle in its vicinity [21] [22].

Example:

- Height of obstacle = 11 meters
- Station location = 77 – 110 meters

5.1.3. Temperature and humidity sensors

Sensors for measuring air temperature and humidity are largely influenced by the surface where they are located. Dark surfaces absorb more sunlight and emit more heat, which affects the accuracy of the measured values. Weather stations that are located over surfaces such as asphalt and gravel will measure significantly higher temperatures and lower air humidity values compared to weather stations located over grassy areas [21] [22].

Based on the above-mentioned information, it is important that the weather station is placed in the best possible conditions in order to prevent measurement errors [21] [22].

5.1.4. Standards

The installation of sensors at the weather station is also subject to established rules or certain standards, which must be followed in order to obtain the most adequate data [23] [24].

Sensor type	The height of the sensor	Sensor positioning
Air temperature Humidity	1,5 m ± 1 m (AASC) 1,25 m 2 m (WMO)	The sensors must be placed in a ventilated booth that will protect them from solar radiation. It is recommended that the sensors be placed at least 30 meters from concrete or asphalt surfaces.
Anemometer Wind direction	3 m ± 0,1 m (AASC) 2 m ± 0,1 m/10 m ± 0,5 m (AASC) 10 m (WMO)	The sensors must be at least 10 meters away from the highest obstacle

5.2. Designing and modeling and images from the design

For our prototype model, we need a device on which we will place individual sensors. We used a tripod whose height is approximately 200cm to meet the frame in which the sensors are to be placed. The device itself has a low weight and is foldable, which will allow it to be easily moved according to our needs during measurements. At the top, it has a shoulder on which an anemometer with a direction indicator can be attached, as well as an anti-radiation booth with sensors for measuring temperature, air humidity and air pressure.

The anti-radiation booth must be well ventilated for the accuracy of the readings and must above all protect the sensors from the heat radiated from the ground surface or obstacles. We modeled the anti-radiation booth in the Autodesk Inventor Professional program. We created the model of the anti-radiation booth so that it is easy to assemble. After modeling the booth in Inventor, we then printed it on a 3D printer [24].

5.3. Coding

The sensors we use need to be correctly coded in order to function. For coding, we used Arduino, which allows relatively easy coding of sensors using the libraries contained in its databases. Each sensor needs its own unique code, according to which it can perform its function. In the code, we can define what the given sensor should do, in what form we want the values to be displayed. With some sensors, we also add calculations from the values they measure to obtain the values we need.

6. TESTING OF THE METEOROLOGICAL STATION

Testing and subsequent validation of measured values from meteorological stations takes a long period of time. During this period, the data results of the tested meteorological station are compared with a station that has undergone this process in the past and is currently used as one of the main sources of weather data. The measurement accuracy of the devices, their deviations and also the reliability of the individual components are monitored in the specified time period. In our case, we tested the weather station over a short period of time, so the overall validation of our results is only informative. This means that the results measured by us cannot yet be used as the main sources of information, but only as possible supplementary information. The goal of testing is to achieve the highest possible accuracy of the values at our meteorological station in comparison with a professional meteorological station, according to which we compare the acquired results.

We decided to place our meteorological station for the given time period near the Žilina airport in the village of Kotešová. The location of the station was approximately 600 meters away from the extended axis of the runway. The aerial distance of the location of our station from Žilina airport was 1.7 km. We chose this location for our testing because METAR reports are issued at that airport. The regularity of these reports and their simple free availability allowed us to easily obtain correct information about the weather near the airport. METAR reports will serve us as data according to which we will evaluate deviations in the values measured by our meteorological station.

During the period when the weather station collected data, we accumulated METAR reports issued at a particular airport. We sorted the data according to the values needed for our comparisons.

For example:

- Wind direction [°]
- Wind speed [knots]
- Air temperature [°C]
- Air pressure at sea level [hPa]

7. DEVIATIONS OF MEASURED VALUES

In our results there were deviations of the values from the values of the METAR reports. Deviations can be observed for each measured element. We averaged the values we measured during the given interval and then rounded them to the nearest whole number. In order to better approximate the values of the individual deviations with which our devices measured, we created separate calculations. We calculated the differences in the given values for the entire test period and for all the elements we measured. We averaged the resulting differences in absolute values and thus calculated the average deviations for each measured element.

7.1. Wind direction

The average deviation measured by the wind direction indicator we used was 9.27 degrees. Due to the fact that the given instrument was able to measure wind direction angles from 16 different angles, and thus we point out the limited measurement range of the instrument, we can round the given deviation value to a value of 10 degrees. By using a more accurate instrument that would provide wind direction data in the entire angular range, such deviations could be avoided.

average value deviation	Wind direction
	9,27
average rounded value of deviation	10

7.2. 2Wind speed

The average deviation measured by the anemometer we used was 3.08 knots. The occurrence of the given deviation could be caused by the mechanical design of the device and its function of switching individual switches. In addition to the mechanical factor, the location of the weather station and the surrounding terrain also caused deviations. The anemometer we used was placed at a height of 2 meters, that is, at such a height the device provides data on the surface wind speed. The location of the anemometer of the professional station was according to WMO standards, which means its location at a height of 10 meters. Wind speed data at different altitudes will almost always vary due to the ruggedness of the terrain.

Average value deviation	Wind speed
	3,08
Average rounded value deviation	3

7.3. Temperature

The average value of the deviation measured by the SHT 31 sensor used by us was 0.23 degrees Celsius. According to the data measurement range specified by the manufacturer, the measurement accuracy range is up to 0.3 °C. During the testing period, we obtained values in decimal numbers and thus all air temperature data were rounded from these values. By real testing of this sensor, we proved that the stated measurement range data are real. We can eliminate the inaccuracy of the sensor based on the calculated deviation compared to the measurement deviation stated by the manufacturer. The resulting deviations could therefore be due to the use of insufficiently insulating material of the anti-radiation cover. By using a material with better characteristics, these deviations could be eliminated to a minimum.

Average value deviation	Temperature
	0,23

7.4. .Dew point temperature

The average value of the deviation in which our SHT 31 sensor provided dew point temperature data was 1.19 degrees Celsius. The accuracy of the measurement of the given value is not listed in any table, because we added this value to the sensor code based on the calculation from the obtained values provided by the sensor. The resulting deviations are therefore due to the

inaccuracy of the data measured by the sensor. In the previous part concerning the air temperature, we used the obtained deviation to verify the accuracy of the sensor when measuring the air temperature. Based on this fact, we can claim that the cause of the deviations in this case may be the insufficient accuracy of the air humidity measurement. The manufacturer states that the accuracy of the air humidity measurement is up to 2%, but this value could be verified if the given sensor was compared with the air humidity values measured by the relevant meteorological station.

Average value deviation	Dew point temperature
	1,19

7.5. Air pressure at sea level

The average value of deviation in which our BMP 180 sensor provided air pressure data at sea level reached a value of 1.86 hPa. The manufacturer states that the measurement range of the BMP 180 sensor is up to 2 hPa. The values obtained by us were within the specified range when compared with the values from the METAR reports. As we have already mentioned, the value of air pressure at sea level is recalculated based on the input value of the altitude of the location of the meteorological station and the obtained value of air pressure in the given area. Since the data on the altitude of the location of the meteorological station is fixed and changed only in the event of a change in the location of the station, we can thus declare that the resulting deviations in values were caused by the sensor range of measuring air pressure values in the given area.

Priemerná hodnota odchýlky	Tlak vzduchu na hladine mora
	1,86

8. CONCLUSION

The goal of our work was to design, model, program and test our own meteorological station. During the design of the meteorological station, we selected individual sensors with an emphasis on their accuracy of measurements and on their range in which they can measure the given values. We designed parts such as the anti-radiation cover and the server box with a focus on their practicality of use. We also emphasized the requirements of proper ventilation and protection of the sensors of the anti-radiation cover. We chose to use a specific tripod, where the given components were attached, on the basis of its simple folding and carrying over longer distances.

The process of modeling the components of the anti-radiation cover and the server box took place in the Autodesk Inventor Professional program. We then printed the modeled components on a 3D printer.

We programmed the sensors using the Arduino software, where we programmed the individual components according to our needs. During programming, the sensors were connected to the PCB board, which allows easy connection and disconnection of sensors and devices. Such a connection makes it possible to easily add or remove the sensors that we want to be connected. By using a PCB board, we avoided the possible problematic removal of faulty sensor connections. By using it, we got easier handling of device pins. We then stored them in the assigned locations at the weather station and plugged them into the server box.

Testing of our meteorological station took place near the Žilina airport in Dolný Hričov in the village of Kotešová for 14 days. We compared the results measured by us with the METAR reports that were issued at the given airport. We obtained data for comparing measurements from freely available internet sources.

By comparing the results, we gained an overview of the accuracy of the data measurements of our weather station. The measured values related to wind direction, wind speed, air temperature, dew point temperature and air pressure at sea level. We compared our measured values with METAR report values. Later, we addressed the factors that could affect the accuracy of our measurements. For example, the inaccuracy of the sensors, the distance of the location from the airport, insufficient thermal insulation of the anti-radiation shield material and others. Subsequently, we paid attention to the resulting deviations of the measured values and calculated the average value of the deviations for each monitored element. In the case of deviations, we discussed their possible origins and by calculating the average values of deviations for individual elements, we verified the accuracy of the data provided by the sensors we used. By calculating the average values of our deviations, we verified and confirmed the accuracy ranges of the sensors given by the manufacturer.

Based on testing over a short period of time, our measured data can only be considered informative and cannot be considered an adequate source of weather information. All the data measured by us serve only to demonstrate the accuracy of the measurement and the reliability of the given components.

By building, testing and providing the results of our weather station measurements, we have created a weather station concept that has many options for expanding it with additional sensors for measurements.

We proposed a possible optimization of our weather station by mentioning additional devices, sensors and their functions. With the use of the given sensors, a simpler operation of the meteorological station could be achieved.

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OPTIMIZATION AND SUSTAINABILITY OF CONVENTIONAL PROPULSION UNITS IN THE CONTEXT OF CURRENT ENVIRONMENTAL TRENDS

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Abstract

This article focuses on the current situation in the aviation industry in relation to environmental trends. In the introductory part, the situation on the aviation fuel market, their production and their current price is presented, while the emphasis is on familiarization with a more ecological form of traditional fossil fuels, namely sustainable aviation fuel. The reader is informed about the current situation in connection with emissions and greenhouse gases produced by air transport and the effort to reduce them and in the future their complete elimination. The second part presents the approach of aviation authorities such as EASA, FAA and ICAO, as well as their goals for reducing emissions and greenhouse gases and current projects for sustainable aviation. The article focuses on the implementation of sustainable aviation fuel in aviation and the issues associated with its use. The third part deals with the latest projects of aircraft and power units manufacturers. Other strategies such as CORSIA and ETS are presented, as well as climate conferences dealing with this issue. We point out the different approaches of countries in connection with the issue of reducing emissions. In the conclusion, we will evaluate the current situation with the economy and ecology in aviation from a global point of view, the actions of the authorities, manufacturers and point out the shortcomings.

Keywords

aviation fuel, sustainable aviation fuel, sustainable aviation, ecological strategies

1. INTRODUCTION

As in the whole world, in the world of aviation, ecology and sustainability is a hot topic. Aviation authorities are putting pressure on carriers to operate their flights in the most possible ecological way. In the terms of this direction, manufacturers of aviation equipment must also adapt, developing technologies that reduce the production of emissions of their aircraft and engines. Currently, aviation has focused on the development and implementation of sustainable aviation fuel (SAF). The use of sustainable aviation fuel is in initial phase and its price is high. The United States, as well as the European Union, are committed to further improving this technology, with the need to find new means, technologies, and also verify these technologies and build the entire infrastructure for the production of such fuel. The article also presents other options for reducing emissions, such as airspace optimization using free route airspace, functional airspace blocks (FABs) or improvements of SID and STAR procedures. The latest trends in aircraft and propulsion units manufacturing and their relationship to emissions reduction and sustainability are presented.

2. SUSTAINABLE AVIATION FUEL

The aviation industry contributes nowadays about 2% of the total carbon emissions of all industries, in the near future we expect continuous growth of air travel volume . Aviation has no sufficient short-term fuel alternative such as ethanol or electricity due to the energy density required, although it is possible to use jet fuel in fuel cells for local electricity generation in various applications.

Current aviation fuel production processes require huge facilities that are complex and expensive to operate, while the source of fuel production is oil. Reducing carbon emissions in the aviation industry is essential to combat global warming and increasing greenhouse gas concentrations. Use of alternative aviation fuel can achieve 50-95% reduction in carbon emissions and is therefore considered the most effective way to achieve carbon neutral aviation. For this reason, it is necessary and important to continue to address the used sources for the propulsion of aircraft engines to achieve a reduction in the emissions produced [1].

Biofuel, sustainable aviation fuel or SAF (Sustainable Aviation Fuel) is fuel that comes from renewable plant or animal sources. The energy of these fuels comes from biological carbon fixation, which is the conversion of carbon dioxide into organic compounds by living organisms. Examples of biofuels include:

- Bioethanol – alcohol produced by fermentation of carbohydrates found in crops such as corn. Non-food sources such as grasses are being developed for ethanol production
- Biodiesel – produced from vegetable oils and animal fats by a chemical process known as transesterification
- Methane - biogas produced by anaerobic digestion, decomposition of biodegradable material by microorganisms, from animal manure, waste from landfills or plant material [2].

Biofuels, if produced in a sustainable manner, can contribute more to climate change than fossil fuels mainly because, unlike fossil fuels, biofuels have the potential to remove carbon dioxide from the atmosphere during biomass growth as part of their

production and use cycle. A key strategy of this initiative is the development and widespread use of biofuels of the required quality in air transport. Significant and sustained research and development of biofuels suitable for use in aviation is relatively new. Currently, however, it is necessary to find an alternative to fossil fuels if we want to achieve real carbon neutrality and reduce the environmental burden. The current primary focus is on a sustainable "drop-in" biofuel suitable for use in turbine engines. "Drop-in" fuel is a fuel that can be mixed with fossil fuel-based fuel and used without requiring any rebuilding of engines, airframes, or fuel distribution systems. To be considered sustainable, a biofuel should come from renewable sources that do not displace food crops or compete with food crops for land or water use. Ideally, they will also have a carbon-neutral life cycle (growth/production/use) and it is also desirable that the growth and production of biomass stocks has a positive local socio-economic impact. Some of the oleaginous plants that meet these criteria include:

- Camelina – an oilseed crop used as a rotation crop in modern agricultural practices
- Jatropha - A non-edible drought tolerant plant that can grow on marginal land
- Algae – simple, photosynthetic organisms that can be grown in wastewater or seawater

Aviation biofuels produced from these and other crops are referred to as synthetic paraffinic kerosene (SPK) or esterified free fatty acid (HEFA) fuel. In 2011, the international aviation and fuel communities approved the blending of petroleum fuels and biofuels for use in commercial aviation [2].

Current SAF Facts:

- More than 450,000 flights have taken off thanks to the SAF
- There are 7 production methods
- More than 300 million litres of SAF produced in 2022
- SAF can reduce emissions by up to 80% during the entire life cycle.
- In 2022, the purchase of the SAF for approximately 17 billion US dollars is agreed
- So far, more than 50 airlines have experience with SAF [3].

Despite being touted as a solution to reducing carbon emissions, SAF is generally much more expensive than standard Jet A-1 aviation fuel. Airlines are therefore worried about how they will be able to use SAF, as they are expected to fulfil their emission obligations to the authorities, while the main reason for the slow integration is the price. IATA noted that with the right policy support, SAF could account for 2% of all aviation fuel by 2025. The year 2025 is therefore set to become a turning point in SAF's competitiveness in the field of fossil fuels.

Currently, SAF is neither plentiful nor cheap. In Europe, the typical price of fossil-based kerosene is €600/t, compared to SAF made from cooking oil, which can range from €950/t to €1015/t. Prices vary, but the total unsubsidized cost can be four times higher per gallon than regular jet fuel. The carbon savings from SAF, while significant, are also relatively expensive, measured in dollars per ton of reduced CO2 production. Politicians around the world are taking drastic steps to cut costs and increase supplies. In the US, tax credits and other financial incentives play a huge role in reducing the cost of SAF, while in the EU the proposed mandatory SAF shares are expected to be supported by an increase in their production. By 2040, we do not expect a significant reduction in SAF costs, as the availability of raw materials for certain types of SAF is limited, and the production and overall competitiveness of sustainable fuel types must also be significantly increased [4][5][6].

3. APPROACH OF AVIATION AUTHORITIES

Aviation authorities like the European Union Aviation Safety Agency (EASA), the Federal Aviation Administration (FAA), and the International Civil Aviation Organization (ICAO) have been actively involved in promoting sustainable aviation in recent years. The aviation industry is a major contributor to greenhouse gas emissions, and as concerns about climate change have grown, these authorities have recognized the need to take action to reduce the industry's impact on the environment. One of the key approaches of these aviation authorities has been to set environmental standards and regulations for the aviation industry. For example, the ICAO has established a set of environmental goals for the industry, which include improving fuel efficiency, reducing carbon dioxide emissions, and minimizing noise pollution. The ICAO has also developed a global market-based measure for carbon offsetting and reduction, known as CORSIA, which aims to offset the growth of international aviation CO2 emissions from 2020 levels.

The EASA, on the other hand, has been working on updating regulations to ensure that new aircraft designs and technology are more environmentally friendly. In addition, the EASA has developed guidelines for the certification of sustainable aviation fuels, which can be made from various feedstocks such as waste oils, non-food crops or municipal solid waste, among others. These guidelines provide a framework for the use of sustainable fuels that can reduce carbon emissions by up to 95%.

The FAA has also been taking steps to promote sustainable aviation. The FAA's Continuous Lower Energy, Emissions and Noise (CLEEN) program provides funding for research and development of new technologies that reduce emissions and noise. Additionally, the FAA has established a program to incentivize airlines to use more fuel-efficient aircraft, and has worked with the aviation industry to develop a voluntary program called the Aircraft Certification Environmental Program, which encourages the use of more environmentally friendly technologies and practices in aircraft design and operation.

Another approach taken by these aviation authorities is to promote the adoption of sustainable practices in the industry. For example, the ICAO has been working to promote the use of sustainable aviation fuels and has established a task force to develop guidance for the deployment of such fuels. The FAA has also been promoting the use of sustainable aviation fuels, and has worked with airlines to develop sustainable aviation fuel supply chains [7][8][9][10][11][12][13][14][15][16][17][18].

4. OPTIMIZATION OF THE AIRSPACE

4.1. Functional Airspace block

European airspace is divided into seven functional airspace blocks (FABs). A functional airspace block is an airspace management concept in Europe that involves the coordination and integration of air traffic services in a defined airspace block. The FAB aims to improve the efficiency and safety of air traffic management in Europe by reducing fragmentation and increasing cooperation between the various Air Navigation Service Providers (ANSPs) and their respective national authorities. FABs are established based on geographic proximity and operational requirements and usually consist of several neighbouring countries. Each FAB is governed by a specific set of regulations and agreements and is responsible for managing the airspace within its boundaries. The FAB concept was first introduced in 2004 as part of the Single European Sky initiative, which aims to harmonize and integrate air traffic management across Europe. FAB implementation has been gradual and as of 2021 there are nine FABs established in Europe covering most of European airspace [19][20].

Among the advantages brought by the implementation of FAB in the European airspace, we can include:

- Improved safety: By coordinating and integrating flight services in a defined block of airspace, FABs can improve safety by reducing the risk of crashes and other safety incidents.
- Increased efficiency: FABs increase efficiency by reducing airspace fragmentation and improving the coordination of air traffic services. This can lead to shorter flight times, minimization of delays and lower fuel consumption, resulting in cost savings for airlines and reduced environmental impact.
- Increased capacity: FAB increases capacity by optimizing the use of airspace and resources such as air traffic controllers and communication systems.
- Harmonization of regulations and procedures: FAB can harmonize regulations and procedures in multiple countries, making it easier for airlines to operate cross-border flights and reducing the administrative burden on air navigation service providers (ANSPs).
- Increased collaboration: FAB encourages increased collaboration between ANSPs and their respective national authorities, which can lead to greater sharing of expertise and best practices [19][20].

4.2. Free Route Airspace

Free Route Airspace (FRA) is a relatively new concept in air traffic control that allows aircraft to fly between designated entry and exit points in defined airspace without being restricted to predefined Air Traffic Control (ATC) routes. In FRA areas, aircraft operators can plan their preferred routes and flight paths based on their operational needs, and air traffic controllers ensure that all aircraft remain safely separated from each other.

FRA is typically implemented in upper airspace where there is less air traffic and more room for flexible routing. Increasingly, FRA is also being applied to areas of lower flight levels thanks to new and more accurate technologies and procedures. FRA is based on a new generation of air traffic management systems capable of tracking aircraft in real time and providing more accurate and timely information to air traffic controllers. These systems include Automatic Dependent Surveillance–Broadcast (ADS-B), which allows aircraft to transmit their position, altitude and other data to ground receivers, and the Airport collaborative decision-making (A-CDM) system, which allows all parties involved in flight operations to share information and make joint decisions. To ensure safe and efficient operations, air traffic controllers use advanced computer systems to monitor and control aircraft in real time and to ensure that all flights follow prescribed distances and are not compromised. Coordination with the neighbouring airspace sector and other stakeholders in the air traffic management system is also needed. Full implementation of the FRA is expected by 2025 [21][22][23].

By fully integrating this strategy into flight operations, it is possible to save:

- billion nautical miles
- 6 million tons of fuel
- 20 million tons of CO2
- Fuel worth 5 billion euros [21].

The proportion of flight time flown in FRA airspace was 68% in 2021, compared to 8.5% in 2014. We estimate that FRA implementation has saved 10 million tonnes of CO2 since 2017. This corresponds to approximately 170,000 return flights between Madrid and Riga. In order to advance cross-border implementation of FRA, NM (Network manager) should increase its efforts in the implementation of cross-border projects by air navigation service providers. In addition, the implementation of new airspace design projects by 2030 is expected to further reduce CO2 by 2.5-3.5% per flight with the current trend of increasing flight efficiency [24]. However, the goals of the ”Fit for 55” plan are to achieve a 55% reduction in the production of clean greenhouse gases, which means that the introduction of the FRA and its development will only contribute very little to meeting these regulations and goals.

4.3. SID&STAR

SID and STAR are two commonly used terms in aviation related to aircraft navigation. SID stands for Standard Instrument Departure. This is a published procedure for navigating an aircraft from the airport runway to the en-route flight phase using designated navigation points. The purpose of the SID is to ensure the safe and efficient flow of traffic by providing a predetermined route for departing aircraft. SIDs include altitude and course limitations, as well as information on required radio frequencies and communication procedures.

STAR stands for Standard Arrival Route. It is also a published procedure that navigates pilots using predetermined waypoints from the flight phase to the landing phase. The purpose of STAR is to ensure the safe and efficient flow of traffic by providing a

predetermined route for arriving aircraft. STARs contain altitude and speed restrictions as well as information on required radio frequencies and communication procedures [25][26].

One of the disadvantages of SID and STAR is that they can increase the complexity and workload of pilots and air traffic controllers. These procedures require both parties to be highly skilled and experienced, which can be challenging for less experienced pilots and controllers. This can lead to delays and problems, especially during periods of high traffic. Another disadvantage of SIDs and STARs is that they can be restrictive and inflexible. For operational reasons, pilots may prefer to use their own routes or deviate from the prescribed route, but this is not always possible. This can lead to inefficiencies and delays as pilots may be forced to steer the aircraft along a fixed route. In terms of environmental sustainability, SID and STAR can have a negative impact on noise and air quality, especially in areas near airports. Aircraft following these procedures may produce more noise and emissions, which may affect local communities and the environment.

When simulating a flight from Amsterdam Airport to Frankfurt Airport, the effect of different parts of the route on the flight time was fully tested using three types of flights. The first case was a typical flight plan that would currently be executed using SID and STAR and navigation using waypoints. Two more test flights were conducted to see what effect each particular variable had on flight duration and efficiency. The second test flight used only SID and STAR, but did not use waypoints after the final waypoint on SID was reached or until the first waypoint on STAR was reached. The last test flight was done without using any SIDs or STARs or waypoints and was essentially flown straight through. The results show that simplifying the flight plan by removing waypoints and/or SIDs and STARs significantly reduces flight time and fuel consumption. From the results, it can be seen that on this particular route, the removal of waypoints does not bring any significant benefits, as only 1 minute of flight time is saved. The fuel saving is slightly more, 2.4%, compared to a flight using waypoints. The same can be said about the distance saved, which decreased by only 7.4%. When SID and STAR are removed from the flight plan, the benefits are much greater. When it comes to time saved, there is a big advantage over flying a typical route, saving a total of 12 minutes (22%). Fuel savings of 21.5% are also significant.

From the above results, it can be concluded that there are advantages for short flights using SID and STAR and without waypoints compared to the current way of conducting the flight. Significant reductions in fuel consumption and time can be achieved if flights are operated on direct routes regardless of any restrictions [22].It should be noted, however, that efforts are constantly being made to optimize the use of SID and STAR, including the use of RNAV (Area Navigation) procedures, Continuous Descent Operations (CDO), flexible procedures and dynamic airspace configurations.

5. THE LATEST PROJECTS OF ENGINE AND AIRCRAFT MANUFACTURERS

5.1. Airbus

The Airbus A321XLR is a long-haul narrow-body aircraft project. Airbus A321XLR has a longer range, which is up to 15% greater than the previous version of the A321LR. It can fly a distance of up to 8,700 km and has a capacity of up to 220 passengers. Intergenerational progress amounts to 30% less consumption per passenger. The main reason for the development was the need to provide transport capacity and a range that would allow the operation of the aircraft in an even greater horizon. In addition, the cargo space and the usability of the cabin for passengers have also been improved. Other improvements include a new and more powerful engine that delivers lower fuel consumption and thus lower running costs. Aerodynamic improvements contribute to reducing drag and increasing flight efficiency. Thanks to new avionics technologies and instruments in the cockpit, the controllability of the aircraft and the safety of operation are improved. The Airbus A321XLR has won the favour of many airlines due to its improvements and advantages. Hundreds of these aircraft have already been ordered as proof. Thus, the A321XLR is one of the most successful aircraft projects today and is expected to be an important player in the market for years to come [27][28][29].

Airbus ZeroE is a project that aims to create the world's first zero-emission commercial aircraft. The goal of the project is to lead the entire aviation industry to decarbonization and reduce the negative impact of aviation on the environment. The main energy source for the Airbus ZeroE propulsion is hydrogen, the combustion of which produces no emissions. Three conceptual models were revealed as part of the project. The first concept is a jet engine with a range of more than 2,000 nautical miles, capable of operating across the continent and powered by a modified hydrogen turbine engine. Liquid hydrogen will be stored and distributed using tanks located behind the rear pressure dam. The second concept is a turboprop design that is also powered by hydrogen. This concept would be able to fly more than 1,000 nautical miles, making it a good choice for short flights. A third concept is a blended wing aircraft in which the wings are joined to the main body of the aircraft with a range similar to the turbine design concept. The exceptionally wide hull section opens up multiple options for hydrogen storage and distribution and for cabin layout. The ZeroE project is still in the conceptual stage and Airbus plans to continue to develop and refine the designs in the coming years. The company aims to have the ZeroE aircraft in commercial operation by the mid-thirties. Airbus has pledged to be able to produce aircraft with zero carbon dioxide emissions by 2035 [30][31].

The Airbus Maveric project aims to develop a new type of aircraft with an asymmetrical design of the fuselage and V-shaped wings, which should be able to reduce fuel consumption and carbon dioxide emissions. This aircraft should be suitable for short routes and should be able to significantly reduce the noise produced. The first prototypes of the aircraft are currently being tested, and it is expected that it could enter service within the next few years. According to estimates, the Airbus Maveric aircraft should be able to reduce fuel consumption and carbon dioxide emissions by 20%, with a positive impact on the environment and climate change. The Airbus Maveric project is an important step for the company in its efforts to improve the environmental sustainability of aviation [32].

Airbus is also dealing with the issue of SAF, considering its use as a key strategy to reduce the environmental impact of its aircraft and operations. Airbus has set a goal for all its aircraft engines to be certified for the use of 100% SAF by 2030. This goal

is part of the company's broader efforts to reduce its carbon footprint and contribute to the decarbonization of aviation. Airbus is also involved in several projects

5.2. Boeing

Among his current most promising projects we can include:

- Production of the 777X aircraft
- Recycling of materials
- Development of recyclable materials
- EcoDemonstrator project

The Boeing 777X represents the latest generation of commercial aircraft produced by the company. The Boeing 777X uses the latest technologies, including advanced on-board systems that allow the aircraft to achieve high flight efficiency and safety, improved flight control and navigation. Thanks to these technologies, it can significantly optimize fuel consumption and thereby reduce emissions. One of the most significant advantages of this project is its high capacity. The Boeing 777X can carry up to 425 passengers, which is 20% more than its predecessor, the Boeing 777-300ER. Another advantage of the Boeing 777X project is its fuel efficiency. The aircraft uses state-of-the-art GE9X engines, which are 10% more efficient than the engines of its predecessor, the Boeing 777-300ER. According to data from Boeing, the Boeing 777X is up to 12% more fuel efficient than its closest competitor, the Airbus A350-1000. Boeing has also significantly worked on the lower noise level of the aircraft due to increasingly strict standards around airports [33][34].

Boeing has long-standing commitments to recycling and developing new eco-friendly materials, environmental protection and sustainable development. The company is committed to reducing greenhouse gas emissions, minimizing waste and using renewable energy sources. As part of these commitments, the company has developed various recycling projects. An example can be cooperation with the company ELG Carbon Fiber for the recycling of carbon fibers from aircraft production [35][36].

The Boeing EcoDemonstrator is a project that aims to improve the environmental sustainability of aviation by testing new technologies and innovations. One of the main areas of focus of the EcoDemonstrator project is fuel technologies. Boeing is testing different types of biofuels made from different sources, such as vegetable oils, waste oils and even residues from alcohol production. In addition, Boeing is also testing new technologies that enable better monitoring of aircraft emissions The Boeing EcoDemonstrator tests new materials and structural elements that can help reduce the weight of aircraft and thus further increase their efficiency. Boeing EcoDemonstrator also tests new technologies in flight operations. Boeing has been testing new technologies that allow pilots to use alternative flight paths that minimize the amount of fuel that is consumed during flight [37][38][39].

5.3. Embraer

The company's latest project is the E2 project. The E2 is a project of Embraer's newest aircraft series. These planes are intended for 80 and 132 passengers respectively in the largest version, so we can consider it as a smaller transport plane. Embraer was able to achieve up to 25.4% higher fuel efficiency per passenger than the first E series, while it has 10% lower fuel consumption compared to competing aircraft. In this way, they were able to adapt to the current trend of using smaller but more efficient and profitable aircraft. The E2 series also reduced noise by up to 65% compared to the E series, thanks to the use of noise-absorbing materials, air conditioning dampers and improved chassis aerodynamics. The use of new power units also contributed to the reduction of noise, which allows aircraft to optimize the flight path and thus increase fuel efficiency. Thanks to this, it can reduce the production of emissions by 30%, 37000kg per flight, which represents 1 million tons of CO2 of a fleet of 10 aircraft of this type in 10 years [40][41][42].

The Energia project is the latest project of the Embraer company, where it also cooperates with Air New Zealand and Ruili Airlines. Embraer presented four concepts of the Energia program as its vision for sustainable aviation with zero emissions until 2050. The concepts included the Energia Hybrid project in the form of a nine-seater aircraft with electric motors with a range of at least 926 km and a single-piston engine, and the Energia Electric project, in which they presented a fully electric nine-seater aircraft. The third concept was the Energia H2 Hydrogen Fuel Cell, a 19- to 30-seat aircraft using fuel cells to convert hydrogen into electricity. The fourth was the gas turbine-powered version of the Energia H2, a 35- to 50-seat aircraft with two gas turbines that would use hydrogen for short flights and sustainable aviation fuel (SAF) for longer flights. Emissions reduction of up to 90% is estimated for these aircraft [43].

6. CONCLUSION

The aviation industry makes great efforts to comply with the requirements of aviation and governmental authorities (e.g. EU)authorities. The introduction of sustainable aviation fuel into air transport is a complex issue, financially extremely costly and lengthy process, and therefore we currently perceive its benefits as minimal. It will take a long time to develop and build the entire infrastructure for its production. By optimizing the airspace, better results would be achieved in a shorter period of time, but especially the reduction of emissions created by air transport to achieve significant goal in climate change protection. If we focus at air transport from a global perspective, it creates less emissions and greenhouse gases than other means of transport, such as road and shipping. Also, the inaction of some states in activities aimed at the sustainability of air transport, but also in industry, such as China, degrades the efforts of participating states to create a sustainable aviation, in which billions of dollars are invested to develop new technology and innovation.

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DESIGN AND IMPLEMENTATION OF AN ALTERNATIVE ROTAX 915IS ENGINE MANAGEMENT SYSTEM

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Abstract

The content of this article is design and implementation of an alternative Rotax 915is engine management system. In my research, I worked with a wide-spectrum control unit ECU MASTER designed for the optimization of the injection time of spark-ignition engines and also the control of the ignition advance taking into account several sensors of engine input parameters. The article was created as part of research into the issue of optimal control of piston engines. Current methods of controlling engines and their systems, in principle, allow very precise control of important systems of modern piston engines, especially with regard to the ignition and fuel system. The inclusion of microprocessor units with multiple options for input parameters allow the control unit to take into account even less important parameters, which, however, help the control unit to keep the engine running smoothly while maintaining high combustion efficiency. The elaborated design of a possible alternative engine control system is subsequently connected with the practical realization of this control system. The result of the research is the design of the control system of the Rotax 915is engine and the subsequent practical production and adjustment of the control unit under the name ECU MASTER, which verifies the universal applicability of such a unit for various combustion engines.

Keywords

engine management, piston engine, ignition system, fuel system, ECU MASTER

7. INTRODUCTION

The aviation industry is an ever-evolving industry that emphasizes new technologies and improvements to increase the efficiency of various components. In my work, I therefore focus on an alternative way of controlling the Rotax915is engine. It is a four-cylinder piston engine, mainly used in ultralight aircraft, sport aircraft or home-made aircraft. The main goal is to "revive" the exhibition piece. One of the tasks in carrying out the research was to ensure the lowest possible costs with the limitation of purchasing original system parts. This involved making the best use of the parts and components we had physically in the workshop. I worked with a classmate on starting the engine. In my part of the work, I mainly focused on designing the fuel, oil and cooling system. In my research, it is also important to mention the ECU master Ignition control unit, which we used to set the parameters when starting the engine. We did not have to buy the control unit and thus eliminated the expenses associated with the control member of the drive unit.

8. INTRODUCTION TO THE ISSUE

A piston engine is a very complex system that consists of many interconnected parts. For optimal engine performance, all components must work in balance and harmony.

Engine control is a process that controls the operating behavior as well as the engine itself. The main goal is to maximize the efficiency and performance of the drive unit. For the desired behavior of the engine, the correct timing of the fuel injection, the timing of the ignition and the correct moment of opening and closing of the opening and exhaust valves are important. The air-fuel mixture is also a very important aspect of improving performance and engine response. The controls also check engine parameters such as engine temperature, oil pressure and, last but not least, exhaust emissions. By optimization control of piston engine we can reduce fuel consumption, in connection with the reduction fuel consumption, reduce exhaust gas emissions and ultimately increase performance engine.

9. CURRENT STATE OF THE SOLVED PROBLEM

In the past, piston engine control was much simpler and less sophisticated like today. Early engines used a carburetor to mix air and fuel and relied on for manual choke and throttle adjustments to regulate engine power. They were later introduced electronic ignition systems that allowed for more precise control ignition timing. However, these systems still relied on simple mechanical components and lacked the advanced sensors and computing power of modern ones engine control systems. [1,2]

9.1. FADEC

"Full authority digital engine control" (FADEC) is a computer controlled system aircraft engine ignition and control. It consists of a digital computer, called "Engine Electronic Control Unit" (EEC) or "Engine Control Unit" (ECU) and other accessories. The FADEC system can be used with both types engines, both jet and piston. It will find its use in modern commercial aircraft but also military aircraft, for digital control of all aspects of the engine instead of technical or analog electrical controls. [2]

FADEC systems respond to pilot inputs, using data from sensors such as for example, engine temperature, engine pressure, fuel flow, air density and others automatic adjustment of engine settings, which ensures performance optimization. There are inputs analyzed up to 70 times per second. The systems are self-monitoring, while including system redundancy aimed at preventing failures. The system has 2 channels, the first is active and the other is in the so-called in "standby" mode with activation in case of failure. [2]

9.1.1. Applicability in piston engines

The FADEC for reciprocating engines works by using a digital computer continuously monitors and controls engine operation. The system adjusts fuel injection, timing ignitions and other variables based on data from various sensors such as sensor throttle position, air flow sensor and oxygen sensor. [2,3]

With the FADEC system, engine performance can be optimized for a wider range operating conditions, including changes in altitude and temperature. The system too it can detect and repair engine faults, improving safety and reliability. [2,3]

10. THEORETICAL KNOWLEDGE

A piston engine is a type of internal combustion engine that converts fuel into mechanical energy by using the force of the expanding gas. Basic principle of operation of a piston engine is the compression of the mixture of air and fuel in the cylinder. It will then be pressed and expands rapidly after ignition. The induced pressure on the piston converts thermal energy combustion to mechanical. [1,4]

In the case of combustion engines, we start from the second theorem of thermodynamics. It follows that the conversion of thermal energy into mechanical work cannot take place voluntarily. Heat machines operating in circulation are used for such a change of work. [1,4]

10.1. Otto Cycle

He is considered to be the first creator of an internal combustion engine working in a four-stroke cycle the German Otto Nikolaus, after whom the Otto cycle is named. At present ho we know in connection with the ideal analysis of the spark-ignition combustion cycle. When analyzing we considers an instantaneous constant volume combustion process. Analysis provides an overview of the engine's efficiency under changed conditions, whether of construction or appearance for operation. [4]

10.1.1. Otto cycle diagram

The diagram defines the phases depending on pressure and volume. By displaying all phases in one diagram, the space was bounded by two adiabats and the same number of isochores. [4]

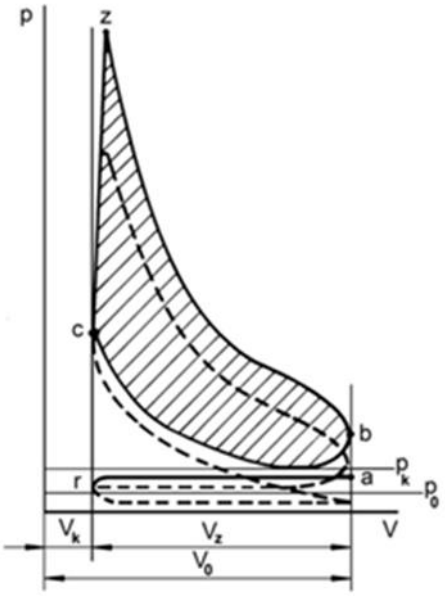

Figure 1 - Engine indicator diagram with and without turbocharging

10.1.2. Work cycles

With a four-stroke gasoline engine, we are talking about four cycles during which it changes the composition and condition of the working substance with which the engine works. They take place in a very short time physical and chemical processes that repeat for two revolutions of the crank shaft. [5]

- Suction
- Compression
- Expansion
- Exhaust

10.2. Piston combustion engines

For the drive of various means of transport, devices or construction or others mechanisms, combustion, electric, steam or solar engines are mostly used. Most often, however, we find combustion engines that convert thermal energy into mechanical work. A suitable type of fuel-air is burned in the designated space mixtures. The mixture ratio is adjusted with regard to the requirement of rapid ignition and burning without the rest if possible. In piston engines, the transfer of thermal energy takes place in the four work cycles mentioned above. The released energy from the fuel is transferred to the piston in the form of gas pressure, which causes the movement of the piston in the engine cylinder. Sliding the movement of the piston is transformed into a rotating movement with the help of the crankshaft. [6]

10.3. Ignition system

In gasoline engines, one of the most important systems is the ignition. Ignition system in a piston engine is responsible for providing the spark that ignites the fuel mixture and air in the combustion chamber of the engine. Modern ignition systems

use computer controlled sensors for optimization spark timing and ensure that it occurs at the right moment for optimum combustion. Some systems also use multiple spark plugs to ensuring complete fuel combustion. [5]

10.4. Fuel system

The fuel system of the piston engine is responsible for supplying fuel to the combustion chamber chambers. Fuel is usually stored in the fuel tank and distributed by the fuel pump pipe pumped from the tank by the fuel pump. When the fuel is fed to the engine, it mixes with air in the carburetor or fuel injection system to form flammable mixture. A carburetor is a mechanical device that mixes fuel and air in the correct ratio, while the fuel injection system uses electronic sensors and fuel supply control injectors. When fuel is mixed with air, it is ignited by the spark from the spark plug, creating the power that drives the engine. Fuel system is a critical part of the engine and proper maintenance is essential for optimum performance and fuel economy. [5,7]

10.4.1. Injection

Injection of volatile fuels is not just a modern trend. Its primal it was used in aircraft engines, where it performed not only the function of good atomization mixture but also met important conditions. The main task of injection is to create a precisely determined ratio of fuel and air. The injected fuel must be in a certain proportion to the amount of air taken in. [6]

10.5. Lubrication system

The piston engine oil system is responsible for lubricating the moving parts of the engine, reducing friction and wear and heat dissipation. The oil is usually stored in an oil tank in the tub under the engine and is sucked into the engine by a pump. The oil then circulates through the block engine and cylinder head, where it lubricates components such as the crankshaft, connecting rods and cam shaft. As the oil circulates, it takes the heat generated by the engine and conducts it to the radiator oil, where it cools before returning to the engine. The oil also helps clean the engine by captures and suspends dirt and metal particles that can cause damage. Over time, the oil can become contaminated and break down, resulting in reduced lubrication and increased wear and tear. It is important to regularly check and change the oil so that ensured proper lubrication and engine performance. [6]

10.6. Cooling system

The piston engine cooling system is designed to maintain optimum operating temperature of the engine by removing the heat generated during combustion process. This is typically accomplished by circulating coolant through the engine block and head a cylinder that absorbs heat and sends it to the radiator to dissipate it. There is coolant usually a mixture of water and antifreeze and is circulated by a water pump. In addition to the liquid cooling system, some engines are also air-cooled components such as cylinder fins that help dissipate heat. [6]

10.6.1. Air cooling

The basis of this type of cooling is the flow of air flowing around the engine parts. It is a system of direct heat removal into the air. To ensure sufficient cooling, it is necessary that the components and the motor have the largest possible contact surface with a flowing medium, which is ensured by the cooling ribs. This heat removal process is increased by the speed and nature of the air flow, the material of the structure orcombinations. [6]

10.6.2. Liquid cooling

For more efficient cooling, a liquid with a higher specific heat is used, which it has resulting in more intense transmission. The heat-carrying medium is mostly distilled water mixed with antifreeze. The entire system works under pressure and is therefore pro the liquid more difficult to reach the boiling point. Excess pressure is released by the radiator cap, so as not to damage the integrity of the cooling system. Accumulated thermal energy in the medium it is supplied to the heat exchanger through the casing, the double wall of the head and the cylinder blocks. In exchanger, the heated liquid is cooled by air, which ensures heat removal to atmosphere. The liquid cooled in this way returns to the engine and cycle ensures a constant supply of cooling medium. The thermal energy of the liquid is also used for heating in the medium. [6]

11. WORK METHODOLOGY

All Internet sources and book publications were searched using the literature search method. By comparison, all available resources were compared. By subsequent choice and selection resources suitable for the work have been allocated. The main content of the information is contained from book publications, but it is appropriately supplemented with professional, electronic sources. Work and obtaining information is carried out by the method of processing when it is obtained necessary information on individual areas of the issue. The analysis obtained a detailed view of the individual drive unit systems. Information we have received so far were used in other parts of the work. Suitable alternatives were selected using the method of analogy components of specific systems to ensure functionality and propulsion requirements units. Using the experiment method, they were constructed on the basis of the obtained information drive unit systems. During testing, individual systems were tested separately and leaks and design issues were eliminated. Subsequently, it was examined by observation functionality of the system after successful implementation. Testing resulted in results at starting the drive unit as a whole.

12. WORK RESULTS

The practical part of this work presents the design and implementation of an alternative method steering for the Rotax 915is engine. It focuses on the construction of fuel, oil and the cooling system to start the malfunctioning engine that is in the workshop.

We designed the new systems based on the requirements of the given drive unit. They took advantage we use as many original parts as possible, which we supplemented with the necessary

components. At in the alternative parts, we worked with the parts that were provided to us in the workshop or which we had. We bought some parts. We replaced the fuel system main fuel and sump tank, pump and all wiring related connections these components. In the lubrication system, we replaced the oil tank with parts for connecting a new oil tank. We preserved the cooling system as much as possible and just added a cooler. I only removed the collecting tank and I went to the pressure tank built in an outlet in the form of a hose for the excess amount of coolant.

12.1. Fuel system

For the implementation of the alternative, we chose the central tank, considering the original request acrobatic system. During aerobatic flying, the position of the fuel changes, caused by gravitational force in a vertical downward direction. Therefore, we ensured the position of the pump so that met the requirements. Fuel intake takes place in the center of the spherical fuel tank, which ensures fuel supply at any position of the tank. However, we had to take into account requirements for material that would ensure strength and resistance to internal pressure.

That's why we chose a spherical tank. However, we had to modify the cap for ours needs. The fuel system at work consists of the main fuel tank, from which it flows down gasoline and flows through a filter located under the tank. The filtered fuel enters the collection tank, from which it is subsequently pumped out by a pressure pump and fed to inlet of the injector ramp. The injector ramp distributes fuel to the injectors on both sides of the motor unit. The return control valve is used for draining excess fuel from the system to maintain the required value fuel pressure in the fuel rail. Excess fuel is diverted back to the collection tank. The check valve also includes a pressure regulator that reduces the pressure in the fuel system to optimal.

After connecting all parts of the proposed fuel system, we first checked all connections. First, we tested the functionality of the injectors, and after success tested, we started the fuel system without ignition. The fuel flows nicely through the reverse the valve supplied back to the collection tank.

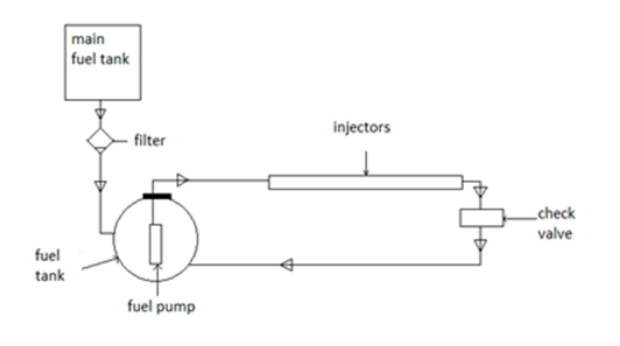

Figure 2 - Fuel system diagram

12.2. Lubrication system

At work, we replaced the oil tank with a round one. Material requirement was strength against internal pressures. However, we had to have an oil tank adjust with an oil drain hole. When connecting the oil system, we were limited by some requirements from the manual. According to the installation manual from the manufacturer, we had to place the oil tank by 360 mm lower than the engine axis. To comply with this requirement, we had to put a fuel tank to a higher stand, which we ultimately had to modify with an intermediate piece. We chose a spherical oil tank. We had to fit it properly to connect the tank modify for our needs. The modification included drilling a suitable hole for the connection return branch and the creation of a suitable mounting system on the stand. We were pacing with aluminum, in which we drilled suitable holes for attachment.

We used 10W-40 four-stroke engine oil. We chose it because of its viscosity for proper lubrication of the drive unit. Suitable temperature is from -25°C to 40°C.

To seal the opening, we used two-component epoxy glue, for fulfillment requirements for strength and sealing potential.

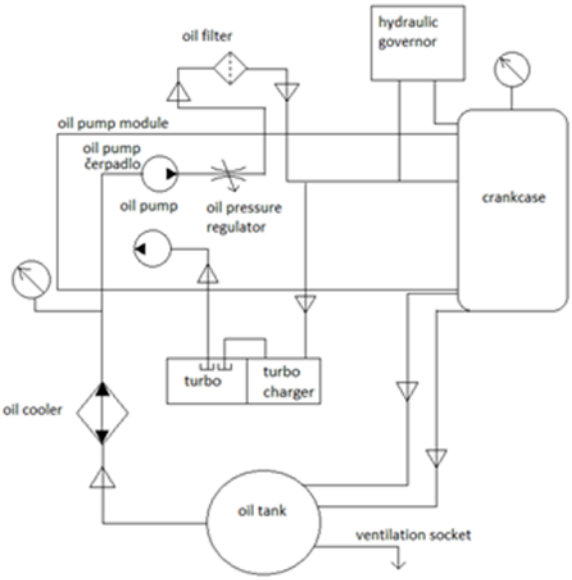

Figure 3 - Oil system diagram

To ensure optimal pressure in the oil system, we have introduced a sump into the collection tank venting valve, through which it will be removed in the event of overpressurization of the system excess amount of gases and air from the oil.

12.3. Cooling system

In our work, we focused on modifying the system in the form of removing the collection tank. For cooling, a cooler is built into the system, in which the liquid is cooled and further enters the engine through the cooling branch. Drainage of excess cooling medium provided through the outlet directly from the overpressure tank. For our alternative cooling system, we used distilled as a coolant water, which we finally poured into the

pressure tank. Given that the engine is placed in the workshop on a stand, there was no need to use antifreeze.

The cooling system consists of an overpressure tank in which the coolant is located medium. In case of excess pressure, a hose outlet is made from the overpressure tank, which will remove the excess amount of coolant from the system if necessary. The coolant enters the cooler from the overpressure tank, from which it is pumped out using a pump. It is distributed to the engine, specifically to the cylinder heads, which are cooled precisely by liquid. When modifying the system, we installed a cooler in system and we connected the entire system to the cooler with suitable hoses.

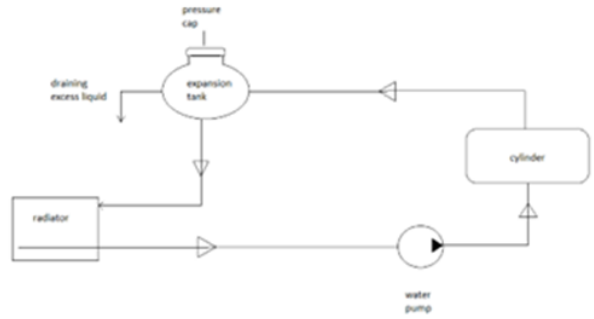

Figure 4 - Cooling system diagram

12.4. ECU MASTER CDI-TCI V8.41

The ECU MASTER control unit is a wide-spectrum unit for contactless controls ignition timing and injection timing for spark-ignition combustion engines with one up to twelve cylinders. Redundant sensing enables integration into all types engines from motorcycles, cars to aircraft engines or generator stations. It has working speeds in the range of 0 to 65,000 rpm and a working temperature from -40 to 80°C. It offers the sensing of parameters such as vacuum, temperature, output to tachometers, but also offers fuel pump switching control, exhaust valve servo, electronic pedal, PID speed controller and many others. The support of 5D maps is also a positive benefit advance and injection. We used this unit in our work for its graphic display and a good user interface. We also had it at the department, which eliminated costs associated with the purchase of the control unit.

12.4.1. Connection of systems to the control unit

We used inputs to the control unit to connect all components. In my work I mainly focused on connecting the injectors. In the above scheme, we are for our needs had to adjust the connection of the injectors, where we connected to one input two injectors. We used inputs 10B and 10D.

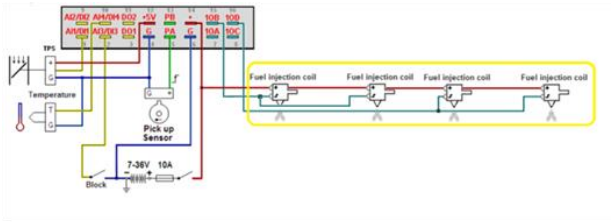

Figure 5 - Connection to ECU Master

12.5. First engine start

After connecting and testing all systems, correctly setting the parameters in the control room unit, we finally started our engine. We tested the correctness of our proposal and confirmed success. The engine has not yet been completely smooth as it needs to be adjusted injection timing and advance curves to optimal values, but this activity can be considerably time-consuming, therefore its implementation will be beyond the scope of this final paper work.

Figure 6 - First test

13. CONCLUSION

In this job, I worked on starting the Rotax 915is power unit. In the theoretical I worked partly with book publications, professional articles and internet publications resources. By choosing the right materials, I secured a good base for practical, constructive part of the work. Subsequently, I put them all good use in the practical part acquired information and knowledge to successfully connect all the missing parts to system and thus ensured the functionality of the systems. We tried all the parts that were missing replace with the best possible efficiency and the least possible cost.

The assignment of the final work was fulfilled and fully verified by the functional start of the engine. During the development,

we encountered several problems, but we successfully solved them they solved. We worked towards the main goal with sub-goals, and thus verified it the correctness of the solution. The output is a prototype engine that can be used on University of Žilina as a teaching aid or can also be a basis for others investigation.

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UNIVERSITY OF ŽILINA

MARKETING OF LOW-COST CARRIERS

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Abstract

The article deals with the marketing of low-cost airlines and marketing strategies. The article primarily focuses on three selected airlines - Wizz Air, Ryanair and easyJet. The aim of this article is to propose specific possibilities for improving marketing activities based on the theoretical basis obtained from relevant sources and the subsequent processing of the practical part. Proposals are based on the analysis of marketing strategies, including marketing mix, Porter's five forces model, perception map, passenger segmentation, BCG matrix and Ansoff matrix, and evaluate the success and effectiveness of airline marketing activities. The results of the analysis show that airlines could improve their marketing activities through various strategies, such as increasing investment in digital marketing, improving service and customer experience, adapting prices and product packages to the needs of different passenger segments, and expanding the market into new areas. These recommendations can help airlines improve their competitiveness and market success and contribute to their long-term success.

Keywords

marketing, marketing strategy, marketing of low-cost carriers, low-cost carriers, Wizz Air, Ryanair, easyJet.

1. INTRODUCTION

These days, low-cost airlines are an increasingly popular travel choice for many people. This final thesis focuses on the issue of marketing of low-cost airlines. The aim of the work is to propose specific possibilities for improving the marketing activities of selected airlines with the aim of improving their competitiveness and success on the market. The proposal is based on the analysis of marketing strategies and activities of airlines, with an emphasis on their success and efficiency.

The first chapter provides an overview of the professional literature in the field of airline marketing, with an emphasis on low-cost airlines. At the same time, it provides information on developments and trends in this area.

The second chapter, Methodology of the work, explains the methods used in the work and describes the selection of airlines and the basic models of marketing strategies that were used in the analysis. Next, this chapter explains the steps and procedures that were used in researching the marketing activities of low-cost airlines.

The third chapter of this final thesis focuses on the analysis of marketing strategies of selected airlines using marketing mix, Porter's five forces model, perception map, passenger segmentation, BCG matrix and Ansoff matrix.

The fourth chapter describes specific marketing activities of selected companies. These activities are described in detail and analysed in terms of their effectiveness and success in the market. It also considers how these activities contribute to the overall strategy of companies and how it affects their competitiveness.

The last chapter of this article focuses on proposing ways to make the marketing activities of airlines more efficient. They are based on the analysis of marketing strategies and assets of selected companies, a summary of the possibilities of improvement and optimization of these activities, which could lead to better results in the field of marketing.

2. METHODOLOGY

The analysis is the first step in this methodology and allows us to obtain the necessary information about the marketing of low-cost airlines. In this step, we will focus on researching relevant literature and sources that will help us better understand the topic of our work. As part of this step, we will also analyse the strategies and tactics these companies use to acquire customers and stay competitive.

When creating a marketing strategy, we must consider several factors, including the competitive environment, customer needs and preferences, and strengths and weaknesses. These basic models of marketing strategies allow us a systematic approach to creating an effective and sustainable marketing strategy. Therefore, in the third chapter, we will devote ourselves to a detailed analysis of each of these models and apply them to real examples in the business environment. Based on this analysis, we will be able to create a comprehensive view of marketing strategies and provide guidance and recommendations on how we can improve our results on the market.

Synthesis is the second step in our work methodology and allows us to generate new ideas and perspectives. In this step we will try to combine the information we got in the first step and create new ideas. This step will help us find out how low-cost airlines can improve their strategies and improve their competitiveness. We will also focus on the use of new technologies and digital tools in the marketing of low-cost airlines.

Comparison is the third step of the work methodology and allows us to compare different approaches to the topic and

discuss their strengths and weaknesses. In this step, we will focus on comparing the different marketing strategies of low-cost airlines and discuss how these strategies work and what could be improved. We will also try to compare the different digital tools used by low-cost airlines and discuss the impact they have on their marketing strategy. This step allows us to make a final summary and evaluate our results.

3. MARKETING MIX AND ITS APPLICATION IN SELECTED AIRLINES

In addition to the marketing mix, we used other marketing models because the nature of the work required it. The basic elements of each model will be analysed and explained in detail to help understand how these models can be used to achieve success in the market. In this chapter, we will focus on the application of these marketing tools in the environment of selected airlines. Our goal is to explore how these tools help airlines identify their customers, improve their products and services, and increase their competitiveness in the market.

3.1. Marketing mix 7P´S

The marketing mix is an important tool for any business because it helps determine a strategy that will be effective in reaching customers and improving business performance. The concept of the "marketing mix" was introduced by Neil Borden in the 1950s, and the mix of different means was soon renamed the 4Ps by McCarthy. The 4Ps of the marketing mix are important to highlight some unique aspects of low-cost airline marketing. The 4P marketing mix includes four key elements: product, price, place, and promotion.

The 7P marketing mix is an extension of the classic 4P marketing mix concept. In addition to the four key elements, it also includes three other elements, namely people, processes, and physical evidence. This expanded model helps better account for marketing activities that are important to certain industries and types of businesses. A clear diagram of the 7P marketing mix is shown in figure no. 1.

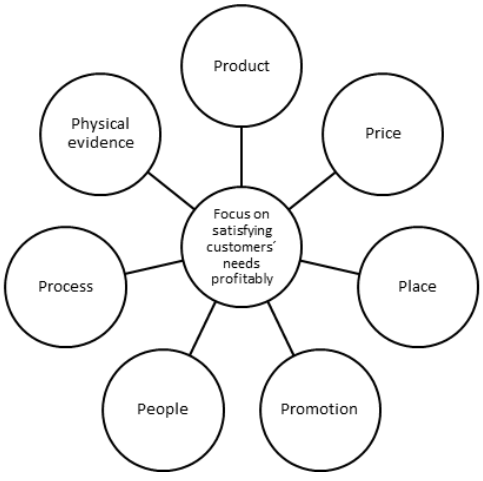

Figure 1 - The Marketing Mix 7P´s

3.2. Porter's five forces model

Another of the marketing strategy models is Porter's five forces model. This marketing tool is used to assess the level of competition in each industry and uses the economics of industrial organizations. Its purpose is to effectively assess the competitive environment and potential profitability of the industry. If these forces change, it can directly affect the industry and the companies within it. Therefore, it is important to understand and respond to them for companies to maintain or gain a competitive advantage.

Here are Porter's five forces:

1 Threat of substitute products or services

2 Threat of existing competition

3 Threat of new competition

4 Bargaining power of suppliers

5 Bargaining power of customers

3.2.1. Threat of substitute products or services

Traveling by car or train can be an alternative to flying, but for some journeys traveling by air can be more time efficient. For example, for a trip from London to Barcelona, it would take several days to travel by car or train, while a flight would only take a few hours.

3.2.2. Intensity of rivalry between competitors

Competition among low-cost airlines in Europe is very high. By 2021, Ryanair said it wants to become the largest airline in Europe, competing with other low-cost carriers such as Wizzair and EasyJet, as well as traditional airlines.

3.2.3. Threat of new competition

In 2021, Flyr announced its plans to enter the low-cost market in Europe, which could be a potential threat to the likes of Ryanair, Wizzair and EasyJet. Flyr plans to begin operations in 2022 to compete with existing low-cost airlines.

3.2.4. Bargaining power of suppliers

In 2021, airlines complained about high rental fees at airports, especially during the COVID-19 pandemic, when flight volumes were significantly reduced. Ryanair, for example, has accused airport operators of not sufficiently reducing the rent charge, which is still a significant cost to airlines.

3.2.5. Bargaining power of customers

Customers tend to compare prices between low-cost airlines and choose the one that offers the lowest prices. For example, in 2021, Ryanair decided to reduce ticket prices to a minimum to retain customers during the pandemic and compete with other airlines.

3.3. Perceptual map

A brand positioning map, also known as a perception map, is a graphical representation of how consumers perceive the positioning of a product or brand relative to competing products or brands. This map allows marketers and product development managers to better understand how consumers perceive their brand or product relative to their competition. A brand positioning map often includes two dimensions that are relevant to consumers, such as price and quality, and each brand or product is shown as a point on this map. The most common way to create a perceptual map is to construct two X and Y axes that are perpendicular to each other. It is not the only way to create a perceptual map, but it is the most used. Brands or products that are closer to each other are perceived by consumers as similar or comparable, while those that are further away are perceived as different. A brand positioning map can help marketers identify opportunities for new products or linking existing products to consumer demands. Such a map provides a clear, but on the other hand, subjective view of where the company is within the competition.

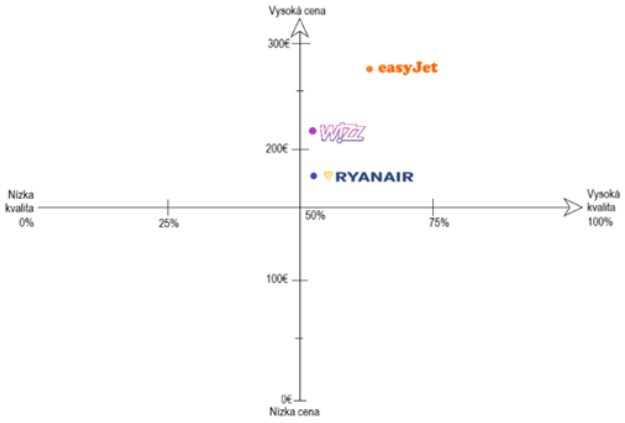

Figure 2 - The Perceptual Map

Based on the collected data, we created a perceptual map (Figure no. 2), where we displayed the ticket prices and quality of the airlines Wizz Air, Ryanair and easyJet. On the X-axis we have placed the quality rating of the airlines, where easyJet has the highest rating and Wizz Air and Ryanair have the lowest rating. On the Y-axis we have placed the ticket prices, where Ryanair has the lowest price and easyJet has the highest price.

3.4. Segmentation

Customer segmentation is the process of dividing customers into different groups based on common characteristics, needs and preferences. These groups can then be targeted with marketing campaigns and offers that are tailored to their specific needs. In the case of low-cost air transport, customer segmentation is an important tool that provides companies with customers with the greatest potential for purchases and thereby companies can gain a better position in the market.

In low-cost air transport, customer segmentation can be implemented using the following criteria:

3.4.1. Demographic segmentation

Customers are segmented according to their demographic characteristics, such as age, gender, income, education, and marital status. These characteristics can influence the customer's preferences when choosing a destination, type of travel and ticket price.

3.4.2. Geographical segmentation

In geographic segmentation, customers are divided based on their geographic location, such as by country, region, or city. This allows airlines to target specific destinations and target groups of customers interested in traveling to specific areas.

3.4.3. Psychographic segmentation

Psychographic segmentation divides customers according to their lifestyle, values, interests, and personality traits. This segmentation allows airlines to target customers who have similar interests and preferences and tailor their offers and marketing campaigns based on their needs.

3.4.4. According to the type of travel

Customers are segmented based on their type of travel, such as business travel, tourism, or visiting friends and family. This allows airlines to tailor their offers and services based on the needs of specific types of passengers.

3.4.5. According to the frequency of flying

Customers are divided based on how often they fly. This allows airlines to tailor their offers and services to frequent flyers and offer them better prices and increased benefits. For example, loyalty point programs or discounts for regular travellers. Benefits may include faster check-in, the ability to choose your seat on board, improved food services, and more. These benefits can be attractive to regular travellers and can motivate them to use the airline's services more often.

Figure no. 3 shows a bar graph showing the distribution of visitors of three airlines - Wizz Air, Ryanair and easyJet - by gender. The graph has 6 columns, with the first set of three columns showing the representation of women and the second set of three columns showing the representation of men.

The X-axis shows the individual companies that are compared, and the Y-axis shows the percentage of visitors in each gender group. The columns are colour coded for each airline. In the first three columns we see the representation of women. Wizz Air has the highest percentage of female representation with 51.71%. It is followed by Ryanair with 53.92% and easyJet with 53.59%. In the second group of columns we see the representation of men. Ryanair has the highest percentage of male representation with 46.08%, followed by easyJet with 46.41% and Wizz Air with 42.29%.

This bar graph allows us to easily compare the representation of visitors by gender in individual airlines and to draw conclusions about the preferences of individual groups.

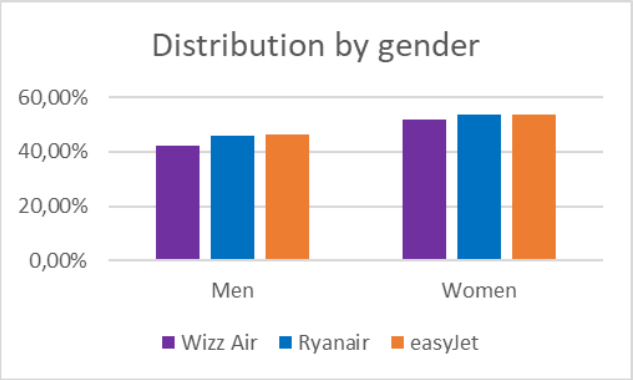

Figure 3 - Distribution by gender

Another division is the division by age. Bar diagram in picture no. 9 shows the percentage representation of passengers in individual age groups in three airlines - Wizz Air, Ryanair and easyJet. The X-axis shows individual age groups, and the Y-axis shows the percentage of passengers in each airline. The columns are color coded for each airline. We see that the overall highest percentage of passengers are in the 25-34 age group. Wizz Air has the largest share of passengers with 34.75%, followed by Ryanair with 32.21% and easyJet with 30.14%. In the 18-24 age group, Ryanair has the highest percentage of passengers at 18.08%, while easyJet has the lowest percentage of passengers in this age group at 16.99%. In the 35-44 age group, easyJet has the highest percentage of passengers with 21.66%, while Wizz Air has the lowest percentage of passengers in this age group with 22.50%. In the 45-54 age group, Ryanair has the highest percentage of passengers at 14.38%, while easyJet has the lowest percentage of passengers in this age group at 15.74%. In the 55-64 age group, easyJet has the highest percentage of passengers with 9.69%, while Wizz Air has the lowest percentage of passengers in this age group with 7.71%. In the over 65 age group, easyJet has the highest percentage of passengers at 5.78%, while Ryanair has the lowest percentage of passengers in this age group at 4.55%.

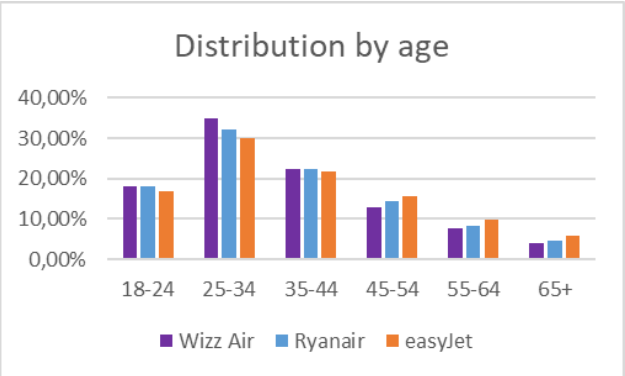

Figure 4 - Distribution by age

3.5. BCG matrix

The BCG matrix consists of four quadrants that account for high and low market share and high and low growth potential. Each quadrant is named and has specific characteristics.

Each of the four quadrants represents a specific combination of relative market share and growth:

1. Low growth, high share: companies should milk these "cash cows" for cash to reinvest.

2. High growth, high share: companies should invest heavily in these "stars" because they have high future potential.

3. High growth, low share: companies should invest in these "question marks" or discard them depending on their chances of becoming stars.

4. Low share, low growth: companies should cull, get rid of, or relocate these "pets".

3.6. Ansoff matrix

The Ansoff matrix is an analytical tool used to formulate a growth strategy for a company. This model was developed by Igor Ansoff in 1957 and is still popular today in the field of strategic planning and marketing. The matrix consists of four categories: existing products in existing markets, new products in existing markets, existing products in new markets and new products in new markets. Each category represents a certain type of growth strategy that a company can choose.

The Ansoff matrix is divided into four quadrants. The primary goal of the matrix is to identify the company's growth opportunities, so it is necessary to combine markets and products and divide them according to whether they are new or already existing. Subsequently, a matrix is created in which markets are located on the horizontal axis and products on the vertical axis. We further divide both variables (i.e., markets and products) into existing and new. The intersection of existing and new products and markets creates four quadrants that determine our specific growth strategy. In the following table we see the Ansoff matrix with four quadrants.

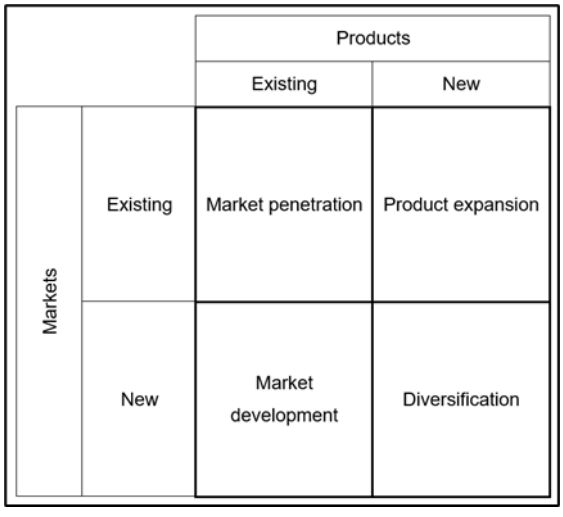

Figure 5 - The Ansoff Matrix

3.6.1. Ansoff matrix for Wizzair

Market penetration

Wizz Air can increase its market share in current markets by improving its offer and competitiveness against other low-cost airlines as well as traditional airlines. This may include improving service quality, increasing the number of flights, increasing flight capacity, expanding the number of destinations, and increasing cost efficiency.

Product development

Wizz Air may introduce new products or services, such as including the provision of travel insurance or car hire directly from their website. They can also expand into the premium segment of the market where they could offer luxury flights or services.

Market expansion

Wizz Air may enter new markets, for example new countries or new destinations. They could also increase the number of flights in existing markets to welcome more passengers.

Diversification

Wizz Air can invest in other areas that are linked to tourism, such as bus travel across Europe.

3.6.2. Ansoff matrix for Ryanair

Market penetration

Ryanair could focus on existing markets and try to gain more market share. They can offer cheaper ticket prices than the competition, improve the quality of their services and increase brand awareness.

Product development

Ryanair could develop its existing products, for example with more comfortable seats on board. Another alternative is to improve the quality of services, for example by ensuring a problem-free Wi-Fi connection on board the plane.

Market expansion

Ryanair could try to find new markets, for example by expanding its destinations or starting flights to new countries.

Diversification

Ryanair could develop new products that may or may not be related to air travel, such as an airport transfer or a complete journey planner. They can also expand into other industries such as tourism.

4. ANALYSIS OF MARKETING ACTIVITIES OF SELECTED LOW-COST AIRLINES

Marketing channels are the ways in which companies communicate with their customers and try to sell their products or services. These channels can include various media such as TV and radio ads, print ads, digital media ads, email marketing, social media and many more. Each marketing channel has its own advantages and disadvantages, and not every channel is suitable for every company or product. For example, television advertising can be effective for large brands with extensive advertising budgets, while small businesses might choose other channels such as email marketing or social media. It is important to choose the right marketing channels for your company and product to achieve maximum results within the designated budget and target market. Organic search and direct search are key channels for airlines such as Wizz Air, Ryanair, and EasyJet to acquire new customers and retain existing ones. Organic search occurs when a customer uses a search engine on the Internet and finds a company's website. A direct search occurs when a customer enters the exact name of a website into a search engine. There are some factors that explain why airlines like Wizz Air, Ryanair and EasyJet use these channels the most. One factor may be that airlines have strong brands and a strong online presence, so customers may be motivated to search directly for the company's website. In addition, organic search and direct search are relatively inexpensive and effective ways for companies to get traffic to their website. This is not to say that airlines do not fully utilize other marketing channels. Every company has unique needs and goals that influence their decisions about which channels to use. For example, companies can use social media to increase brand awareness and direct marketing, such as email marketing, to acquire new customers and retain existing ones. Overall, however, organic, and direct search remain important channels for airlines due to their efficiency and cost-effectiveness.

5. POSSIBILITIES OF IMPROVING THE MARKETING OF LOW-COST AIRLINES

5.1. Social networks

This table no. 1 shows the number of fans and followers of each company on various social media such as Facebook, Instagram, Twitter and TikTok.

Table 1 - Fan base on social networks

	Wizz Air	**Ryanair**	**easyJet**
Facebook	3 412 878	5 012 213	1 873 244
Instagram	574 tis.	971 tis.	431 tis.
Twitter	67,3 tis.	713,9 tis.	576,9 tis.
TikTok - Likes	0	29,1 mil.	2,6 mil.
TikTok - Follows	2,9 tis.	2 mil.	223,3 tis.

In terms of marketing, individual companies could improve their social media presence by trying to better interact with their fans

and followers. They can try to share relevant and interesting content that might engage their target audience.

Wizz Air has a relatively small number of fans and followers on Twitter and TikTok compared to Ryanair and easyJet. It can try to improve its presence on these platforms by posting regular and interesting content that would appeal to travellers and aviation fans. Wizz Air could improve its operations by publishing regular and interesting content that would appeal to travellers and air travel fans. She can also try to communicate better with her fans and followers to gain their trust and loyalty.

From the table, we can see that Wizz Air has not yet published any post on TikTok, therefore it has 0 likes and only a small number of fans in this box. The company could change this situation by participating more actively on TikTok and posting regular and relevant content that would engage its target audience.

Wizz Air could publish short videos on TikTok that would show travel and the adventures that come with it in an interesting way. For example, it could post videos that show interesting places that passengers can visit, or videos that show how passengers can prepare for a flight. He could also use popular trends and funny moments to attract the attention of his followers and thus increase his visibility on TikTok. In addition, Wizz Air could use influencer marketing and work with popular influencers on TikTok to help it gain new fans and increase its awareness on the network. By doing so, they could improve their presence on TikTok and increase their visibility to travellers who might be interested in their services.

Ryanair has a huge number of likes on TikTok, which means that its content is popular and attracts a lot of attention. However, it has a negligible number of fans compared to the number of likes. He can try to improve his presence on TikTok by sharing interesting content that could motivate people to follow him and become his fans. It could also improve its presence on TikTok and other platforms by seeking more engagement and interaction with its fans. It can also seek to better personalize its content and try to reach travellers and fans directly and relevantly.

EasyJet has a relatively low number of fans across all platforms, including TikTok. It can try to improve its social media presence by regularly sharing interesting and relevant content that would engage travellers and aviation fans. They could also use influencers and work with them to increase their visibility and gain new fans.

easyJet could improve its presence on all social media by trying to regularly share interesting and relevant content. She can also seek to collaborate with influencers who would help her gain new fans and increase her visibility.

5.2. Webpages

Table no. 2 expresses the traffic of selected airlines' websites, which includes information on monthly visits, new visitors, number of pages per visit, duration of visit and exit rates.

Monthly visits indicate the number of visits to the site for one month. Monthly new visitors refer to the number of unique visitors who visited the site for the first time in each month. Visits/New Visitors indicates the average number of visits per new visitor. Visit duration is the average time a visitor spends on a site, while pages per visit refers to the average number of pages a visitor views during a single visit. Bounce rate expresses the percentage of visitors who left the page without taking any action (e.g., clicking a link or filling out a form). A higher bounce rate can be a sign that visitors didn't find what they were looking for or didn't feel motivated enough to stay on the site longer. The green colour in the table represents the company that is the winner in the given category, i.e., the best among the three and the red colour indicates the company with the worst results.

Table 2 - Official website traffic

	wizzair.com	**ryanair.com**	**easyjet.com**
Monthly visits	17,85 mil.	48,79 mil.	22,30 mil.
Monthly unique visitors	7,846 mil.	21,22 mil.	10,79 mil.
Visits / Unique visitors	2,28	2,3	2,07
Visit duration	0:06:56	0:07:04	0:06:59
Pages per visit	6,21	7,21	5,49
Bounce rate	29,47%	30,63%	34,61%

Based on the data provided, airlines should take some of the following steps to improve their marketing activities:

1. To improve the user experience on websites:

Since Ryanair and easyJet have relatively high bounce rates, these companies could try to improve the user experience of their websites. This could include improving site navigation, simplifying the booking process, or providing more information about travel packages and offers.

2. Improve content quality:

Companies could try to improve the quality of their website content to attract more visitors and keep them on the site. This could include improving the visual design, providing more information about destinations, or providing useful travel tips.

3. Focus on acquiring new visitors:

Since Ryanair has the highest number of visits per unique visitor, focusing on acquiring new visitors could be beneficial for the company. They can do this by using digital ads and marketing campaigns aimed at new visitors.

4. Increase the conversion rate:

Companies could try to improve the conversion rate of their website, which could lead to an increase in site visits as well as an increase in conversions. They can do this by optimizing landing pages, testing different versions of the site, or improving site content to increase demand for their services.

5. Strengthen social media:

Businesses may consider boosting their social media presence as these platforms are becoming increasingly popular and are a great way to reach potential customers. They could invest in advertising campaigns and focus on sharing interesting content and stories related to their brand.

6. Use email marketing:

Email marketing can be an effective way for companies to keep in touch with existing customers and reach potential customers. They can send personalized emails such as news and offers to keep their customers interested.

7. Improve SEO:

A high ranking within search engines can be important for companies to increase the number of visits to the site. Companies should consider optimizing their website for SEO, which includes things like using keywords and improving their site content.

These steps could help airlines improve their marketing activities and attract more customers to their sites. However, it is important to remember that every company is unique and may require different steps and strategies to achieve its goals.

6. CONCLUSION

Based on the analysis of the marketing strategies of three selected low-cost airlines - Wizz Air, Ryanair, and EasyJet - we concluded that these companies have very similar marketing strategies. All three companies use the 7P marketing mix, which means they focus not only on price, but also on product, place, promotion, processes, physical environment, and people.

However, Ryanair seems to be the most effective company in terms of pricing strategy as it offers the cheapest tickets of the three. These companies are big competitors in the market, which leads to fierce competition.

Given the results of the analysis, we created a perceptual map that allowed us to visually compare the position of these three airlines on the market. Based on the perception map, we saw that Ryanair appears to be the cheapest option, but EasyJet and Wizz Air have a stronger position in some areas.

Based on the analysis, we have identified some areas where these companies could improve their marketing strategies. Companies could improve their promotion and communication with target groups to increase awareness of their product offerings. In addition, they can expand their product portfolio to increase value for customers and improve their competitiveness in the market.

Overall, we conclude that low-cost airlines have very similar marketing strategies that focus on achieving competitive advantage through pricing strategy and process optimization. However, to maintain a strong position in the market, these companies must constantly improve and adapt their marketing strategies to the changing needs and preferences of customers.

Overall, marketing has been shown to be a key factor in the success of low-cost airlines. Their ability to offer low ticket prices while maintaining quality service and customer satisfaction depends on an effective marketing strategy.

The results of this work can be useful for all those interested in the marketing of low-cost airlines. Moreover, this work can provide new ideas and inspiration for other researchers in this field.

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PROSPECTS FOR THE DEVELOPMENT OF BRATISLAVA AIRPORT AND THE INFLUENCE OF RELATIONS BETWEEN AIRLINES AND THE AIRPORT ON THE DECISIONS OF THE AIRPORT MANAGEMENT

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Abstract

The research deals with the development of Bratislava Airport Milana Rastislava Štefánika. The primary goal of the work is to evaluate the current situation at Bratislava Airport, its equipment, layout, continuity of services, operational performance and evaluation of the airport's allocated and used capacity. The research is divided into a theoretical and a practical part. In the theoretical part, it is necessary to present a theoretical view of the basic concepts in aviation, the history of Bratislava Airport, the historical development of the number of passengers transported at this airport, the development of airlines operating in Slovakia and their influence on this airport, a brief evaluation of the number of destinations to which Bratislava Airport flies and considering the possibility of specializing this airport as a secondary airport for Vienna Airport. The essence of the practical part is the evaluation of the current situation at the Bratislava airport, the analysis of privatization possibilities and the implementation of a qualitative survey using a questionnaire. Based on the analysis and evaluation from the survey of the opinions of interested subjects, optimal alternatives for the further development of Bratislava Airport are provided in the context of broader management relations with airlines, as well as an evaluation of privatization options and their potential contribution to the development of Bratislava Airport.

Keywords

Airport, Civil aviation, Development, Questionnaire

1. INTRODUCTION

This thesis focuses on the prospects for the development of Bratislava Airport, more specifically to bring closer the prospects for the future use of an airport, whether as a primary airport or as an aerodrome of a secondary position for Schwechat airport. From the point of view labour and, of course, the financial aspect, it is necessary to evaluate the equipment and disposition of the airport. The main objective of this work was to highlight the possible future of the Airport Bratislava, take stock of the state of the airport, see the past of the airport a reminder of the diverse history of its origins. Of course, it was justified. Neglect of the advantages and disadvantages of low-cost airlines and their impact on Bratislava Airport. The work is divided into four main chapters, which contain sub-chapters for better clarity of the content of the work. The initial chapters focus on the general importance of BTS airport from a historical point of view, as well as to illustrate the history and chronology of air carriers in the territory of the Slovak Republic. A great deal of emphasis has been put on clarifying both current and planned the intention of MR. Štefánik airport and the possibilities for future expansion of available destinations. Equipment and the airport ' s continuity of service and operational performance was also properly classified in this thesis. Assessment of the allocated and used capacity of the airport, or status and the intention of the low-cost companies could not be absent to clarify the overall issue research. As is already common knowledge, and therefore has to be mentioned in our diploma work, possibility and analysis of privatisation opportunities. In the last chapter we started explore in more detail the views of stakeholders on the way forward ownership and development of BTS. Getting to know the public is a very important aspect of this work. Opinion of the surrounding company and, in particular, proposals for optimum alternatives for the further development of BTS in the context of wider management relationships with air operators. In the final result, , We have expressed our view, as well as that of the respondents to the questionnaire, and we have assessed prospects for the development of the Airport Bratislava.

2. HISTORY OF AIRPORT BRATISLAVA

The biggest international airport in Slovakia has come to be known for its start of regular air transport in a very spectacular way. The date was 1923, and the AERO A-14 aircraft landed in Vajnory under the aegis of Czechoslovak Airlines flying from Prague to Bratislava with a single passenger. Initially, a heavy head was caused by the proximity of the Little Carpathians due to the possible complications and limitations of air travel, but over time these complications became negligible. It was 1947 that the history of air transport in Bratislava began to be written when the first preparatory works led to its creation. Even though everything, the people said, was ready for takeoff, it wasn't until a year later that the airport was officially built. The first step towards achieving the objective of a functioning airport was the construction of a runway. This year, history marks the beginning of the construction of the largest Slovak airport, located in the cadastral area of Ivanka, near the Danube.The first point in the existence of each airport is the creation of runways for the landing and take-off of aircraft. Construction began with the construction of runway 04-22, for which runway 13-31 was created at right angles. These runways, which are considered to be the cornerstone of Bratislava airport, are still used to land

aircraft in any weather. Since 1948, work on the construction of the airport has slowly but surely led to completion and, officially, in 1951, regular air traffic began at the airport, 9 kilometres from the capital city.The first companies to have had the honour of taxiing the runway at Bratislava airport were Czechoslovakia's Airlines. Over time, 1. of August 1970, the Deputy Prime Minister of the Slovak Socialist Republic, Štefan Sádovský, handed over to the use of a completely new fitting-out area at Bratislava Airport. A very important milestone in the aviation world in 1970 was the commissioning of the L-410 Turbolet, a twin-engine aircraft from the workshop Let Kunovice. This elegant transport aircraft, which was mainly intended for regional transport, has been recorded in the history of the Slovak fleet over time. As with any business, not just an airport but a well-functioning business, it is undergoing changes during its lifetime. The fleet was changing quite rapidly, as were passengers' claims to some comfort as to whether ground security had to be exchanged. The summary resulted in the need to invest in the extended scope of the airport. So it was decided to build a new passenger departure terminal, with, of course, some sufficient pre-station capacity. This refurbishment also brought the airport a new central boiler room with additional power equipment for the substation, a new communication system, and also a very substantial expansion of the equipment area. At that time, the Ministry of the Interior Airport also had an airport, which needed a building for its operations. Of course, it could not have been missing from the airport recovery plan. The 1980s brought a significant extension of the 04-22 runway, which was one of the first points of today's airport, from the original 1,900 metres to 2,900 metres. Not even the 13-31 runway, which was extended from a modest 1,500 meters to 3190 meters, remained unnoticed. This complex refurbishment of the runway system has placed the airport in a series of leading and important airports. Of course, it was not only passengers who left Bratislava airport who could not be thought of, so 1994 is being recorded as a successful year for arriving passengers for whom a new arrival terminal has been built. We can certainly regard this stage of airport development as a separation between arriving and departing passengers. A year later, the airport management decided to build a new modern firehouse, which had settled between the runways. This significant event and undoubtedly a successful step has moved our airport from the sixth category to the seventh category, which allows for the landing of large-capacity aircraft. In 1997, the airport embarked on a much-needed refurbishment of the runway 13-31 safety system for take-offs, landings and lighting. This year, however, not only has the history of the reconstructions in question been established, but the idea of a link with the Danube Biscuit was created, and it was therefore possible and very appropriate to build an aviation fuel depot. 1998 was also the starting point for today ' s LPS SR, as a new control tower was created. During the great and prosperous journey, the airport was slowly but surely approaching another significant point in its history. The year 2004 was being written, and the Slovak Airport Administration was successfully transformed into a joint stock company, where Bratislava Airport was renamed the Airport M.R.Štefánika – Airport Bratislava (BTS), in honour of our important Slovak statesman, scientist, inventor and especially the pilot Gen. PCDD Milan Rastislav Štefánik. One cannot forget the success of a given year and the emergence of a phytosanitary centre.on the day that Slovakia joined the European Union, the airport started to try to meet the criteria that would move us into the Schengen airspace. In view of the inadequacy of the airport, the requirement to perform security checks on aircrew and passengers was first introduced. These passengers have been reassigned. While the ordinary passenger was being checked at the terminals, the crew and the commercial passengers received a new general aviation terminal, the G.A.T. terminal. The name was derived from the English name General Aviation Terminal. The Board of Directors of the Airport M. R. Štefánik – Airport Bratislava has not forgotten about passengers who were without the need for an entry passport control, and so Terminal C, which is the terminal of the arrival hall, was constructed. September 2006 is a major year of privatisation. The Government of the Slovak Republic announced its withdrawal from the privatisation contract for the airport as the privatisation conditions were not met. Much of the change was due to the creation of the airport. [1] [2] [3]

3. CURRENT STATE OF THE AIRPORT AND INTENTION TO EXTEND THE DESTINATION

The current state of the airport needs to be assessed against its background. The name of the commonality has been approved and is also used in the presence of Airport M.R. Štefánika — Airport Bratislava, a.s. (BTS). The used IATA / ICAO code is BTS / LZIB. The location is already apparent from the name of the airport — Bratislava. The airport is situated 9 km northeast in the ratio of distance to the centre. The ground area of the airport is 143 000 m2 and the building is 48 545 m2. The aerodrome reference point is 481012 north and 0171246 east at 133m elevation and 10 000ft AMSL (3048m) AMSL transfer height. The climate of the aerodrome is, on average, the temperature for the year 2021, measured in January. -5 ° C, max + 10 ° C and in July min. + 18 ° C, max + 28 ° C. The runway system of an aerodrome consists of a runway 13 / 31 with RWY 31 having a length of 2950 m x 45 m (extended to the displaced threshold RWY31) and RWY 13 having a length of 3190 m x 45 m. The runway surface of runway 13 / 31 shall be of concrete CN50 / R / B / X / T. The operation of the airport is CAT III A LVP which is an accurate approach to CAT II at minimum. A Category III A approach is an instrument landing with no decision height or a decision height of less than 100 feet (30 m) and a runway visual range of at least 700 feet (200 m). CAT I relies only on the altimeter indications for decision height, whereas the approaches CAT II and CAT III use a radio altimeter (RA) to determine decision height. ILS shall be deactivated by internal fault detection. The main difference between CAT II / CAT III operations is that category II provides sufficient visual orientation to allow a manual landing in DH, while category III does not provide sufficient visual references and requires an automatic landing system. The runway 04 / 22 runway system shall have a length of 2900 m x 60 m and the surface shall also be of concrete, but the components CN54 / R / B / X / T CAT I. The operating time of the airport shall be 24 hours. The current airport has two perpendicular runways with a cementobetone surface. As we have already mentioned the parameters of runway 13 / 31, it can be concluded that this runway is the primary and priority runway of the airport. From the point of view of direction 31, the runway is equipped with a navigation and lighting system enabling us to make an accurate instrument approach. Therefore, this runway belongs to CAT III A category. However, from the perspective of direction 13, it is classified as non-instrumented, so it serves an accurate approach. As far as

the 04 / 22 runway is concerned, from direction 22 it is also equipped with a navigation and lighting system, but which allows accurate instrument approach under CAT I conditions. From 04 it's also classified as non-instrumented, so it's a non-precision approach. Both these runways are currently intersected at a distance of 904 m from the threshold of the take-off runway 13 and 1428 m from the threshold of the take-off runway 04. There are currently 35 fixed-wing aircraft stands on the turntable, and if we included the turntable Charlie, which is used for general aviation flights, we would have 48 stations.

The building complex consists of three parts:

- A terminal with a common terminal for arrivals and departures
- A terminal designed to serve arrivals and departures outside Schengen
- The General Aviation Terminal (GAT).

On the ground floor of the terminal there are 28 equipment counters and one counter dedicated to the registration of excess baggage. All these Check-in counters are equipped with a system that allows the use of the equipment systems used by the various airlines. An airport information system has been procured to provide comprehensive passenger information. In the area reserved for passengers waiting for departure, there are 8 exits in the section for the fitting out of flights in the Schengen area and 5 exits for the fitting out of flights to countries outside the Schengen area, He's got 13 exits. The airport has free Wi-Fi access to the entire building. Of course, there must not be a lack of comfort offered by the possible use of commercial establishments, the business of the salon, the cafeteria, the ATMs or the continuous information service for passengers who are disabled or immobilised, a contact point for calling the assistance services is available, or it is possible to report in advance to the airport via a telephone link to the airport.At present, in addition to the runway system and terminals that we have already specified, the airport also consists of a fuel depot, the volume of which consists of seven vertical above-ground tanks for JET A-1a one underground horizontal tank for AvGas with a total nominal capacity of 4780 m3. The above-ground tanks are placed in a reinforced concrete, chemically insulated bath. Currently, only two of the six tanks are used by the airport, so a capacity of 1400 m3 is sufficient. The seventh tank was added only in 2015, which is equipped with modern technology and is located in a separate drainage tank. This tank has a capacity of 1410m3. There is an access road and a train leading to the fuel depots.The rescue and fire station is also a very important part of the airport. The essential task in the event of an accident or incident shall be to rescue persons, organise rescue work, assist in the event of an outbreak of fire or assist in the event of unwanted circumstances. Frequent activities have included, for example, assistance in filling aircraft with fuel, excursions to extraordinary aviation events, or the elimination of oil spills. The station is equipped with special fire-fighting equipment such as Protector C-4 vehicles, supplied by SIMON ACCESS, Scania CAS 60 from the THT shelf and Tatra 815 CAS-32. Protector C-4 accelerates from 0 to 80 km / h for 40 seconds, with a tower output of 5,000 litres per minute and a pump output of 7,000 litres per minute. The Scania vehicle achieves the same acceleration as the protector; the power of the tower is 4 500 litres per minute and the pump is 6 000 litres per minute. The Tatra 815 CAS-32 has a tower capacity of 3,000 litres per minute and a pump capacity of 3,200 litres per minute. It should also be noted that the Airport M. B. The station is able to upgrade its unit to category 8 within 2 hours. I think we can all agree that the airport is in pretty good shape for emergency assistance.

In view of our graduate work, we have decided to incorporate the available data from the annual report of the airport of MR. Štefánika for the year 2021, where ownership, its capital, was declared, into:

- 19 ordinary shares with a nominal value of €3,319,392
- 1 share with a nominal value of €3,319,391
- 1 share with a nominal value of €3,319,390
- 6 709 ordinary shares with a nominal value of €33 194
- 643 ordinary shares Of a nominal amount of €34

All shares that exist are linked to the name of the shareholder and take the form of a security. The current situation of the airport of M.R. Štefánika with regard to the shareholder structure was unchanged during 2021 and the only shareholder of the airport company is the Slovak Republic, on whose behalf the Ministry of Transport and Construction of the SR acts (100%).

3.1. Destinations currently offered by Bratislava airport:

Brussels – From Bratislava Airport it is possible to transport to Brussels thanks to the direct airline operated by Ryanair. This link is made from Bratislava airport to Brussels-Charleroi airport at an interval of four times a week. The days of operation are Wednesday, Friday, Saturday and Sunday.

Dalaman - The city, located in the south-west of the country of the Turkish Riviera, can only be visited twice a week by Ryanair's direct flight from Bratislava on Tuesday and Saturday.

Dubai – This destination is offered and brokered by Smartwings on a weekly basis. It's also a direct flight from Bratislava to Dubai.

Dublin – by providing this favourite destination, Ryanair will take the aircraft up to three times a week. The operating hours from Bratislava to Dublin are on Mondays, Wednesdays and Fridays.

Edinburgh – If we wanted to go to one of Europe ' s most romantic cities, we would certainly like the possibility of leaving Bratislava directly twice a week. These trips are facilitated by Ryanair every Wednesday and Sunday.

Eindhoven – the direct connection of this airport to Bratislava airport is one of the best tourist options offered to us at relatively favourable prices that Ryanair offers to the majority. But why do we call it the best tourist opportunity? We only have to make one flight and we are in Eindhoven from where we can jump to Luxembourg and Belgium. Bratislava Airport offers its

passengers the opportunity to make use of this connection twice a week.

Hurghada - this Egyptian resort is one of the most popular destinations for tourists seeking the beauty and purity of the red sea. Smartwings is offering to broker flights from Bratislava, currently twice a week during the winter season (Tuesday and Friday), but this is changing considerably during the summer season.

Copenhagen – the beauties of Copenhagen See during the days of operation, which are Monday and Saturday.

Leeds – Bradford – Leed – Bradford airline tickets were offered to Ryanair with the possibility of departing once a week on Saturday.

London – This city, which is considered, inter alia, a city of many nationalities and cultures, can be visited thanks to a direct flight from Bratislava, brokered by Wizz Air, every day of the week. Well, it looks like this destination is really popular!

Malta – This favourite holiday distillation must not be absent from the offer of departures from Bratislava airport. Malta is an island state and we have an offer of departures from Ryanair, which provides scheduled air services every Thursday and Sunday.

Manchester – If we decided to switch from watching football on TV to watching it live, Bratislava Airport offers flight opportunities every Tuesday and Thursday via Ryanair.

Milan — Milan is considered a city of fashion and therefore the availability of this destination by offering a direct flight will be exploited by any fashion enthusiast. The connection with Bratislava is provided by Ryanair, which offers a connection with this city by flights of up to four times a week.

Rome — as the saying goes, all our journeys lead to Rome, so Ryanair has decided to provide passengers from Bratislava Airport with twice-weekly flights on Monday and Friday.

Skopje – The city of Skopje is considered the bead of the Balkans. The city is very diverse, with different nationalities living together, and it is certainly worth looking at the amazing nature the country offers. Bratislava ' s connection with Skopije is offered by Wizz Air on a regular basis twice a week, every Tuesday and Saturday.

Sofia – the unforgettable architecture, beautiful parks, or beautiful hills is what Sofia offers us. I'm sure every passenger in this town is gonna get their way. Wizz Air offers this option to fly to Sofia up to four times a week.

Thessaloniki / Thessaloniki – The city is considered to be the second largest in the region of Macedonia and Ryanair has therefore decided to operate flights from Bratislava Airport on a scheduled service twice a week, on Monday and Friday.[4], [5]

4. AERODROME EQUIPMENT AND AVAILABILITY FOR SERVICE CONTINUITY AND OPERATIONAL PERFORMANCE

The increase in air travel is causing a revolution in airport travel. As the focus is increasingly shifting towards greater humanisation of transit areas that promote comfort, ergonomics, privacy, cooperation and concentration, terminal facilities at airports are assuming an increasingly important role in the experience of modern air passengers. The aim of the airport terminal equipment is to improve the well-being of passengers by ensuring their smooth passage as well as by facilitating pre-flight and post-arrival processes. The airport company ' s portfolio of services is broken down into services relating directly to the servicing of air transport facilities for the equipment of passengers and ancillary activities carried out for the benefit of passengers and other users as part of their needs at the airport — non-flight activities. Part of all services are provided by the airport and other services are provided through subcontractors. The main object of the business is the provision and leasing of airport infrastructure and services to air carriers.

The airport services provided shall be divided into:

Airport services:

- check-in of passengers (check-in of travel documents, registration of baggage)
- baggage handling (handling, sorting, preparing for departure)
- check-in of air cargo (receipt, preparation of cargo and departure / arrival documentation)
- ground handling of the aircraft (ensuring the safety of the aircraft, stowing airport machinery of various kinds on request for air transport, aircraft displacements, etc.).)
- aircraft balancing services • biosecurity • 24-hour central information service
- assistance services for passengers with a disability

Non-flight activities:

- renting out non-residential premises and storage facilities
- renting out advertising areas and parking spaces • supplying and distributing energy to outsiders

Security and rescue and firefighting services:

- security
- performing rescue and firefighting services

Outsourced services:

- fuelling of aircraft
- Packaging and weighing of luggage
- catering services (cafés, fast food, restaurants)
- business services (duty-free shops, shops, souvenirs)
- Mastercard Caproni lounge

- car rental companies
- urban public transport services
- long-distance transport services
- Service taxi
- automatic teller machines
- tourist information service

The Airport Company ' s Commercial Activities Department continued in 2021 the commercial activities of non-flight activities as required by passengers as well as visitors to the airport in an effort to increase the revenues from non-flight activities. The purpose of the non-residential rental is to offer the right product of the mix so that the services offered meet the requirements of passengers, taking into account the competing services of international airports. Although the whole of 2021 was accompanied by the COVID-19 pandemic, the Commercial Activities Department entered into new contractual relations not only in the area of non-residential rental but also in the area of advertising rental. The potential for events that may disrupt ' normal commercial operations ' at airports creates the need for robust business continuity management plans. These plans shall be used to identify the potential risks faced by the organisation; to determine how these risks will affect commercial operations; to implement controls and measures designed to mitigate these risks; and to monitor, test and evaluate the strategic plan in order to keep it up to date. The Airport Continuity Management Manual is intended to provide airport authorities (operators and / or owners) with appropriate plans that take into account a wide range of possible events to enable them to prepare for and cope with a disruption of operations and to resume normal operations as soon as possible, making full use of business continuity planning. This guidance document provides factual information and effective management tools to ensure that airports can maintain the flow of passengers and goods, enable the provision of services to customers, maintain the flow of commercial income and protect their infrastructure. Bratislava Airport has not only highly qualified and trained personnel, but also adequate technical equipment to provide all the required passenger and ground handling services. It is also at Bratislava airport to use the Cargo department, which will ensure that cargo is transported to the requested destination. [6], [7], [12]

5. EVALUATION OF THE ALLOCATED AND DEPLOYED CAPACITY OF THE AIRPORT

Airport M. B. Štefánika – Airport Bratislava is the main and largest airport in the Slovak Republic, through which approximately 2 million passengers pass each year (despite the pandemic situation). Within Central Europe, Bratislava airport is in a very favourable location, and connecting it to other transport segments such as rail, water or road is also a significant factor. All these factors give Bratislava Airport great prospects of becoming a major civil aviation operator in terms of passenger and cargo traffic. From the past, we could mention a few milestones in the creation of Bratislava Airport and its overall use. Work on the establishment of Bratislava Airport started in 1947, when the first phase of construction of the airport was fully under way. At that time, a runway was built in the direction 04-22 and in the direction 13-31, which we know today. In the following years, a terminal was built which also had its own pre-stations, new communication systems were put in place, and a central boiler room was built, as well as additional facilities for the main substation. Over time, the building has also expanded the building space that has served to date. During the lifetime of the airport, it was concluded that, in view of the number of passengers and the number of aircraft using the runways, it was necessary to reconstruct them and to extend them accordingly, so that the capacity offered by the airport could be fully utilised. In the long term, there was a problem with the mixing of departing and arriving passengers, so the airport management decided to vertically separate these passenger flows. The implementation of the project has begun, using the capacity to deliver Terminal B, which is still known to us today. The capacity of the Bratislava airport is also being increased by a modern fire-fighting armory, which has helped significantly to position the airport from category 6 to category 7, which in this case also ensured the landing of large-capacity aircraft. A few years ago, for the comfort of travellers and, of course, airport staff, Process and transportation system for baggage. Bratislava Airport is divided into two parts, airside and landside. The Airside part is the area of the airport used for the operation of aircraft to which I have access by an airport employee who has passed security checks. In this part, we ordinary passengers can see through the terminal windows all the processes of handling our flight. Bratislava Airport owns or leases the necessary equipment to operate efficiently. Part two, Landside is available to all. This section contains all the necessary communications for transport to the airport, buildings that are used by external entities, or common facilities at the airport such as cafes, equipment counters, etc. The airport of MR. Štefánika is a very good place because it is accessible not only to passengers who live in Bratislava, but also to passengers who come to the airport only for departure. The arrival by car is relatively simple, a short distance from the airport to find a motorway that takes passengers directly to the airport. The link between the railway station and the airport is also favourable, as one urban transport link will take us to the airport. As far as airport capacity is concerned, it is relatively well used for the purposes of passengers, and there will also be external operators who make efficient use of the airport premises. Some airlines have a base at the airport and some premises are used by transport companies, which take these premises as a way of streamlining the process of equipping their cargo. Not only does the airport lend out its buildings, but it also offers the possibility of parking private aircraft, whether it has acquired the possibility of using hangars for aircraft maintenance or spraying companies. It could be said that M.R. Štefánika Airport effectively offers its premises and facilities to other entities, while these companies contribute to the airport register. The capacity of the airport shall be fully utilised as far as possible. [7], [8],[12]

6. THE IMPACT OF LOW-COST AIRLINES ON AIRPORT BRATISLAVA

In the current difficult situation for European aviation, one sector is doing exceptionally well, low-cost carriers. While traditional carriers are experiencing serious difficulties, withdrawing the routes offered and reducing the number of

employees, the low-cost sector continues to expand at a huge pace. There is evidence that low-cost carriers are even becoming dominant players on a significant number of intra-European routes. Low-cost airlines are becoming important factors in planning the development of airports. Their requirements differ from those of traditional carriers. They drive the development of secondary airports and cheaper airport terminals. They catalyse ' low-cost airports ' around major airports built for traditional airlines. Over the last two decades, LCC have taken over a large part of the aviation business worldwide. According to the IATA LCC, they already account for 24% of the seat capacity worldwide. The LCC segment is about 50% in Italy and Spain. In less than 10 years, the old airlines, which were once masters of aviation, were wiped out of the European market. The golden years of aviation exclusivity are over. Champagne and caviar are rarely seen on board. It is likely that the passengers next to us will bring home sandwiches. Short-haul air transport has become a commodity. Many passengers are guided by price. As a result, the airline offering the lowest price is most likely to enter into a transaction. In order to be able to offer such low rates, LCCs must become super-efficient at all levels, especially on the ground. Their aim is to achieve a turnover of 25-30 minutes. LCC airports have to adapt to this new business environment, and so has M.R.Štefánik Airport. At present, the runway system of Bratislava Airport has been more or less dismantled by Ryanair and Wizz Air. Air Cairo and Smartwings will appear on the departure boards of Bratislava airport less frequently than the mentioned leading airlines. Of course, we must not forget to also forget the charter flights, which are mediated by airlines, especially during the summer holiday season. According to the statistics, Go2Sky and Travel Service aircraft were the most frequently flown in the past. We are not yet in the summer season at this time. For aviation policy makers, there are many problems associated with the expansion of the low-cost sector. These include the mitigation of environmental impacts, especially on secondary airports, as most low-cost carriers tend to choose routes between regional airports. These airports are often confronted with a huge increase in traffic, which requires huge capital expenditure on infrastructure investments. Ensuring that passengers' rights are respected, especially as some low-cost carriers have different transport conditions compared to traditional carriers. If we were to take into account not only the winter season but also the summer season, we would argue that the airport of M.R. Štefánik is largely occupied by low-cost airlines. [9], [10], [11]

7. CONCLUSION

In the next few years, which will be marked by the recovery of the entire sector from the effects of the pandemic, it will be important for the company to try to consolidate and reunite the units of land that, according to the law, should belong to the airport, but are not owned by the airport due to restitution, bad registration deposits and lost court cases, and at the same time to grasp the best possible opportunity to cooperate with the private sector in the development of freight transport and the possibility of linking the areas adjacent to the airport to the airport's infrastructure. At the same time, the airport needs to work on a terminal redevelopment plan, primarily for Terminal B, and conceptually solve the issue of the composition of carriers, passenger needs, and compensation for the use of the terminal by passengers so that any future construction reflects the above. At the same time, it will be necessary to solve the issue of the construction of a parallel runway or rather a fundamental renewal of the runway system and facilities, which already today partly show signs of moral and technical obsolescence. A company must be mindful of its composition of carriers and operational and safety needs for smooth and safe operations in its development, whether spatial or investment development[40]. In this thesis, the innovative concept of airport company development was studied both theoretically and practically. Future developments arising from our proposals to implement and improve the operation of Bratislava Airport could be implemented in the further development of the airport based on the information received from the travelling public. The final objective of the study was to assess the feasibility of the proposed concept of innovation and future development of M.R.Štefánik Airport. In the practical part, which was carried out by the method of examining the answers of the respondents, we evaluated in the final result that from the total number, a large percentage of respondents use the Bratislava airport for transfer, either as a place of departure or as a place of arrival from the planned trip. They also expressed their views on the accessibility of creating new destinations as well as connecting Bratislava airport with JFK airport. As a result of the responses, we concluded that our respondents were more comfortable with the use of low-cost airlines but were not interested in evaluating the intention of BTS as a secondary airport for Vienna Airport. With regard to privatization, our respondents would prefer a lease or at most only partial privatization, which would help to create new opportunities to improve the functioning of M.R.Štefánik Airport thanks to potential investors. In our thesis, we have also provided data regarding the further development of the airport and the possibilities that could eventually improve its status as a top airport.

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DIGITIZATION OF AIRCRAFT MAINTENANCE PROCEDURES

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Abstract

This paper presents the results of research on the possibilities of implementing digitized procedures in the environment of heavy aircraft maintenance and deals with the design and implementation of digitized procedures in the hangar. The object of the paper is the maintenance procedures in section 10/20 of the BMD department in the company ATB s.r.o. which performs maintenance on the cabin and fuselage parts of the aircraft. In the paper we analyze current maintenance procedures in the designated department and examines the effects of digitized procedures on increasing work efficiency. It proposes the method and individual phases of the implementation of digitized procedures. In the first phase, a solution is implemented to replace the paper form of maintenance documentation, used by mechanics during maintenance, with their digitized form. The other two phases are described theoretically. The thesis identifies obstacles associated with the implementation of the proposed procedures and offers possible solutions.

Keywords

Maintenance, Paperless, Digitalization, Introduction

1. INTRODUCTION

In recent years more Airlines and MRO companies are looking for options to digitalize processes and reduce the need for paper usage in their operations. With evolving technologies and software solutions, it is becoming more available for them to make decisions and move toward paperless operations. In an aircraft maintenance environment trading paper for digital format doesn´t have an impact only on cost reduction and environment but can also enhance effectiveness and safety. [1].

Swiss International Air Lines recently invested in digital solutions to get rid of paper for their operations. Currently Swiss is one of a few airlines doing all CAMO and line maintenance work paperless. Engineers use tablets to work with maintenance documentation. They manage to save about 1.5 million sheets of paper a year with new digitalized solutions, saving time by eliminating time consuming process of transferring paper into IT and reduce the risk of mistakes during the transfer.[2]

In 2017, IATA published guidance material for the implementation of paperless aircraft operations in Technical operations. For paperless maintenance operations, they identified two production control key result areas: workflow optimization and time visibility. To accomplish these, the following measures are considered necessary:

1. Improved task card completion rates

2. Optimal utilization of manpower

3. Improved quality through data-driven process improvement.

In many plans, undue delays in productivity are a direct result of paper-based systems whereby records can be misplaced or destroyed. Some of the biggest productivity bottlenecks involve duplicate data whereby having more than one system in place can create unnecessary data storage that adds to the time and cost required to support business operations. [3]

Recently released software, by company Swiss AviationSoftware Ltd., AMOSmobile/EXEC, is an extension of current AMOS MRO software, designed for mobile devices.

AMOSmobile/EXEC offers a full-scope functional platform for line and base mechanics. It is designed with the goal to enable the paperless execution of all line & base maintenance activities and eliminate tons of paper created in the process of documenting all maintenance steps. [4]

Figure 1 - Amos mobile functions (https://www.swiss-as.com/amos-mro/amosmobile)

In our study, we participate in aircraft maintenance procedures in an MRO company based in Slovakia. As AMOS is the software used to manage maintenance operations in this company, the mobile extension provides an oprotunity to implement this system and move toward paperless operations in the hangar.

2. METHODOLOGY

In our research, we focused on collecting data through observation of maintenance procedures. We achieved this by participating in aircraft maintenance at MRO company based in Slovakia. Aircraft maintenance is a complicated process, its

completion is divided into many stages and performed among multiple departments within the company.

2.1. Research environment

We conduct our research in a base maintenance department, which is responsible for conducting base maintenance operations on the aircraft. We focused on researching the procedures of 10/20 cabin/fuselage section mainly for these reasons:

1. It is the largest section of aircraft base maintenance.

2. It is the department with the most mechanics in one shift.

3. It contains a large variety of tasks, as well as structural inspections

4. Heavy workload and usage of maintenance documentation

Research is conducted during C check on A/C type Embraer 190(E190). It is a twin engine single-aisle passenger aircraft. As previously stated, we were focused on fuselage/cabin maintenance operations. On E190 it encompasses the cockpit, cabin externally/internally, front and aft cargo compartments.

2.2. Methods and focus

While participating in aircraft base maintenance procedures we focused on observation of maintenance procedures in cabin/fuselage section with the following analysis from the point of view of suitability for digitalization. In this paper, we cover two categories of maintenance procedures: Removal and Inspections/findings. During the period of month of research, we observed and documented current maintenance procedures. In the second part we conducted data collection and the following analysis. As a collection sample, we worked with 2 mechanics in the period of 10 working shifts. Here we collected data on the usage of maintenance documentation, printed maintenance documentation, usage of aircraft maintenance software on station computers, number of moves that are needed to be done during the shift and time spent on these events. In the last part we implement digitalized procedures, by replacing printed forms of documentation with a mobile device(iPad) and analyze their impact on aircraft maintenance in our examined environment.

3. RESULTS

In this part, we present and evaluate the results of our research. Our goal was to find a heavy maintenance environment and determine appropriate ways to digitize current procedures. As well as the course of our research, we divide its results into three main parts:

- Observation of maintenance procedures and their analysis
- Collection of data on the use of paper in heavy maintenance
- Proposal and implementation of digitized procedures

3.1. Observation of maintenance procedures and their analysis

This part of the research aimed to identify the procedures for individual parts of the maintenance performance, the documentation used in the execution of the work and to evaluate the possibilities of digitization of the current procedures and the impact on the efficiency of the work performance.

3.1.1. Removal

Removing panels and components from an aircraft is one of the first processes performed on an aircraft after it is accepted for maintenance. Their removal may be necessary for several reasons:

- The component has reached the limit of its service life and must be replaced or overhauled.
- A component or part is damaged and needs to be repaired/replaced
- A panel or part covers an area that needs to be inspected and needs to be temporarily dismantled

As one of the first steps, we found out what type of documentation is used in this process and in what form the mechanics have access to it. The first basic documentation that the mechanic uses is the Workorder, hereinafter referred to as WO. Original WO which is subsequently used as a legal document with a signature and is stored and can only be printed once. The mechanic therefore receives a printed copy marked as "working copy", which he subsequently throws away after the work is done. This document represents a work order, where the mechanic receives information about what performance of work is required of him. It is therefore a document that the mechanic has with him while working on the aircraft. The unique WO number is important information, the mechanic uses it to identify and match the dismantled part to the given WO through TRT and for the subsequent operations performed in the AMOS system, which represent recording the time for the performance of the given work, ordering the material and subsequently adding data to the WO before printing its final version.

Another type of documentation used by the mechanic is AMM, AIPC, Panel List. The AMM is a basic document that the mechanic must have with him during his work. This document contains a detailed procedure/instructions for performing the assigned work, according to which the mechanic proceeds. In the current processes, as well as the WO, it is necessary to obtain a paper version of the AMM. This results in the need to move from the plane to the station, search for the manual and then print it. After the work is completed, the manual is thrown away. It is not possible to store it for further use, the reason is to ensure the use of the current version, as the manuals are often revised and supplemented.

In this process, we identify several advantages for implementing digitized procedures in the form of a mobile device that would allow the mechanic to view maintenance documentation and access MRO software. The main benefit would be continuous access to the current version of the maintenance documentation, which can reduce the risk of errors when using their outdated version and reduce the number of movements performed during the performance of work. The benefit is also

easier identification of individual components, which is important during subsequent inspections and reassembly and prevents delays in the event of problems with incorrect labeling of individual parts. We see the greatest contribution to the simplification of current procedures in the new addition to the AMOS system. With the possibility of implementing the latest version of the AMOSmobile system, which enables the electronic signing of documents, it would be possible to eliminate the printing of the paper form of the WO from the current procedures. [4]

Immediate access not only to the current maintenance documentation but also to the MRO software means simplifying the work for the mechanic and increasing the efficiency of the performed tasks. It allows the mechanic to perform all work directly at the aircraft without having to move to the station and then back to the aircraft. Another advantage is the possibility of ordering material directly from the plane. This reduces the risk of forgetting to order the necessary part, between the time the mechanic discovers the missing/damaged part and the time he gets to the software at the station and orders the goods. This is a key step in preventing a missing part when you go to reassemble components on the aircraft and find that the part is not ready. In some cases, the part is not even available in the company's stock, and it is necessary to wait a long time for its delivery, which can lead to an unwanted extension of the maintenance performance. Another advantage that we identify when ordering goods is the possibility to track the status of the delivery of the goods without having to go to the computer. Thus, the mechanic does not have to leave the plane several times or interrupt the performance of work to find out the availability of the necessary part or consumables that he needs to perform the work. He can monitor in real-time when the part he needs to perform the work was released from the warehouse and time the most suitable moment for its collection to affect the performance of his work as little as possible.

3.1.2. Inspection/findings

Inspections and records of findings are carried out after disassembly or are carried out simultaneously with the disassembly process, which takes place on another part of the aircraft. This process takes place as well as directly on the aircraft in the case of components that have not been dismantled or parts that are part of the supporting structure of the aircraft, as well as outside it in designated places during individual sessions. This is mainly in the case of dismantling components from the aircraft (e.g., PSU, overhead bin, panels).

The type of documentation used for component inspections is CMM. The mechanic uses the paper form of this maintenance documentation for the exact identification of specific components and their subsequent registration together with the damage found.

It is during off-aircraft inspections when it is necessary to carry out inspections on a large number of components such as "overhead bins", that we have identified the possibility of increasing efficiency with the help of digitized processes. This was mainly due to the need to record a high number of damages on a large number of components. Each damage must be assigned to a component and identified by P/N and/or panel number. Subsequently, this information must be transferred to the AMOS system when opening a finding WO. Currently, this data is written by the mechanic on paper, this can lead to errors when writing data and subsequent transfer to the AMOS system in the case of large quantities of components. Also, this process is lengthy and there is duplication of systems. When using the mobile version of AMOS mobile, the mechanic would be able to record this data in the system directly during inspections. [4] This would ensure a reduction in the risk of errors and incorrectly entered data when transferring data from paper form to digital, and at the same time reduce the workload required to perform the given work.

When analyzing the current and proposed digitized procedures, we identified one of the factors that causes a problem in the direct entry of data into the AMOSmobile system, in the case of components consisting of different types of materials. The reason for this is the need to divide the damaged components into groups, according to the method of repair, and then assign them to the appropriate department to repair. Damage to metal parts is sent for repair to the SM department and damage to composite materials to the WSD department. For this reason, it is necessary to perform inspections of individual components first, followed by division into groups according to the type of damage. Only after such a division of components is appropriately marked and assigned for repair to a specific department is it possible to open a discovery WO. In it, groups of components are subsequently entered according to damage, which allows them to be more easily divided into the relevant departments and ensures more efficient execution of the repair itself.

A possible solution for eliminating the intermediate step in the form of paper primary records is the creation of a template, in a program located in a mobile device, for performed inspections of a large number of components. the mechanic would record the damages found during the inspection and then they would be automatically assigned to groups according to the type of damage. This would allow the mechanic to simply copy the sorted lists into the AMOS software and open a new find WO. In this case, we consider the simplest solution to be the creation of a template in the Excel program, for the most frequently repeated inspections in which many components are checked. As a result, templates can be adapted and damage can be distributed to the materials that the component contains. [5] Excel offers options for easy data entry, sorting, and filtering. This will allow the mechanic to simply copy the individual panel names and part numbers from the maintenance documentation into a pre-prepared template and then transfer the sorted lists to the AMOSmobile system. The benefit is the streamlining of the work performed, the unification of all operations into one device, and the elimination of the need to transfer data from paper to digital form.

3.1.3. Data collection

The second part of the research is dedicated to the collection and analysis of data on the use of paper documentation in heavy maintenance processes. In this part, we focused on collecting information from two mechanics, during a time interval of ten days, with whom we cooperated during our work. The basic data, which we set for our research as supporting and at the

same time according to IATA recommendations, are given as key indicators. [3] The basic elements that we monitored related to one work shift:

- Number of used maintenance documentation (and the necessity of printing)
- Number of movements from the plane to the station
- Number of uses of the AMOS system on a desktop computer
- The time that is spent during this activity
- The time required to move between the plane and the station

The goal is to present the possibilities of increasing the efficiency of work performance through the proposed digitized procedures. The examined indicators represent areas whose efficiency can be achieved by implementing mobile devices in maintenance procedures, equipped with the possibility of displaying maintenance documentation and enabling access to the AMOS system.

Table 1 - Measurments mechanic 1(Author)

Hodnoty za 10 dni					
Mechanik 1	Dokumentácia	AMOS	Čas(min.)	Počet pohybov	Čas(min.)
Spolu	40	55	375	61	153
Priemer	4	5,5	37,5	6,1	15,3

Table 2 - Measurments mechanic 2(Autor)

Hodnoty za 10 dni					
Mechanik 2	Dokumentácia	AMOS	Čas(min.)	Počet pohybov	Čas(min.)
Spolu	27	46	370	51	122
Priemer	2.7	4.6	37	5.1	12.2

In the collected data, we can observe the results of the mechanics individually, but also compare the investigated results of the observed factors with each other. An interesting phenomenon occurring in both mechanics is the ratio between the amount of maintenance used in documentation and using the AMOS system. It is clear from the collected data that the number of movements made to use the system is higher than to procure maintenance documentation. From these data, we can conclude that the implementation of the AMOS system. represents one of the basic benefits of increasing efficiency. For both mechanics, the average number of movements per shift is 5 to 6 movements per day. It is necessary to note that this data is variable during each shift and depends on several factors, which we describe later. We have divided the investigation of time into two categories. Measuring the time spent while performing movement and the time spent during activity for working with the system or searching and printing documentation.

An important point is also the evaluation of the factors that influence the collected data and the subsequently presented results. We, therefore, focused on the identification of these factors and their possible influence on the results presented by us.

The performance of heavy maintenance is a complex process, consisting of several individual actions, which take place depending on the difficulty of the given maintenance during several work shifts. Since this process is divided into several jobs, the workload on individual departments and sections of these departments is not evenly distributed over individual work shifts but has a rising and falling character. Our data collection took place during the initial phase of maintenance performance, so it does not include work shifts during which the workload is reduced or during phases in which maintenance documentation and MRO software are not used with increased frequency.

For future research, we consider it necessary to carry out more extensive measurements using the test version of AMOSmobile. This will make it possible to obtain more accurate data on the efficiency of the performance of individual works.

3.1.4. Proposal and implementation of digitized procedures

In the third part of our research, we focused on the design of digitized procedures for section 10/20 performing heavy maintenance, then implementing the procedures into the maintenance process, observing their effects on the performance of maintenance, and then analyzing their usability.

Before the actual implementation of the maintenance process, we prepared the software and hardware. It is the initial step leading to the implementation of procedures in practice. At the same time, it provides an opportunity to examine the compatibility of the used platform with the environment and systems at ATB.

Hardware: In our experiment, we use a tablet from Apple with the production designation iPad Air. [6] We consider this device suitable as a display unit for maintenance documentation intended for mechanics. It has a simple user interface that allows easy use during work, a sufficient size display with a diagonal of 27.69 cm, and a battery life of 10 hours, which allows it to be used during the entire work shift, without the need to charge it. This is necessary to enable the smooth performance of work without interruption. The tablet has a camera and the option of being equipped with a SIM card, which enables data connection even outside the range of the Wi-Fi signal. It is a key element for the use of the equipment during the performance of track maintenance or tests of the aircraft outside the hangar before the end of maintenance and handover to the customer. The tablet has the option of unlocking using fingerprint, which is important for ensuring user integrity and can serve as a form of electronic signature if necessary. [6]

To protect the tablet from damage, we used protective glass panzer glass, which provides protection against breakage, and scratches, and at the same time leaves the tactile properties of the display. [7] We also use the Spigen tough armor protective case, which is designed to protect against drops and damage, and raised edges to protect the camera and camera. It also has the option of placing a tablet, which allows the mechanic to work with the device more easily. However, for future use, we recommend securing the package with the option of attaching it to the arm or thigh using a belt. The reason is that it is easier to work with the device in an environment such as the upper part of an aircraft fuselage. It will enable the mechanic to perform his work more safely and protect the device from the risk of falling

to the ground, which could result in injury to personnel and the destruction of the tablet.

The preparation of the software represented the security of the Embraer Tech pubs application. This app allows customers to access, view and download maintenance documentation on iPads and go paperless anywhere. It has the important function of creating folders and quick access to favorite and frequently used items. [8] The tablet is also equipped with Outlook, Excel, MS Teams applications.

While testing the mobile device in a heavy maintenance environment, we focused on examining several factors. The initial goal was to test the equipment and evaluate the positive and negative effects on the maintenance process and the usability of the equipment during the daily shift.

Among the basic benefits that we noted during the survey was the complete elimination of the need to secure paper forms of maintenance documentation and the elimination of the need to perform movements due to its procurement. During the processes of disassembly, as well as assembly of parts and components, imaging on a mobile device allowed us to view the necessary technical documentation, without the need to interrupt the performance of work.

When working in confined spaces such as aircraft cargo holds, mobile devices are a very useful tool. It replaces the number of papers necessary for the performance of work, which interferes with work. Visibility on the display is also an advantage even under dark lighting conditions.

3.1.5. Disadvantages:

The necessity of increased caution while working with the device. Even though the device is equipped with protective elements, increased attention during work is required to avoid its damage. The work is often carried out in the cramped spaces of the cargo area of the aircraft, where the display can easily be damaged.

During the research, we noticed relatively limited usability in the current phase of implementation. Even though the equipment helps to increase efficiency and reduce the workload of mechanics, in the current phase of implementation its usability is significantly limited, and we identified a relatively low utilization during the shift. The main reason is the restriction on displaying technical documentation, and not allowing access to the AMOSmobile system. The limited usability is also confirmed by the measurements obtained in our data collection, which point to a higher number of necessary movements and more time spent precisely when using the AMOS system. Also based on the mechanics' feedback, we believe that the introduction of this system into the maintenance process will bring a significant increase in work efficiency in some processes.

Even though, based on the review of the first phase of the implementation of the mobile device in practice, in which its usability is limited exclusively to the display of maintenance documentation, we see it as a fundamental step for the further development of digitized procedures in the company. And that is enabling the second phase of the AMOSmobile system implementation system, and the third phase enabling the electronic signing of documentation.

However, it also serves as an initial investment and the creation of a basic platform for other add-on systems such as UAV inspections. A collaboration between Mainblades and KLM Engineering & Manufacturing is working together to develop these solutions. The Netherlands Aviation Authority has approved companies to carry out paint damage inspections at airports in outdoor areas. Their application for conducting flights and inspections as well as damage categorization works on the iOS operating system. [9]

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4. CONCLUSION

In this paper, we describe the initial digitization of procedures in the hangar, when performing heavy maintenance. With developing technologies, new possibilities for increasing the efficiency of work and also safety. Using solutions from the field of information technology arise, and therefore we consider research in this area to be crucial. The digitized procedures and implementation of mobile devices proposed by us can serve as a basis for further research and the introduction of new

technologies. Currently, the possibilities of carrying out inspections using UAVs are being investigated. This technology enables automatic inspections and recording of paint damage. The UAV performs high-resolution imaging, and the software then evaluates signs of damage such as missing labels. The mechanic then has the opportunity to track the found damages on his tablet and examine them in detail. This makes it possible to reduce the time required to perform these tasks up to three times. [10] We also consider it necessary to explore the possibilities of building digitized procedures, using virtual and augmented reality. [11]

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ENHANCING SAFETY IN GLIDER FLIGHTS

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Abstract

The theme of paper is to find out new possibilities in safety improvements during sailplanes flights, focusing primarily on flights when the separation with other traffic is reduced. At the beginning a summary of glider evolution across the centuries is made starting with the interwar period to the shapes that we know from the latest exhibitions. First part of the paper is followed by the analysis of the current available technical measurements which enhance safety and reduce the probability of in-flight collisions during various phases of flight, including latest and most modern technical implementations used by glider operators to enhance the safety of themselves and others. We will also look up for any available legislative rules based both on national civil authority regulations defined by state itself and for regulations that were created by Fédération Aéronautique Internationale (FAI) which covers most of glider competitions organized world-wide. In practical part we followed our thoughts about how to improve the current situation in this part of the aviation industry. In following steps, we decided to ask the glider pilots about their personal experience with reduced separation caused by nearby gliders during different phases of operations. Generally, there is a huge number of mid-air collisions during sailplane competitions and flight phases where pilots are crossing each other by minimal separation (mountain ridge flying). We decided to suggest minor legislative regulations and technical implementations to improve current situation world-wide and make these flights as safe as possible with minimizing of future incidents.

Keywords

glider, safety measures, glider competition, visibility enhancement, anti-collision, technical implementations

1. INTRODUCTION

Glider flying is nowadays a hobby, sport, and a way to become a professional pilot. It is popular and due to the favourable price of the training it attracts many young people, for whom it is often the only way to get closer to real flying and how to get involved in aviation associations, flying schools and aeroclubs.

In their beginnings, gliders were mainly used in the military environment to fulfil various types of tasks, but the new era brought significant progress in this industry as well, and today we perceive these machines on many levels, from simple gliders designed for aviation training needs to high-performance versions able to fly long distances at a relatively high average speed.

This flying sport is one of the most demanding. The pilot is burdened in many aspects and there are often situations where in addition to perfect flying technique pilot needs to use his capacity in the decision-making processes and tactics of the flight itself. Nowadays, we already know powerful navigation systems and flight monitoring systems that facilitate the work of pilots and offer the necessary overview of navigation, speeds or flight other flight information. However, even this does not prevent the relatively high annual occurrence of collisions with other traffic, especially during competition flights, when there are many gliders in one updraft or on the ridge.

The aim is to focus on the high number of collisions between two or more airplanes in different phases of flight, either during the competition flights or during other types of operations across aeroclubs. Glider pilots are often forced to come into proximity to other traffic.

The development of hardware and software components of non-motorized airplanes as well as the modifications of the rules for performing competitive flights may bring a significant shift in the future when any reduction in fatal collisions of airplanes would mean a leap in increasing the safety of glider flights.

2. HISTORY

The history of glider flying and this machines goes back a long way. Records of the first engineless airplane, which was able to take off with a person on board date back to 1853 when the British engineer Sir George Cayley firstly tested his new invention [1].

Figure 1 - One of the first gliders

The first built non-motorized aircraft like today's machines was the Waco CG-4A designed for the needs of the US Army. It was constructed of iron and wood, while the surface consisted of a stretched canvas, which was regularly inspected for safety.

Initially, the gliders were mainly used to carry out "quiet" military operations. They were deployed to move forces as close as possible to their destination so that soldiers could attack the enemy unobserved and without drawing unnecessary attention to themselves.

To perform their required activity, it was not necessary for the gliders to achieve breakthrough performance and have excellent glide.

These were machines weighing more than two tons, and JU-52 or Douglas C-47 type machines used to be used as towing aircraft, which had sufficient engine power to pull these gliders above the place from they were launched [2].

Figure 2 - Waco CG-4A

3. HIGH-PERFORMANCE GLIDERS

The evolution of the development of gliders has brought significant improvements in their aerodynamic properties, gradually improving the final performances such as glide ratio, sink rate and many others. The signature of the new era brought a significant difference in the used wing profiles for the given development period.

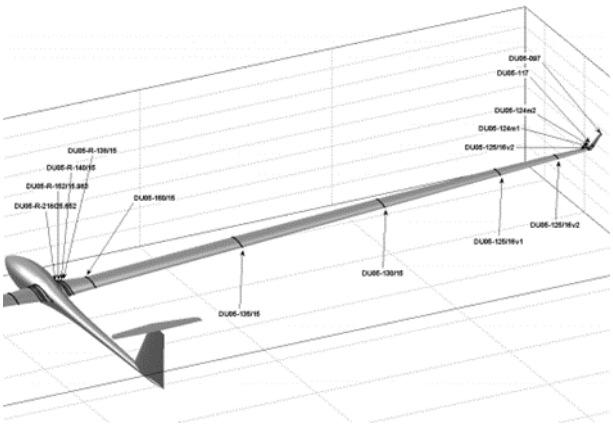

Figure 3 - Modern airfoils

Based on the characteristics of the operation of the given airplane, its designer can select the required type of wing profile. In general, we can divide profiles according to a whole range of criteria (bends of the middle curve, relative thickness, position of maximum thickness).

The development of engineless airplanes also saw progress in the field of materials used. While in the beginning, mostly wooden and later laminate structures were used, today it is durable but fragile composite materials that hold the lead in the production of powerful sports gliders.

Figure 4 - Ventus 3 by

It is characteristic for this era that products from Schempp-Hirth design workshops or other well-known manufacturers are very similar in terms of performance and so to speak, breaking away from the competition is a nearly impossible achievement. Nowadays the construction of a new model of a glider is a huge business risk, and that is why manufacturers pay attention to attributes such as comfort and safety. Interesting question is that what else can we expect from manufacturers in the future [3].

4. SAILPLANE COMPETITIONS

4.1. General rules

A sailplane competition organized under Fédération Aéronautique Internationale (FAI) typically lasts five to ten days with tasks set each day the weather is suitable.

Each contest features flights from the home airport, around turn points, and back to the home field. In poor weather, the course might be as little as 100 kilometres; in excellent weather it could be 500 kilometres or more.

Figure 5 - Fédération Aéronautique Internationale logo

Competitive soaring is all about speed. Fastest pilot around the course is receiving the most points for the competition day. The contest winner is the pilot with the most points at the end of the event. Seconds count and on some days may make the difference between winning and losing. Regional competitions

are held across the country, in Slovakia usually in Prievidza, Nitra or Partizánske, typically lasting up to 14 days and usually include 60 to 100 competitors. A handful of pilots from the national level are selected to compete internationally at the World Soaring Championships organized all around the world. The FAI maintains the rules by which competitions are conducted [4].

4.2. Flying on Course or How to Go Fast—and Far

Once a competition pilot starts the task, the race is on. While the difference between winning and losing can be only seconds. Competition pilots must find the best rising air (thermals) to gain the altitude needed to complete the course. The higher you go, the farther you can go. Thermals are often capped by a fluffy cumulus cloud making the lift. The skill of finding and using these invisible columns of rising air is what makes competitive soaring challenging. Competitors find thermals using their experience and then keep the sailplane in the narrow column of raising air by circling tightly and monitoring their senses and instruments [4].

To be successful, competitors must balance competing forces. Competitors are constantly making many critical decisions on course that will affect their overall performance.

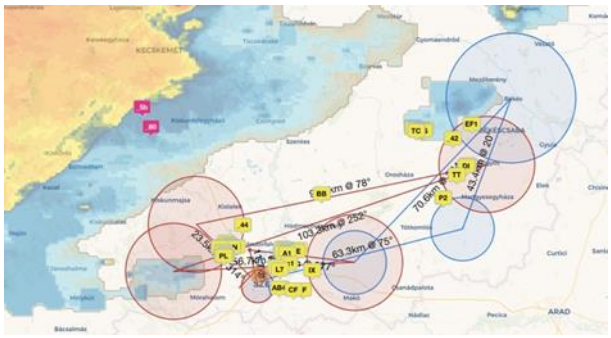

Figure 6 - Racing task

4.3. Finish

Just as every race needs a start, it needs a finish as well. As competitors near the home airfield, they start what is called final glide when they think they have enough altitude to arrive at the field with just enough energy to fly across the finish line and land. Final glides can be started many kilometres away from home airfield. Landing sailplanes are going fast and very low as they cross the finish. Often many gliders arrive at the same time at the finish [4].

5. LEGISLATION AND RULES

5.1. EASA and National requrements

According to EASA CS-22 document, gliders approved for VFR DAY flights are not required to be fitted by any of external light. This requirement is taken over also by the Slovak national legislation. Only requirement associated with external lighting is that if there are any of them installed on the aircraft, they need to be approved by authority [5].

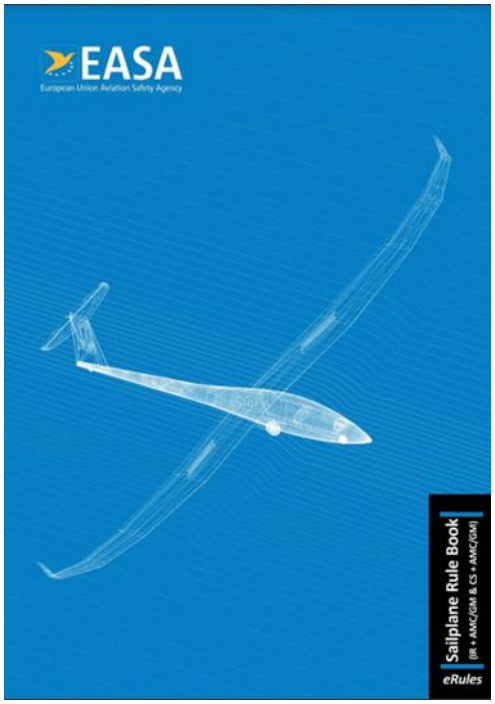

Figure 7 - EASA CS-22

5.2. FAI requirements and competition rules

If there is a talk about the safety in sailplane competitions, we have to look at document called Annex A to Section 3 – Gliding which was published by Fédération Aéronautique Internationale (FAI). All glider competitions organised under FAI shall accept their terms according to this document. At the other hand organiser should have final decision for any other safety precautions like hi-visibility markings or any lightning system of the aircraft.

Judging by competition rules published on roughly all competitions in our country there is requirement to have operating FLARM anti-collision system on board, updated and functioning. This rule is verry often checked by our national authority officers on the starting grid before starting the task. Although after many years there is some first mention about lightning system of the sailplane aircraft and soon sailplanes competing on the highest levels will be technically required to have operating strobe light on board [6].

6. CURRENT STATE

In this section we will discuss the current situation of safety in glider flights in our country and internationally. We would like to introduce you into procedures and safety precautions used by pilots in real.

If we are talking about anti-collision systems used nowadays, we have some options to mention, that they are common and almost used by all the pilots not only in glider competitions, but generally across the aeroclubs and flying schools. At the other hand there are some precautionary systems which are still new-born it will take some time for them to be implemented to the real operation.

6.1. FLARM

FLARM (an acronym based on 'flight alarm') is the name for an electronic device which is in use as a means of alerting pilots of small aircraft, gliders, to potential collisions with other aircraft. Important is that the aircraft should be both similar equipped, so the system is fully working.

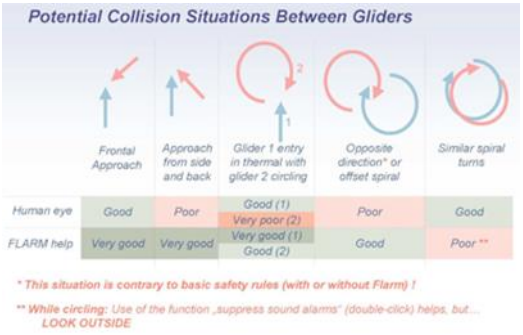

Figure 8 - FLARM vs Human eye difference

FLARM obtains its own aircraft position from an internal Global Positioning System (GPS) unit and a barometric sensor, and this is updated every second. The data is then broadcast by a low power RF transmitter (868.2 MHz) along with a 30 second projection of a likely 3D flight path. Its receiver searches for other FLARM devices within range and processes the information received.

Data on potential conflicts with up to 50 other participating aircraft are stored and aural and visual alerting is used to warn the pilot.

Figure 9 - FLARM display

The FLARM Unit will provide an alert in respect of the greatest current danger by means of a 'buzzer' or 'beep') and illumination of a Light Emitting Diode (LED) indicator. The display will show the threat level and the lateral and vertical bearing of this threat. If a suitable database is installed, FLARM can also warn of the presence of static aerial obstacles such as masts and cables (database must be obtained).

Figure 10 - FLARM during the flight

FLARM system is commonly used across the gliding world and in required on almost all gliding competitions across the world as its defined as requirement of FAI Annex A document.

Advantage of this system is that it's low consuming and saves glider battery as we all know that glider is not equipped with any source of generating electrical power [7].

7. FLASHING SYSTEMS- STROBE LIGHTS

Strobe lights systems mounted on the gliders are still rarely used by pilots. One of this system has been developed by Sotecc company.

Canopy mounted LED flashing system already mounted on more than 2500 sailplanes all around the world brings ideal combination of glider visibility in many situations.

Figure 11 - SOTECC strobe

From the real practice we all know that almost none of the sailplane is fitted by external lightning system. Neither position nor any strobe lights are used [8].

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DEVELOPMENT OF THE DESIGN OF AN EXPERIMENTAL LONG-RANGE FIXED WING UAV

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Abstract

The goal of the article is the design and assembly of a flight-capable platform for testing an experimental hybrid drive developed within the grant project. The input for the entire work is designed for the highest take-off weight of 10 Kg and a pair of driving electric motors with a thrust of 5 Kg each (49,05 N). The content of the article includes basic theory, analyses, simple structural calculations and design methods, the design itself, construction methodology and work results. Analyzes in the article include analyzes of currently used types for the design and construction of hybrid unmanned aerial vehicles and analyzes of materials used for UAV structures with a piston propulsion unit, on the basis of which the design and construction of the UAV was proposed. As part of the design, the construction and design are recalculated and simulated both aerodynamically and strength-wise. Several software were used in the design and simulations: AutoCAD Inventor for modeling and strength analyses, Autodesk CFD for airfoil simulations and XFLR5 for the aerodynamics simulation of the UAV design. In the practical part, the production methodology is described in detail and illustrated with original photographs.

Keywords

unmanned aerial vehicle, maximum take-off weight, structural analysis, design aerodynamics, hybrid propulsion, strength analysis, simulation, production, flight tests, flyght envelope, weight and balance, performnce

1. INTRODUCTION

A hybrid UAV with fixed support surfaces is a winged unmanned aerial vehicle using a combined energy source to drive propulsion units from the rule of electric motors with propellers. Currently, the most widespread technology for hybrid systems is an electric generator set that is driven by an internal combustion piston engine similar to hybrid cars in the automotive industry.

2. ANALYSYS OF THE FIXED WING UAVS CONSTRUCTIONS

Most fixed-wing UAVs have a structure comprising wings (fixed wing) with lift mechanism, "winglets" and ailerons, Fuselage, Tail (Tail surfaces, Vertical Stabilizer, Rudder, Elevator) and Landing Gear. Landing gear is not normally found in the lower weight categories of UAVs, because most UAVs have a VTOL function or are launched using a catapult or take off in the so-called with a "throw from the hand" and lands on the torso. When comparing classic UAVs with an electric energy source for their drive and hybrid gasoline-electric UAVs, there are fundamental differences in the construction used. Because hybrid UAVs, in addition to being more massive, are also stressed differently, especially by heat and vibrations from the combustion engine. Another difference is the MTOW, which for hybrid UAVs can be tens of kilograms (depending on the purpose) and the operating speed (CS – cruise speed), which can exceed up to 100 km/h. Depending on the performance requirements, the design of a hybrid-powered UAV may vary. Most battery electric UAVs with a fixed support surface have a simple hull shell construction with structural partitions mainly for storage of the battery, controls and hardware, while the wings are made in one piece without a strength coating similar to tail surfaces. The most widespread construction material of civil UAVs with a low weight category is polystyrene or balsa wood or composite and plastic materials. The tail is simply connected to the fuselage using a plastic or carbon beam. [2] In the case of the construction of hybrid UAVs, mainly composite materials are used, which can withstand higher temperatures and cyclic stress, and at the same time are suitable for the application of aircraft with a higher MTOW (maximum take-off weight). The unit must be placed between the partitions, which simultaneously form the shape and strength element of the UAV fuselage. Wings require strength cover and beams. Beams are usually designed as carbon hollow logs ("tubes") or web beams ("I" beams). The cover is made of composite carbon or fiberglass, similar to the fuselage and tail surfaces, or wood slats, made of alder wood covered with foil. [3] Compared to standard fully electric UAVs with fixed support surfaces, this brings considerable complications in production, which is reflected in the production costs of the hybrid UAV itself. Overall, it can be assessed that within the design and subsequent production of a flight-capable structure, it will be necessary to use composite materials at least for the production of the fuselage where the hybrid unit is located. It will also be necessary to consider the complexity of the design and construction in relation to production possibilities and available funds.

2.1. General categorization of hybrid UAVs according to EASA legislation

In general, hybrid UAVs have a maximum take-off weight exceeding 2 kg, therefore they are classified according to EASA in subcategory A3 (< 25 kg, CS > 19 m/s) or higher category (if MTOW > 25 kg). This means that the operation of such UAVs is significantly limited by legislation. Every operator of UAV

subcategory A3 is obliged to register such UAV, insure it and provide training for the UAS pilot. Also, the UAV of this subcategory must not be operated in built-up areas with a high density of people and at least 150 m from it, for safety reasons. [1]

2.2. Current use of hybrid fixed wings UAVs

Currently, unmanned aerial vehicles are generally widely used, especially for aerial work, sports acrobatics, hobby flying or in defense. Hybrid UAVs with fixed airfoils, due to their high endurance, range and performance, are mainly used for:

- Experimental purposes (technology demonstrator)
- Atmospheric research
- Mapping and land surveying
- Monitoring of border areas
- Agricultural work (spraying)
- Shipping works [3] [4]

Individual hybrid UAVs often differ in concept. However, most of the currently produced UAVs of this concept use rectangular or trapezoidal wings with a "boom tail" concept of tail surfaces and an arrangement of propulsion units that allows vertical take-off and landing (e.g. quadcopter arrangement) [3]. Hybrid UAVs with a fixed support surface belong to larger aircraft not only in terms of weight but also in terms of size. They have a span from 2 m to 4 m and more, and a total length from 1.5 m to 3 m or more, despite the fact that they are high-performance motor planes, which makes their compactness difficult [3].

2.3. Theory of hybrid drones design and construction development

When developing the design of an unmanned aerial vehicle, it is necessary to take into account, in particular, the required performance of the aircraft (maximum take-off weight, maximum cruise airspeed, max. stall speed, stability, etc.), the budget for construction, the availability of materials and production technology, and the purpose of the unmanned aerial vehicle . On the basis of individual input parameters and options, a basic preliminary design is established, which refers to the aerodynamic, geometric and strength characteristics of individual structural units, such as:

- Wings and its mechanization
- Hull and its elements
- Tail
- Tail surfaces
- Landing gear (undercarriage)

Individual characteristics directly define the performance of the UAV. Their results are obtained by different methods:

- Calculation by simplified equations
- complex detailed calculation (through MATLAB software, etc.)
- using modeling and simulation software (AutoCAD Inventor, Autodesk CFD, XFLR5, Flow 5, etc.)
- by direct measurement in laboratory conditions (in wind tunnels)
- direct flight test in the field

Currently, it is customary to apply design elements and UAVs proven by practice, the functionality of which is verified by basic preliminary calculation, model creation and simulation in computer CAD software or in other simulation analysis software, and finally by flight test in the field.

3. PROPOSAL AND DEVELOPMENT OF THE HYBRID EXPERIMENTAL UAV CONSTRUCTION

The initial requirement for the development of the structure is dimensioning for a maximum take-off (operating) weight of 10 kg, installation of an aggregate with a GP38 combustion engine and a FOXY G2 C5340-7 195KV electric motor-generator, two FOXY C4125-9 drive propulsion units with G-SONIC Sport 40-propellers 30cm/16-12", with an assumed maximum usable pull of 5 Kg (48.05 N) each. The cruising speed was preliminarily selected at 54.612 km/h. Since the structure is to be implemented and tested in the field, the development will emphasize the reliability of the structure, the simplicity of production due to limited financial and production capacities, the high stability of the UAV due to the filling of the structure itself, which will serve primarily to test the functionality of the hybrid unit in the field and its efficiency. The UAV concept will be addressed as the traditional concept of most multi-engine UAVs with a CTOL-type fixed airfoil and a conventional tail.

3.1. Wing and ailerons proposal

The wings will be realized as combined, rectangular in 1/3 and trapezoidal in 2/3 of the wing span, while the trapezoidal ends of the wings will have a positive lift of $\Phi = 3°$. The wing tip termination will be conventional, without "winglets". The wing-fuselage arrangement will be solved in the upper-airplane concept, while there will be an adjustment angle of $\phi = 2°$ between the longitudinal axis of the fuselage and the chord of the wing profile The trapezoidal part of the wing will be geometrically twisted negatively by an angle $\varepsilon = - 3°$ Since the wing will be removable from the fuselage along its entire length and the UAV will not have high cruising speeds, the interference resistance will be neglected and therefore the shape transitions between the wing and the fuselage (and other parts) will not be realized.

The selected airfoil for the main airfoil is the NACA 4412 airfoil, which is generally used for UAVs with fixed airfoils and general aviation aircraft. [6] The wing of the long-range UAV will not be aerodynamically twisted, the NACA 4412 profile will be used in the cross-section of the entire wing. Tilt control mechanization - the ailerons will be differentiated and will be located approximately 80% of the length of the trailing edge of the trapezoidal parts of the wing. Overall, the wing solution will bring the advantage of lift distribution with an area of effect

closer to the root of the wing thanks to the trapezoidal end of the wing, and thus the wing, together with its attachment to the fuselage, will be stressed by a smaller bending moment. At the same time, the wing will not be complicated to manufacture in terms of design due to the absence of aerodynamic twist. The positive lift and upper-plane arrangement of the wing-fuselage will ensure high lateral stability, and at the same time the ailerons with a relatively large span at the trapezoidal ends of the wing will ensure effective pitch control. The negative twist of the trapezoidal part of the wing will bring better directional controllability and reduce the induced aerodynamic resistance, which will also contribute to the tension of the trapezoidal ends of the wing. Therefore, with the given parameters, it will not be necessary to end the wings with "winglets". The FOXY C4125-9 propulsion units with G-SONIC Sport 40-30cm/16-12" propellers will be located parallel to the fuselage axis in the straight part of the wing, with the propeller axis 350 mm away from the straight line crossing the center of the wing plan. Propulsion engines with propellers are attached to the nacelle in the leading edge or as traction drive units. The physical proportions and aerodynamic properties of the wing and ailerons were calculated by simple calculation and simulation in XFLR5 software. Construction modeling and strength analyzes were performed in AutoCAD INVENTOR software. The results of the wing design are summarized in tables and illustrations.

Table 1 - Aerodynamical and geometrical properties of proposed wing

Parameter	**Symbol**	**Value**	**Unit**
Wingspan	b	3	m
Root chord	C_{root}	0,41	m
Typ chord	C_{typ}	0,25	m
Wing surface	S	1,07	m^2
Geometrical twisting	ε	-3	°
Aerodynamical twisting	-	-	-
Arrov angle	χ	-1,53	°
Dihedral	Φ	3	°
Aspect ratio	AS	8,4	-
Tapering	λ	0,61	-
MAC	C_{SAT}	0,365	m
Wing set angle	φ	+2	°

Table 2 - Aerodynamical and geometrical properties of aileron

Parameter	**Symbol**	**value**	**Unit**
Aileron root chord	$C_{a\ root}$	0,085	m
Aileron typ chord	$C_{a\ typ}$	0,065	m
Aileron span	b_a	0,8	m
Max positive deviating angle	$+ \delta_{max}$	25°	°
Max negative deviating angle	$- \delta_{max}$	5°	°
Differentiation ratio	$- \delta_{max}/+ \delta_{max}$	1/5	-
Aileron surface	S_a	0,06	m^2
Aileron tapering	λ_a	0,765	
Maximum lift coefficient of deviated wing	C_{La}	0,65	-
Span ratio	b_a / (0,5 * b_w) * 100	53,3	%
Surface ratio	S_a / (0,5 * S_w) * 100	11,2	%

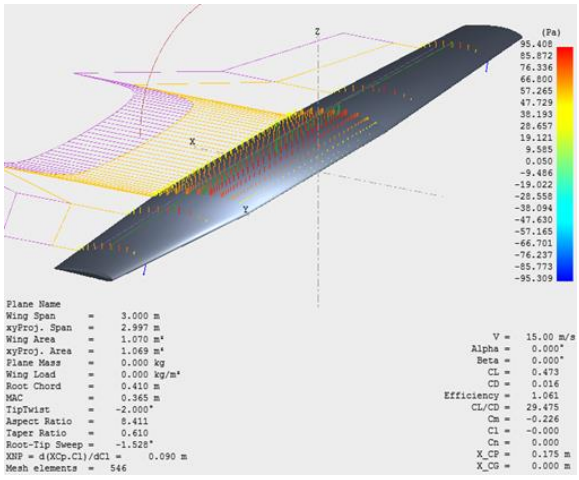

Figure 1 - XFLR5 wing aerodynamical simulation

Figure 2 - AutoCAD INVENTOR wing strength analysis

The areas of influence of lift on the half-spans of the wing are derived by a graphical method.

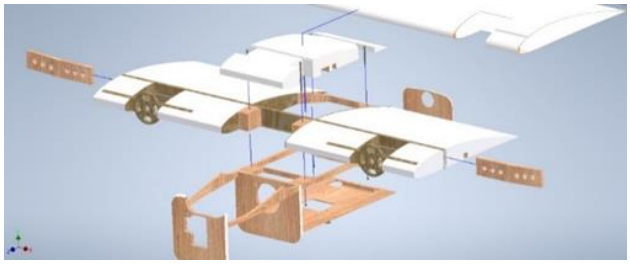

Figure 3 - AutoCAD INVENTOR central rectangular part model

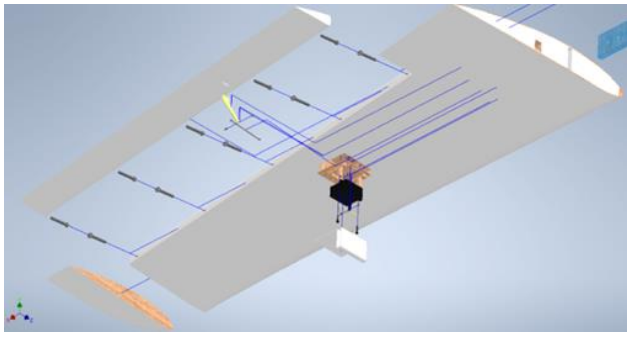

Figure 4 - AutoCAD INVENTOR wing tapered part model

3.2. Fuselage proposal

The hull is designed to be symmetrical with a square cross-section and rounded edges. The design is inspired by a design analysis for a UAV with a fixed airfoil. [5] The tail will be circular in cross-section, conical in shape and will be embedded in the fuselage as an integral part of the fuselage. Geometric parameters are dimensioned with respect to the size and location of the aggregate, fuel tank, battery, and control and monitoring hardware.

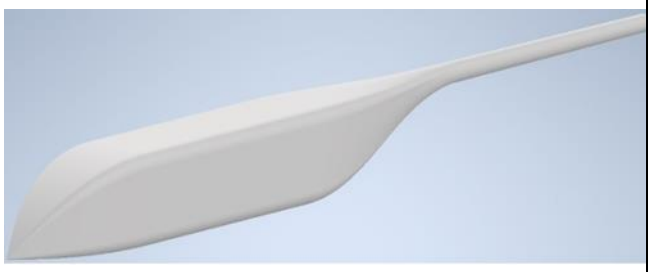

Figure 5 - AutoCAD INVENTOR fuselage design model

Table 3 - Geometrical properties of UAV fuselage.

parameter	**Symbol**	**Value**	**Unit**
Fuselage lenght	L_F	2	m
Maximum fuselage width	W_F	0,2	m
Maximum equivalent ratio	$d_{e\,f}$	0,22	m
Maximum fuselage cross section surface	$S_{p\,F}$	0,0386	m^2
Štíhlosť trupu	λ_F	11,1	%
Wetted surface	$S_{om\,F}$	0,846	m^2

Figure 6 - AutoCAD INVENTOR fuselage wooden inner construction

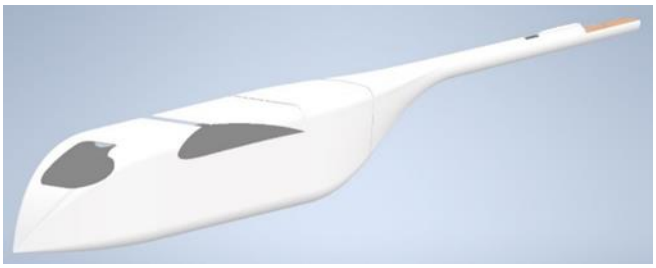

Figure 7 - AutoCAD INVENTOR fuselage composite shell

3.3. Tail surfaces proposal

The tail surfaces were chosen over conventional trapezoidal tail surfaces because they are simple to manufacture, durable, provide relatively good stability and, despite being more sensitive to propeller blow-by and trailing water at higher angles of attack and during the landing phase ("FLARE"), provide good directorship. Another reason for the choice is that it will not be necessary to use a different concept of tail surfaces for UAV purposes and arrangement of propulsion units. As a profile for the tail surfaces, a neutral symmetrical profile NACA 0008, with 8% thickness, was chosen, which, although it has a low critical angle of attack (limited sensitivity to stabilization in case of larger disturbances), but provides minimal resistance compared to thicker profiles [9]. For the selected tail concept, the NACA 0008 profile is sufficient.

Table 4 - Geometrical properties of UAV tail surfaces

Parameter	HTS		VTS		Unit
	Symbol and value				
Root chord	C_{Hroot}	0,24	C_{Vroot}	0,19	m
Typ chord	C_{Htyp}	0,14	C_{Vtyp}	0,13	m
Span	b_H	0,9	b_V	0,27	m
Elevator and rudder soan	b_e	0,9	b_r	0,25	m
Elevator and rudder width	C_E	0,06	C_R	0,07	m

The tail surfaces of long-range UAVs are designed as structural. The leading and trailing edges, including transitions between stabilizers and rudders, are designed as beams, connected by profiled ribs, between which are diagonally placed rod reinforcements. The transitions between stabilizers and rudders are rounded to a radius from the outside. The tail surfaces do not have a strength coating. The cover is made of iron-on modeling white foil.

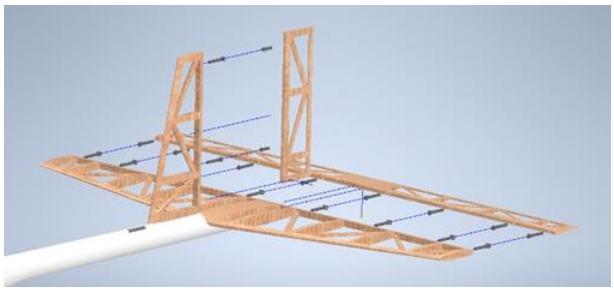

Figure 8 - AutoCAD INVENTOR tail surfaces construction model

3.4. Propulsor engine and hybrid agregath bed

Both engines load the wing with additional torque from thrust, weight, and reaction and gyroscopic torque. Therefore, the engines will be bolted crosswise to the nacelle, which will be embedded in the wing and which will be part of the strength box. The reinforced case is formed from the rear by the main wing beam with an "I" profile made of spruce flanges and a web made of cardboard wood. On the sides, the strength box will be formed by walls made of cardboard wood in the shape of a profile, and in the front part the nacelle itself, which will also have side projections embedded in the core of the wing. On the inside, the strength box will be additionally reinforced with a U-shaped wooden reinforcement made of spruce wood. The strong box with the nacelle will form the motor bed individually for the drive electric motors.

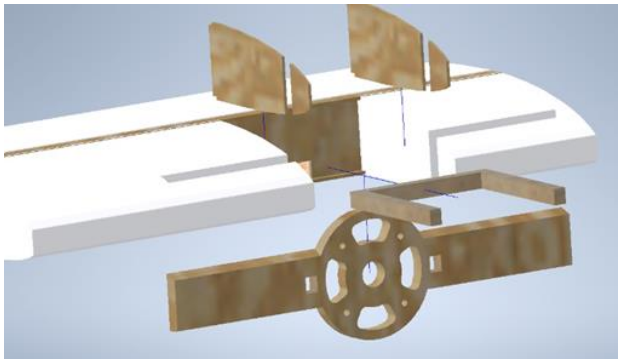

Figure 9 - AutoCAD INVENTOR engine bed construction model

The position of the hybrid unit was chosen in view of the long-range UAV design concept, in the front part of the fuselage ("in the nose"). The unit is located with the piston engine at the tip of the UAV nose, due to the roundness and the need to expose the largest possible area of the piston to the air flow, as the GP38 engine is air-cooled. The entire unit is composed of a piston engine, a flexible coupling without starting the electric motor-generator flange and the electric motor-generator itself. The entire assembly is stored in a cage formed by four screw rods with a diameter of 4 mm and fixed with M4 nuts. The cage with the aggregate is stored in silent blocks and attached to the partitions that are part of the internal structure of the UAV fuselage.

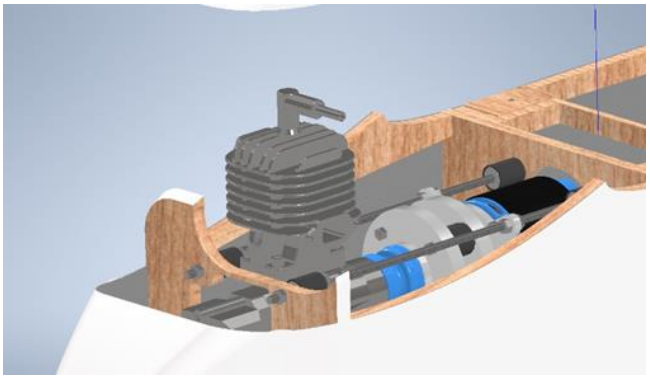

Figure 10 - AutoCAD INVENTOR hybrid agregath bed

3.5. Landing gear propose

The landing gear - the landing gear of the long-range UAV is designed based on the prototype of the tricycle landing gear for transport aircraft [7]. The exact position is developed based on the position of the center of gravity of the balanced UAV and, within the prescribed intervals, the selected angles of the wheel tangents and the vertical axis passing through the center of gravity.

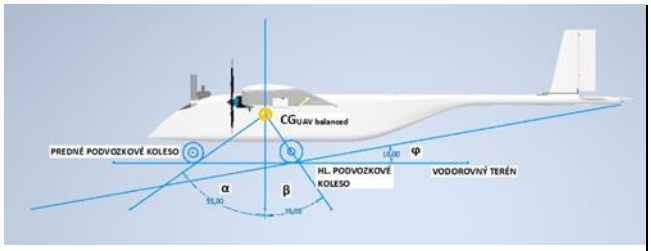

Figure 11 - AutoCAD INVENTOR Landing gear position sketch

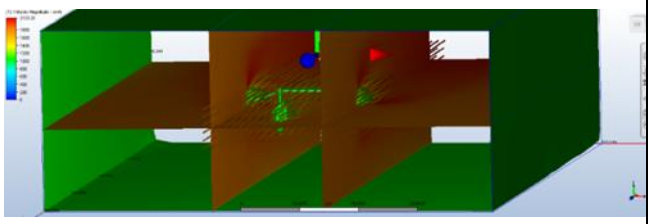

Figure 12 - AutoCAD INVENTOR Landing gear CFD airfoil simulation

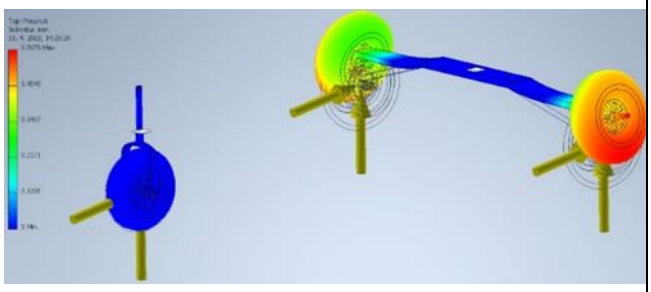

Figure 13 - AutoCAD INVENTOR Landing gear strength analysis

3.6. UAV propose results

Design elements were simulated in CFD software, their influence is negligible. The design was simulated in XFLR5 software and assembled in AutoCAD INVENTOR software. The model was used in the creation of drawings and in the construction of the UAV. Weight and balance, performance and flight envelope have been recalculated.

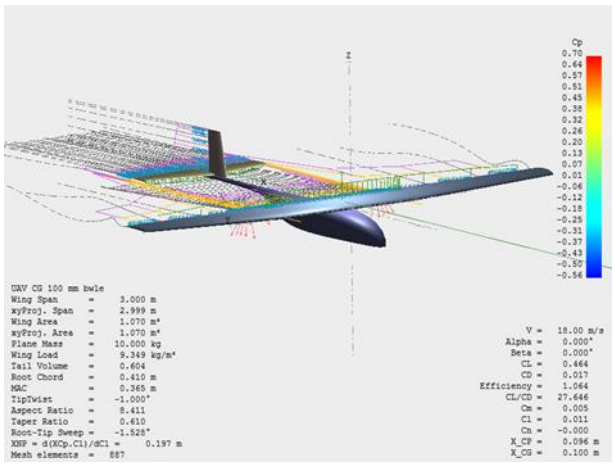

Figure 14 -XFLR5 analysis of proposed UAV analysis

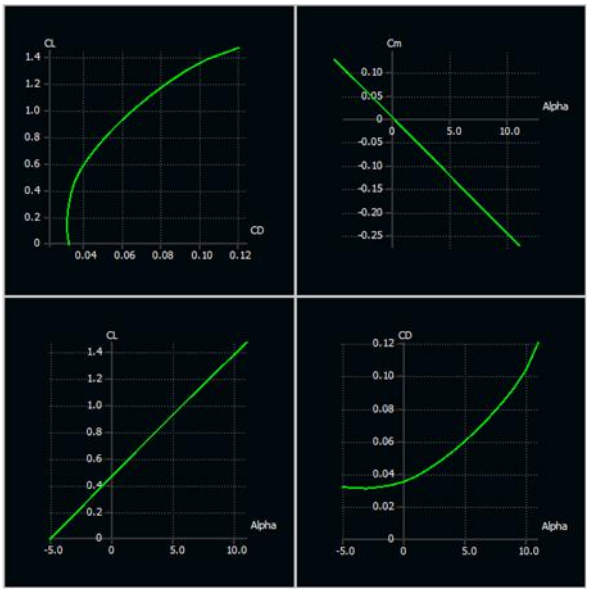

Figure 15 - Aerodynamical properties od proposed UAV design

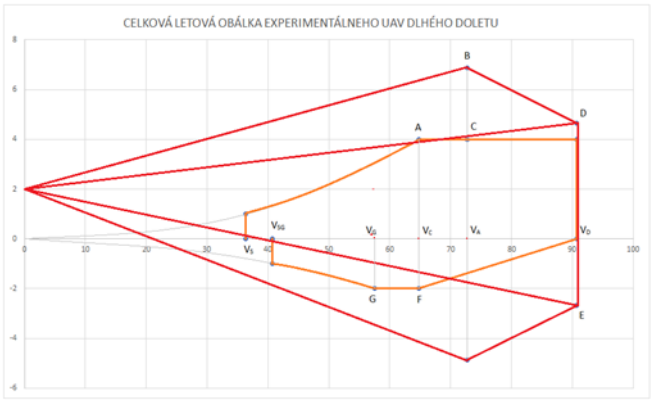

Figure 16 - Calculated UAV flight envelope

Figure 17 - AutoCAD INVENTOR done UAV model

4. VÝROBA KONŠTRUKCIE HYBRIDNÉHO UAV

4.1. Production of UAV wing

The wings were made by resistance cutting from polystyrene blocks. They were covered with balsa wood sheets and finally covered with white modeling foil. Parts of the wing, engine nacelles, servo motor mounts were thrown out of cardboard

wood on a CNC mill. The wings were cut and made similar to a wing.

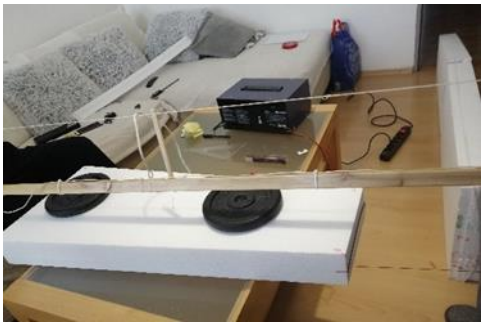

Figure 18 -Process of wing cutting

Figure 19 -Applied wing balsa cover

Figure 20 -Mounted aileron on tapered wing part

Figure 21 -Done UAV wing

4.2. Production of fuselage

The hull is made of fiberglass with epoxy and the internal structure is made of wood. The molds for the fuselage were made of polystyrene covered with foil, and separated with wax during the lamination process. The shell merged with the tail and the shape transition de-laminated. The seat for the wing and the front cover were cut with a flexi sander. Parts of the internal structure were made on a CNC mill and glued into the machined shell.

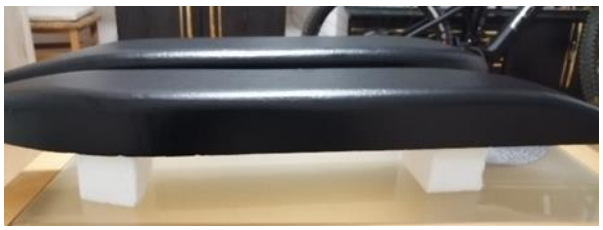

Figure 22 -Positive UAV hull forms

Figure 23 - Laminated part of UAV hull

Figure 24 -Done UAV fuselage shell

Figure 25 - Fuselage Inner construction mounting

4.3. UAV tail surfaces production

Due to unfavorable circumstances, the tail surfaces had to be made non-profiled as it was not possible to mill the profiled ribs on the available CNC mill. The aerodynamic properties of the UAV are not significantly affected, and due to the purpose of the experimental UAV, the unprofiled tail surfaces are sufficient. Similar design solutions are also found on ultralight aircraft and motorized aircraft with STOL characteristics, such as the Piper P-18 "super cub" or Laser 230 aircraft [8].

Figure 26 - Horizontal stab with elevator assembly

Figure 27 - Done horizontal tail surface

Figure 28 - Done vertical tail surface

Figure 29 -UAV tail surfaces mounted on fuselage integrated tail

4.4. UAV landing gear production

The landing gear of the UAV was made on the basis of available semi-finished materials and production equipment. The material used for the production of the landing gear axles is finally available aluminum 6063. Due to the circumstances, the design was used primarily for inspiration in the production of the landing gear for the experimental long-range UAV. Therefore, some shape elements will be slightly different from the design. Despite this, the properties of the landing gear will not change significantly and the landing gear will fulfill its purpose.

Figure 30 -Main gear springs parts

Figure 31 -Main gear mounted on UAV fuselage

Figure 32 - Front gear servo engine ride system mounted on UAV

4.5. UAV production result

The hole in the front cover for the GP38 engine piston will be cut after the first flight test.

Pic. No. 33: Done UAV flyable construction

5. CONCLUSION

The structure is recalculated, simulated and ready for mounting the drive and steering. The first test flight is planned for May 8, 2023.

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