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CUSTOMER REQUIREMENTS FOR AIRPORT MOBILE APPLICATIONS

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Abstract

Digital technologies are increasingly entering into the day-to-day life of everyone. It is possible to observe it in every area, and air transport is no exception. In the context of the digital transformation of air transport, the potential is tremendous, and enterprises in air transport are being forced to constantly introduce new digital technologies to keep up with the competition. The significant trend now is to carry all the information in the pocket - in the smartphone. Many airports around the world are introducing digital technologies into all processes in the airport environment, including the implementation of a mobile application. Competent representatives of many airports have understood that the introduction of modern services can motivate passengers to make more use of the airport and help increase attractiveness and improve the perception of the airport. The aim of this scientific article is to identify requirements of passengers and their expectations from the airport mobile application.

Keywords

airport, mobile application, digital transformation, customer requirements, smart solutions, airport operations

1. Introduction

Digital transformation is the integration of digital technology into all areas of business, which fundamentally changes the way we work and brings value to customers (Siebel,2019). It is also a cultural change that requires organizations to constantly question the current situation and to experiment (Siebel, 2019). Digital transformation is the profound transformation of business and organizational activities, processes, competencies and models to take full advantage of the changes and opportunities of digital technologies and their accelerating impact on society in a strategic and priority way with regard to current and future changes (Iscoop, 2019).

The aviation industry has been at the forefront of the digital transformation since the digital revolution began in 1995 (Burbaite, 2019). Companies around the world are increasingly realizing that the key to unlocking the full potential of the aviation market is not only embracing the digital transformation, but also remaining at the forefront of this development by offering breakthrough solutions based on new forms of digital technology (Valdes et al., 2018).

The aim of airlines and airports is to develop a transformation program that will be closely linked to operations (Valdes et al., 2018). One of the new concepts that can revolutionize ground operations and air traffic is the Internet of Things. Internet-based devices, which will become the standard for increasing customer satisfaction, are gradually seeing growth in the aerospace industry with aircraft data management, scanners, electronic tags and many other applications (Kazda et al., 2013).

1.1. Smart Airport

As a result of the Fourth Industrial Revolution, the concept of smart airports has evolved around the world, eliminating the shortcomings of the conventional airport system (Veber, 2018). Airport 4.0 can be defined as a concept that uses big data and open data to improve its own innovation (Rajapaksha & Jayasuriya, 2020). At these airports, operators create value for operational efficiency by collecting real-time passenger flow data when analysing the passenger profile (Materna et al., 2020). The Internet of Things creates an environment for interaction with various smart devices, and this approach generates many new applications in various areas, such as the environment, health, smart cities and industry (Novák Sedláčková & Remencová, 2021).

The definition of Smart Airport is related to the definition of Smart City. Smart cities use technology for urban life to create a more comfortable and sustainable environment (Bouyakoub et al., 2017). Smart Airport is a subsystem of a specific smart city (Rajapaksha & Jayasuriya, 2020). The system combines city life and aircraft movements. Information is seamlessly exchanged between urban traffic management, suburban traffic management and air traffic management (Mrňa et al., 2021). This connection is intended to achieve the optimization of individual processes and operations of the airport, as well as customer satisfaction (Nagy & Csiszar, 2016).

1.2. Airport mobile application

One of the solutions that can be implemented within the Smart Airport concept is an airport application for mobile devices (Rajapaksha & Jayasuriya, 2020).

Passengers can have information regarding airport services available through mobile applications. In general, the Smart Airport experience begins 48 hours before departure. After entering the details of the itinerary, the application will start working and help the passenger with all available functions. The main options of the smart airport mobile application are activated by route details, such as picking up a passenger's luggage from anywhere. Passengers then do not have to take their luggage to the airport. Thanks to the smart application, the passenger can contact the carrier and his luggage will be picked up from the house and arrive at the airport on time. The passenger will receive ongoing information and reminders about the flight status (Nagy & Csiszar, 2016).

The Google Indoor map will help with the walk in the terminal with instructions for navigating within the terminal (Rajapaksha & Jayasuriya, 2020). When a passenger obtains a boarding pass, he can change his seat according to his preferences. After unloading the luggage, the passenger's guide guides through other formalities, such as a security check. If they have sufficient time to board, passengers can receive special duty-free trade promotions on their mobile phones as a promotional tool to improve airport revenues. Furthermore, this application shows restaurants, toilets, smoking areas, lounges and other facilities that are available during their waiting time. All relevant public announcements come to the mobile phone in the form of both voice and / or text. When the aircraft is ready to board, the passenger should scan the boarding pass at the gate and the RFID scanning device will open the gate on board as well as the boarding bridge to the aircraft door (Nagy & Csiszar, 2016).

2. Analysis of the level of digital transformation of selected European Union countries

Three evaluation indices were selected for the analysis of the level of digital transformation: Network Readiness Index, Global Innovation Index and Digital Economy and Society Index (DESI Index). Each of the indices evaluates various areas of digitization of the evaluated country, thus creating a comprehensive picture of its current state. Based on the geographical point of view, the neighbouring countries of Slovakia were selected: the Czech Republic, Hungary, Poland and Austria.

2.1. Network Readiness Index 2020

The Network Readiness Index measures a country's ability to use upcoming information technology changes to increase its competitiveness and improve living standards in the country. It evaluates more than 60 indicators from the political, regulatory, innovative environment, through the readiness and availability of modern infrastructure, to their overall impact on the economic and social sphere (NRI, 2020).

The index has become one of the world's leading indices for the use of technology to develop and increase competitiveness. At the same time, it has been recognized as a global benchmark for assessing progress and readiness for technology deployment in countries around the world (NRI, 2020).

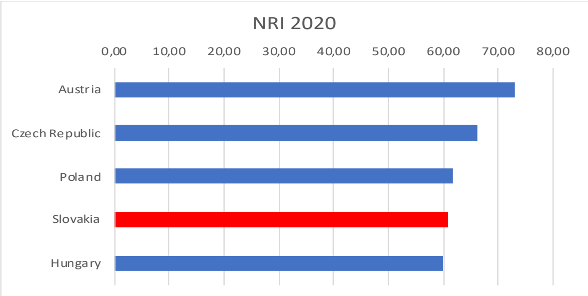

Figure 1: Network Readiness Index. Source: NRI (2020.)

Within the Network Readiness Index for 2020, Austria was leading among the selected countries, which is rated significantly better than the other 4 countries. Slovakia is in 4th place, but the differences between Poland and Hungary are minimal.

2.2. Global Innovation Index 2020

The Global Innovation Index helps to create an environment in which innovation factors are constantly evaluated. It provides detailed indicators of innovation for the economies of the evaluated countries. The Global Innovation Index total score is the average of the input and output sub-index scores (GII, 2020).

The input innovation sub-index consists of five pillars, which capture elements of the national economy and enable innovative activities. The pillars include institutions, human capital and research, infrastructure, market sophistication and business complexity (GII, 2020). The sub-index of innovation outputs provides information on the outputs that result from innovation activities within economies. There are two output pillars, knowledge and technological outputs and creative outputs (GII, 2020).

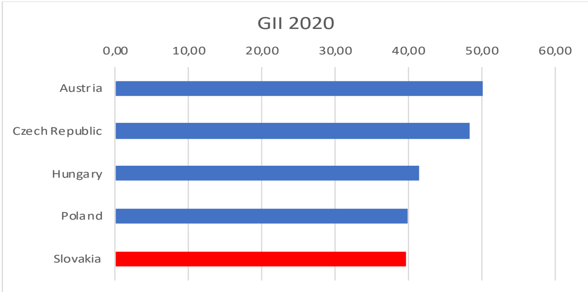

Figure 2: Global Innovation Index. Source: GI (2020).

The Global Innovation Index for 2020 also confirms the high level of digitization in Austria. Slovakia was rated the lowest score among the evaluated countries, but the shortage on Poland or Hungary is minimal, which indicates a very similar situation in each of the countries in the field of innovation.

2.3. DESI Index 2020

The DESI index is a tool for monitoring the state of digitization in European Union countries. It consists of five core areas, including internet connectivity, human capital, the use of internet services, the integration of digital technologies and digital public services. Together, the index evaluates more than 40 diverse indicators in the field of digitization (DESI, 2020).

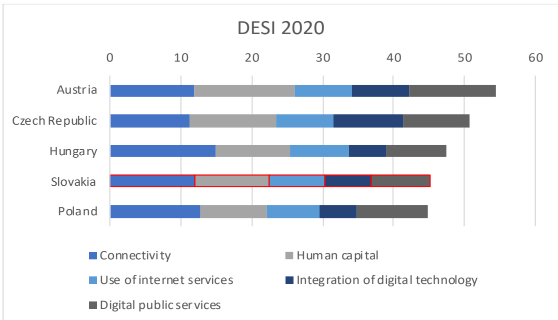

Figure 3: DESI Index. Source: DESI (2020).

As in the previous two indices, Austria achieved the highest overall score within the DESI index, followed by the Czech Republic. Of the selected countries, only Poland has a weaker result than Slovakia.

Based on the performed analysis, it was found that Slovakia lags behind other evaluated values due to valuable aspects. Therefore, it is possible that Slovakia still has reserves in the field of digital transformation, and therefore it is necessary for Slovakia to constantly improve in the field of digitization, bring innovative solutions and make full use of the potential of digital technologies.

3. Competitive analysis of Košice Airport

Košice International Airport is an international airport in Košice. It is the second largest airport in Slovakia according to the number of transported passengers and regular flights (Airport Košice, 2021).

For the needs of the competitive analysis of Košice Airport, airports from the analysed countries were selected. The reason for choosing these countries is the geographical location, as they are neighbouring states of Slovakia. Selected airports are important hubs for air transport in Slovakia. For selected airports, it will be analysed whether they have a mobile airport application, and then the individual functions available in the application.

3.1. Airport Košice

At present, Košice Airport has not created its own airport application for mobile devices. Only a web application is available to customers, which is accessible via a web browser, but it is not possible to download this application to the end device. The web application does not meet all the requirements of users and does not have the functionality as an application of competing airports.

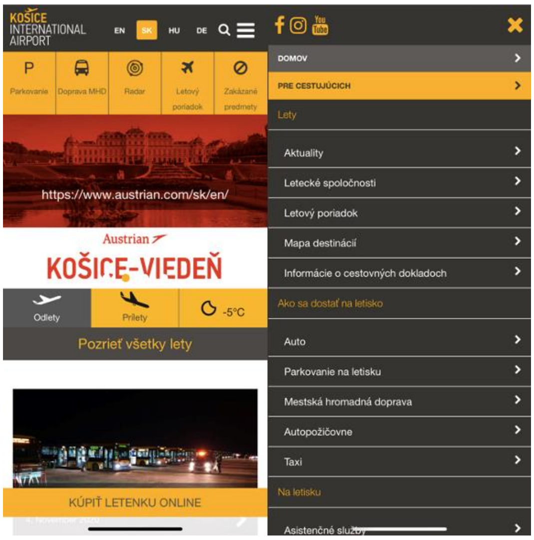

Figure 4: Web application Airport Košice. Source: Airport Košice (2021).

As part of the smart airport concept, it would be appropriate to design and create an airport application for mobile devices. The application could increase the level of digital transformation of the airport and could help increase the attractiveness of the airport for customers, which could result in an increase in the number of passengers carried, and thus increase the profitability of the airport.

3.2. Airport Bratislava

Bratislava Airport and Košice Airport are the two largest Slovak airports. However, like Košice Airport, Bratislava Airport has not created its own mobile application for smart devices, and therefore Bratislava Airport will not be rated.

3.3. Airport Praha

The airport has created its own mobile application, which is available for all Android and iOS devices. The application offers the option of adding a passenger flight in two ways: by scanning the barcode from the boarding pass or by selecting a flight from the scheduled flights displayed in the application. Subsequently, the passenger has all the information about his flight on a smartphone and will be informed of any changes in the form of notifications. In addition, the application is largely informative. The passenger can read instructions and information about the check-in of the passenger or luggage, what restaurants and cafes are available at the airport, as well as their opening hours. The same goes for shops and services. In the next section, the user will find information about parking options at the airport with hyperlinks to the reservation page. There is also an overview of bus and train connections with the airport, as well as a Taxi offer. Answers to frequently asked questions are also available. The application also has a built-in Google map, from which it is possible to navigate to the destination. The last section is all important contact details for the company's management and its address. There is also a form to report the problem directly from the application. The application is only available in English (Prague Airport, 2021).

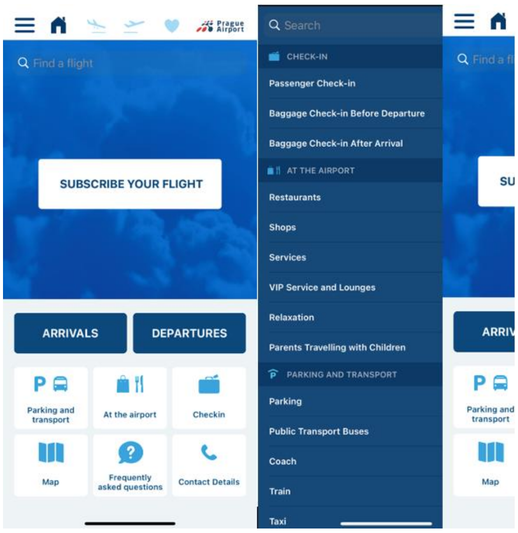

Figure 5: Prague Airport mobile application. Source: Prague Airport (2021).

3.4. Airport Vienna

Vienna Airport offers passengers its own mobile application, which can be downloaded to either iOS or Android devices. It offers the possibility to monitor the flight status of a passenger, who can add it to their flights either by selecting a specific flight from the scheduled flights or by uploading a QR or ticket barcode. The passenger thus receives notifications of changes in flight status in real time to his smart device in the form of notifications. The application also offers the possibility to add the position of his parked vehicle in the parking lot, where it is also possible to add a photo of the vehicle with the exact position. The application also offers an interesting option, a travel list, where the passenger can check if he has not forgotten any of the necessary things needed for his trip. In the application it is also possible to find a map of the airport, within which it is possible to search for a specific restaurant, shop or gate. There is also a list of all available shops, restaurants and services located at the airport. The next section shows information for people coming to and from the airport, in which all transport options are described in more detail, such as car, bus, train, taxi. All available connections are displayed in real time. There is also a separate section for parking lots, where the number of free spaces is displayed, and after clicking on a specific area of the parking lot, the application can navigate the user to this location and calculate the price for parking after entering the time of arrival and departure. There is also a link to the airport's website, an overview of the notifications received and basic information about the application and the company as such. The application is in English (Airport Vienna, 2021).

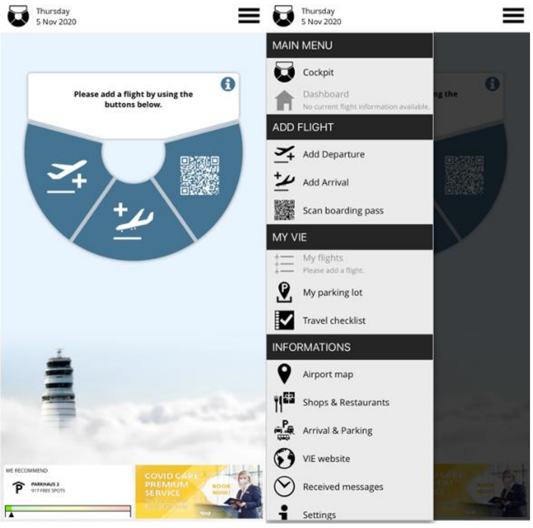

Figure 6: Airport Vienna mobile application. Source: Airport Vienna (2021).

3.5. Airport Budapest

Budapest Airport has its own application. The home screen displays current arrivals and departures. Clicking on one of the flights will display more detailed information about the flight, such as the terminal number and the airline and type of aircraft. Flight notifications are also available, which the user will mark as favourites. Furthermore, it is possible to find information in the application about the possibility of parking at the airport and also about access to and from the airport by bus, train or taxi. In the shopping tab, it is possible to view which shops, restaurants and services are located at the airport with their opening hours. There are also banners of the advertising nature of individual shops available at the airport. In following section, it is possible to find information about luggage, check-in or other important information related to the use of Budapest airport.

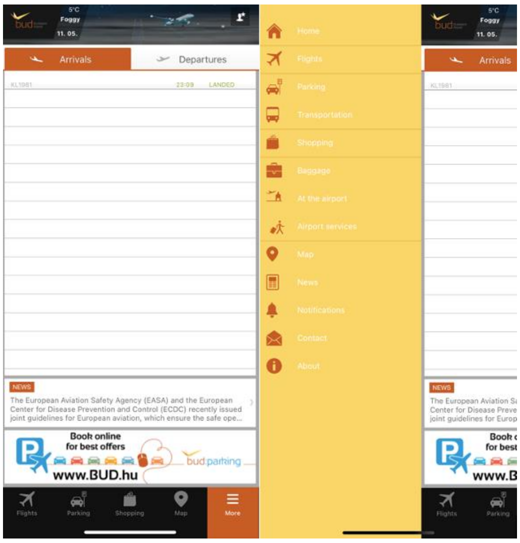

Figure 7: Airport Budapest mobile application. Source: Budapest Airport (2021).

An airport map is also available in the application with the option to view a specific store or service, but it is not possible to navigate. The application also has a news bulletin board where the user can find the latest information and articles published by the airport. The application contains also contact information together with a link to send feedback and basic information not only about the application but also about the airport. The application is only available in English (Budapest Airport, 2021).

3.6. Airport Krakow

Krakow Airport has also created its own application for mobile devices, which is available for iOS and Android operating systems. The home page displays the main menu, the current waiting time during the security check or the current time and weather. An overview of currently scheduled departures and arrivals is available, where after clicking on a specific flight, information about the flight number, aircraft type, check-in number and gate number will be displayed. There is also the option to add the flight to "my flights" and it displays information about the stage of preparation of the flight (baggage retrieval, check-in, gate opening and more). It is also possible to add a flight to the "my flights" list by entering the flight number. Furthermore, the Covid-19 section is available in the application, where after clicking the user will be redirected to the airport website to the Covid-19 section. There is also information on access to and from the airport by car, public road, train or taxi. The next section is a link to the Krakow Airport blog. The application also offers a plan / map of the airport with the possibility of starting navigation to a specific location. There is also information on the shops and services available at the airport. No less important features of the application include a direct link to the telephone numbers of the call centre, emergency services or information about the location of available defibrillators. The application is in English (Airport Krakow, 2021).

Figure 8: Airport Krakow mobile application. Source: Airport Krakow (2021).

3.7. Comparison of airport applications

Table 1 shows the resulting comparison of mobile applications of competing airports: Prague Airport, Vienna Airport, Budapest Airport and Krakow Airport.

Table 1: Comparison of mobile applications. Source: Author.

	Prague	Vienna	Budapest	Krakow
English language	*Yes*	*Yes*	*Yes*	*Yes*
More language options	*No*	*No*	*No*	*No*
iOS	*Yes*	*Yes*	*Yes*	*Yes*
Android	*Yes*	*Yes*	*Yes*	*Yes*
Information regarding arrivals	*Yes*	*Yes*	*Yes*	*Yes*
Information regarding departures	*Yes*	*Yes*	*Yes*	*Yes*
Add a flight by selecting from upcoming flights	*Yes*	*Yes*	*Yes*	*Yes*
Add a flight by scanning QR code	*Yes*	*Yes*	*No*	*No*
Flight status change notifications	*Yes*	*Yes*	*Yes*	*Yes*
Summary of notifications received	*No*	*Yes*	*Yes*	*Yes*
Information regarding check-in	*Yes*	*No*	*Yes*	*No*
Information regarding baggage	*Yes*	*No*	*Yes*	*no*
Restaurants	*Yes*	*Yes*	*Yes*	*Yes*
Shops	*Yes*	*Yes*	*Yes*	*Yes*
Services	*Yes*	*Yes*	*Yes*	*Yes*
Travel list	*No*	*Yes*	*Yes*	*No*
My parking space	*No*	*Yes*	*No*	*No*
Parking	*Yes*	*Yes*	*Yes*	*Yes*
Public bus transport	*Yes*	*Yes*	*Yes*	*Yes*
Public train transport	*Yes*	*Yes*	*Yes*	*Yes*
Taxi	*Yes*	*Yes*	*Yes*	*Yes*
FAQ	*Yes*	*No*	*No*	*No*
Map	*Yes*	*Yes*	*Yes*	*Yes*
Navigation	*Yes*	*No*	*No*	*Yes*
Contact info	*Yes*	*No*	*Yes*	*No*
Information regarding weather	*No*	*No*	*No*	*Yes*
Waiting time at security check	*No*	*No*	*No*	*Yes*
Quick contact for medical service	*No*	*No*	*No*	*Yes*
Defibrillator position information	*No*	*No*	*No*	*Yes*
Modern design	*Yes*	*Yes*	*Yes*	*Yes*
Clarity and comprehensibility	*Yes*	*Yes*	*No*	*Yes*

4. Analysis of the level of demand for the implementation of a mobile application for Košice Airport

As part of the previous focus on this issue, we conducted primary research, which focused on the level of demand for the implementation of applications of the Smart Airport concept at the airports in Bratislava and Košice. One of the research goals of the research was to find out which application of the Airport 4.0 concept would be most welcomed by the respondents at the airport in Košice.

The questions were answered by respondents who used Košice Airport at least once in the last 5 years. A total of 155 respondents answered the question. Table 2 shows the number of "Yes" answers for the individual applications of the Airport 4.0 concept and their percentage.

Table 2: Primary research findings. Source: Author.

Application	**Yes**	
	Amount	**%**
Self-boarding	96	16
Indoor navigation	62	10
Biometric services	88	14
RFID baggage tags	80	13
Autonomous baggage tags	105	17
Kiosk for lost baggage	67	11
Airport app for mobile devices	118	19
Total	616	100

Based on the evaluation of the respondents' answers, it was possible to assess that the respondents at the airport in Košice would most welcome the airport application for mobile devices, which represents 19% of all the answers counted. Therefore, it is possible to say on the basis of the research that the respondents would welcome the implementation of an airport application for mobile devices at the airport in Košice.

5. Methodology

5.1. CTQ Diagnostic Method

Within the diagnostic method CTQ, the general requirements of customers for quality are transformed into specific, measurable indicators. The main tool of the CTQ method is the creation of a CTQ tree, which shows the transformation of general customer requirements into specific measurable parameters. General requirements for the quality of a mobile application include technical parameters such as availability, functionality, clarity, security or price. The aim of the application of the method is to find out what quality the current web application for Košice Airport has from the point of view of users.

The first step was to create a CTQ tree with a defined passenger need, i.e., as found out through marketing research, respondents would welcome the creation of a mobile airport application that would be available for download directly to the terminal rather than improving the current web application, which is only available through a web browser.

The second step was to compile the first level of the CTQ tree, which contains the general requirements of passengers for the mobile application. Furthermore, it was necessary to specify the requirements for the second and third level of the CTQ tree, which were obtained by a questionnaire from customers of Kosice Airport.

The third step was to create a questionnaire with such questions that it is possible to find out the real situation after answering them. Subsequently, it was necessary to define the target group, which are passengers who use Košice Airport and the airport's web application.

The fourth step is to calculate a sample to determine the number of respondents from whom it is necessary to obtain answers. The calculated sample size represents at least 384 respondents.

6. Results

The primary research was carried out in the form of an electronic inquiry through a questionnaire via the Google Forms website. Respondents were contacted via the social network - Facebook. The research results were processed in Microsoft Excel.

The comparison of customer requirements for the application with the actual measured parameters is expressed in the following table 3.

Table 3: Comparison of customers' requirements. Source: Author.

	Requirements			Current state
	Level 1	Level 2	Level 3	Website app
Creating mobile application	Availability	Multiple language options	min. 2	4
		Multiple operating systems	min. 2	3
		Price	max. 0€	0
		Multiple terminal devices	min. 2	3
	Clarity	Modern design	75% satisfaction	55%
		App guide	yes	no
		Responsive design	100% success	91%
	Functionality	Terminal battery consumption	max. 10%/hour	10-15%/hour
		Application stability	100% success	97%
		Number of available functions	min. 8	5
		Quick search	yes	yes
		Arrival information	yes	yes
		Departure information	yes	yes
		Option to mark favorite flight	yes	no
		Notification	yes	no
		Basic information about check in	yes	no
		Basic information about baggage	yes	yes
		List of restaurants, shops and services	yes	yes
		Parking information	yes	yes
		Public bus information	yes	yes
		Information on waiting time at the security check	yes	no
	Security	Request consent for the processing of personal data	yes	no
		The ability to create and log in to your own account	yes	no
		Number of login methods	min. 1	0
	Customer care	Frequency of feedback requests	1x/year	0
		Application update frequency	1x/month	0
	Speed	Response time	1 second	< 1 second
		Search time	2 seconds	< 1 second
		Subpage loading time	1 second	> 1 second

Within the availability, the CTQ method found that the application meets all 4 requirements. The web application is available in 4 languages, it can be accessed from more than 2 operating systems and also from more than 2 end devices. The web application is completely free, which was also a customer request.

In terms of application clarity, none of the three customer requirements listed are met. Only 55% of respondents are satisfied with the modernity of the application design, responsive design was functional in only 91% of cases and, in addition, the application does not contain an application guide.

As part of the functionality of the application, it was found that the application consumes more than 5% of the battery of the terminal device than required by customers. Also, in 3% of cases, the application was not stable. According to the respondents, the total number of functions of the application is 5, while the request was at least 8 functions. Although the web application provides a quick search option, it displays information about arrivals and departures, but it is not possible to mark your flight by selecting from the displayed flights. The presence of notifications or basic information about check-in is also absent. Basic information about luggage, a list of restaurants, shops and services, and information about parking and public bus connections are available in the web application. However, the application does not provide information about the current waiting time at the security check.

In the security section, not a single customer requirement is met, because the web application not only does not require consent to the processing of personal data, but it is also not possible to create your own account and then log in to it.

As part of customer care, it was found that the web application never once offered respondents the opportunity for feedback on satisfaction with the application.

Regarding the speed of application, the CTQ method found that the application meets two of the three requirements. The unfulfilled request was only due to the loading speed of the web application subpages.

The current application offers an insufficient number of functions, it is not clear enough and the design is not modern enough. For example, the new application would provide customers with the ability to add their flight to a favourite so that the customer can later receive notifications of flight status changes (check-in information, gate number, delays, and more). This could make it easier and more pleasant for many passengers to travel through Košice Airport.

7. Conclusion

One of the aspects of increasing the attractiveness of the airport is the introduction of digital technologies, which bring new possibilities and opportunities. This paper is focused on customer requirements for airport mobile application; new airport application for mobile devices, which offers a wide range of functions, is clear and easy to use for all types of customers. The application offers from basic information about check-in, luggage, arrivals and departures through real-time notifications to the possibility of creating and logging in to the account or sending the feedback.

Based on the analysis of the digital transformation of selected European Union countries, it was found that Slovakia lags behind its 'neighbours' in each of the three rankings, and therefore it is essential for Slovakia to constantly introduce new innovations and solutions in the field of digitization, thus increasing the general level of digital transformation.

As result of the competitive analysis, it was found that the surrounding airports such as Prague, Vienna, Krakow and Budapest already have such an application. Although Košice

Airport has a web application, people prefer to use mobile applications over web applications.

Based on the research, which focused on the level of demand for the implementation of applications of the Airport 4.0 concept at the airport in Košice, it is possible to say that among the intelligent solutions, respondents would most welcome a mobile application.

After creating a new, high-quality, feature-packed application, it is possible to anticipate an increase in interest in traveling using Košice Airport, which could mean an increase in the number of passengers transported, increased profits and last but not least to the increased customer satisfaction. The recommendation is to create a mobile application, which is only the first of a whole range of intelligent solutions that would be appropriate to implement in the future at Košice Airport.

References

Airport Košice, 2021. [Online] airportkosice.sk. Available at: <airportkosice.sk>

Airport Krakow, 2021. [Online] apps.apple.com. Available at: <https://apps.apple.com/us/app/krakówairport/id1137117233>

Airport Vienna, 2021. [Online] apps.apple.com. Available at: <https://apps.apple.com/sk/app/viennaairport/id541132906?l=sk>

Bouyakoub S., Belkhir A., Guebli W., Bouyakoub F. M., 2017. Smart airport: an IoT-based Airport Management System, Proceedings of ACM ICFNDS, <http://dx.doi.org/10.1145/3102304.3105572>

Budapest Airport, 2021. [Online] apps.apple.com. Available at:<https://apps.apple.com/gb/app/budairport/id852966997>

Burbaite R., 2019. Digital transformation in aviation: Big Data, IoT, AI & mobility. [online] aerotime.aero. Available at: <https://www.aerotime.aero/ ruta.burbaite/23948-digital-transformation-in- aviation-big-data-iot-ai-mobility>

DESI, 2020. Digital Economy and Society Index. [Online] ec.europ.eu. Available at: <https://ec.europa.eu/digital-single-market/en/digital-economy-and-society-index-desi>

GII, 2020. Global Innovation Index. [Online] globalinnovationindex.org. Available at: < https://www.globalinnova tionindex.org/gii-2020-report#>

Iscoop, 2019. Digital transformation: online guide to digital business transformation. [online] iscoop.eu. Available at: <https://www.iscoop.eu/digitaltransformation>

Kazda, A., Badanik, B., Tomova, A., Laplace, I., Lenoir, N. 2013. Future airports development strategies. Komunikacie, 2013, 15(2), pp. 19–24.

Materna, M., Novák, A., Novák-Sedláčková, A. 2020. Economic impact and current position of Žilina Airport within its catchment area. Transport Means - Proceedings of the International Conference, 2020, pp. 193–197

Mrňa, D., Badánik, B., Novák, A. 2021. Internet of things as an optimization tool for smart airport concept. European Transport - Trasporti Europei, 2021, 82.

Nagy E., Csiszar C., 2016. Airport Smartness Index – evaluation method of airport information services. services, Osterreichische Zeitschrift Fur Verkehrswissenschaft vol. 63, 25-30. [online] real.mtak.hu. Available at: <http://real.mtak.hu/67163/1/3_20_u.pdf>

Novák Sedláčková, A., Remencová, T. 2021. Adoption of Digital Technologies at Regional Airports in the Slovak Republic. Transport Means - Proceedings of the International Conference, 2021, 2021-October, pp. 616–621

NRI, 2020. Network Readiness Index. [Online] networkreadinessindex.org. Available at: <https://networkreadinessindex.org/wp-content/uploads/2020/10/NRI-2020-Final-Report-October2020.pdf>

Prague Aiport, 2021. [Online] apps.apple.com. Available at: <https://apps.apple.com/cz/app/prague-airport/id581517376>

Rajapaksha A., Jayasuriya N., 2020. Smart Airport: A Review on Future of the Airport Operation. Global journal of management and business research: A administration and management, vol.20, ISSN: 2249-4588

Siebel T., 2019. Digital transformation: survive and thrive in an era of mass extinction. Rosetta Books, 256p. ISBN 978-1948122481

Valdes R. A., Comendador V. F. G., Sanz A. R., Castan J. P., 2018. Aviation 4.0 more safety through automation and digitization. Aircraft technology, 2(4), 25-41. doi:10.2495/SAFE170211

Veber J., 2018. Digitization of the economy and society. Management Press, 200p. ISBN 978-1948122481

https://doi.org/10.26552/aer.C.2021.2.2

POSSIBILITIES OF USING 3D PRINTING TECHNOLOGY IN PRODUCTION OF AIRCRAFT COMPONENTS

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Abstract

The article provides the reader with a brief overview of the technology of industrial 3D printing used in the manufacturing process of aerospace technology. It includes analyses of the position of 3D printing in the aerospace industry and the forecast of its future development based on the marketing analysis of strengths / weaknesses, opportunities and threats. Many airlines and AMOs (Approved Maintenance Organizations) rely on externally supplied spare parts delivered over long distances. The whole process is expensive and time consuming and means a lost profit for the company. The performed SWOT analysis can therefore ultimately help the AMO manager to re-evaluate their production process in the light of the current innovative and progressive technology of industrial 3D printing.The aim of this work is to point out the existence of innovative 3D printing technology in aerospace production and to emphasize its preferences compared to conventional manufacturing techniques and procedures, thus providing a final perspective on the future of the 3D printing industry and its long-term sustainability

Keywords

3D printing, additive manufacturing, fly to by ratio, AMO

1. Introduction

Competitiveness is the driving force behind industrial innovation and technological advances, leading to more efficient production methods that take into account aspects of the ecological footprint, the urgency of timely production and savings achievement (Pecho et al., 2019). 3D printing meets all these criteria in its entirety, which is why it has found application in many areas of industry. 3D printing, often referred to as "additive manufacturing" (AM), has become, in addition to the medical industry, an integral part of the production processes of the automotive industry, architecture, marketing, food industry and the arts. However, the most obvious progress has undoubtedly brough to the world of aviation and space research. With increasing safety and performance requirements and requirements for air transport in general, there is a need to replace conventional technological practices and create new technology that will provide a comprehensive solution to environmental, technical and financial shortcomings. 3D printing by reducing aircraft weight, increasing the level of adaptation and overall construction efficiency poses new challenges for the further potential development of air transport (Kloski & Kloski, 2017).

2. 3D printing technology

The term "3D printing" as we know it today has a very deep history, dating back to the 1980s. 3D printing can be defined as *"the production process by which three-dimensional (3D) solid objects are created. It allows you to create physical 3D models of objects using a series of additive or layered support structures, where the layers are sequentially arranged to create a complete 3D object."* (Kloski & Kloski, 2017). Each printed object is based on a 3D model (template) stored on the user's computer. Using the printer software, the model is imaginarily cut into hundreds to thousands of thin 2D layers and later transformed into a set of printer instructions. The whole production is an additive process. In practice, this means that the resulting product is created by precise application of individual layers of material on top of each other, which transfers from the 2D plane to 3D space (3D Printing.com).

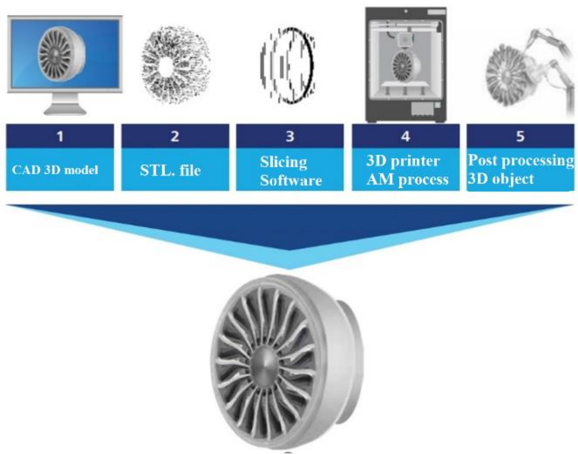

Figure 1: Principle of 3D printing technology. Source: COYKENDALL, (2014) edited by Authors.

3. SWOT analysis of industrial 3D printing technology applied for the aerospace engineering manufacturing purposes

The aim of the SWOT analysis is to evaluate the current state and future development of the researched object. In order to illustrate the position of 3D printing technology on the market following tables are used:

Table 1: Schematic representation of the strengths and weaknesses of 3D printing in aviation, as well as its opportunities and threats. Source: Authors.

Strengths	**Weaknesses**
• component weight reduction • production of spare parts • improved development cycles • design consolidation • reducing costs and buy-to-fly ratios • ecological aspect of production	• expensive technology • the need for a skilled workforce • small production volume • limited dimensions of printed products • rising unemployment
Opportunities	**Threats**
• long-term reduction of the share of air transport in CO_2 production • increasing level of air transport safety • cost reduction • 4D print	• demonstrable negative impact on human health • the arrival of new competitive technology on the market

3.1. Analysis of Strengths

3.1.1. Component weight reduction

Weight is one of the most important indicators in the aviation industry (Table 2) because, lighterequals cheaper and in connection with air transport especially. 3D printing of aircraft components with more efficient geometry, grid structure or topological optimization undoubtedly helps to reduce the weight of parts. An ideal and at the same time groundbreaking example of reducing the weight of an aircraft component is the hinge of the engine nacelle, whose purpose is to hold the engine cover when it is opened.

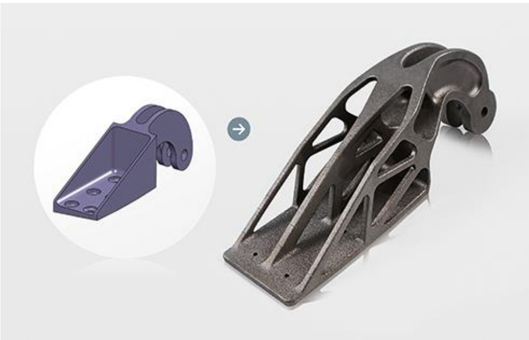

Figure 2: Demonstration of the original component and its current design. Source: TCT Magazine (2014).

By adding a 3D printing factor to the production of this component, it significantly reduced the proportion of waste from secondary machining, thus reducing titanium consumption by 25% (Iljaszewicz et al., 2021). The overall weight of the components was reduced by 35-55%, thus reducing the weight of the aircraft by approximately 10 kg. Ultimately, removing only 1kg of each aircraft with a capacity of 600+ could save up to 90,000 litres of fuel per year and prevent the release of up to 230 tons of CO_2 into the atmosphere (Leandri, 2015).

3.1.2. Production of spare parts

In the process of maintenance of aircraft, it is very important to ensure the availability of spare parts in order to minimize time lost in maintenance time, because whenever the aircraft does not fly, it loses money. It is crucial for airlines in the maintenance area to reduce the delivery time of spare components. By incorporating additive manufacturing into the work process, it is possible to rapidly reduce stock quantities and produce smaller volumes on request with a catalogue of parts that have been designed for the additive manufacturing process.(LENDRI, 2015) The Royal Netherlands Air Force is a perfect example. Its fleet includes various types of helicopters, fighters and cargo planes (Apaches to NH90s and F16s). These machines have a large number of unique parts that are not easy to work with. The Royal Netherlands Air Force therefore began printing its own tools on 3D printers. For example, when transporting jet engines, some openings need to be covered with special covers. Procurement of these parts is expensive and has long delivery times. In contrast, printing them on the Ultimaker 3D printer takes only about two hours (Additive- X, n.d.).

3.1.3. Improved development cycles

One of the many benefits of 3D printing is based on eliminating unnecessary assembly steps. It enables faster prototyping, conceptual design without additional tools, and provides rapid testing methods (Bugaj et al., 2019).

3.1.4. Design Consolidation

The benefit is to eliminate the need to join or assemble several parts of a given component together by welding or in any other way that potentially reduces reliability and durability (Galieriková et al., 2018). It is possible to produce complex spare parts using additive production technology.

3.1.5. Reducing costs and buy-to-fly ratios

Very expensive or hard-to-reach materials, such as titanium (Ti6Al4V) or Inconel 718 superalloy, are mostly used for the production of aircraft, and therefore their efficient use is important. The Buy-to-Fly indicator is an indicator of the efficient use of materials. *„The buy-to-fly ratio refers to the weight of the raw material purchased, compared to the weight of the final part."(Materialise).* At present, this indicator averages around 10:1. Involving the 3D printing technology as a production process, airlines have a high probability of achieving the ideal value of this parameter of 1:1, which means 100% efficient use of working material. Minimizing the weight of the raw material needed to produce a particular component, regardless of industry or application, will always have a positive impact on cost savings. The less a company needs to buy in order to produce a particular part, the higher the potential profit.

3.1.6. *Ecological aspect of production*

3D printing is becoming more environmentally friendly production compared to traditional production processes. Through the implementation of 3D printing technology into the production and maintenance processes of airlines, the share of air transport in CO_2 production is indirectly reduced.

Table 2: Assessment of identified strengths. Source: Authors.

	Efficiency <1-5>	Weight (0-1)	Calculated Value	Maximal value
Component weight reduction	5	0,2	1	1
Production of spare parts	4	0,10	0,4	0,5
Improved development cycles	4	0,10	0,4	0,5
Design consolidation	5	0,2	1	1
Reducing costs and buy-to-fly ratios	5	0,2	1	1
Ecological aspect of production	5	0,2	1	1
SUM	**-**	**1,00**	**4,8**	**5**

3.2. Analysis of Weaknesses

3.2.1. *Expensive technology*

The implementation of additive manufacturing as a production technology in connection with aircraft maintenance requires a certain financial initial investment. Smaller companies can't afford 3D printers for metal alloys. They thus rely on traditional production methods and technologies.

3.2.2. *The need for a skilled workforce*

This is not a shortcoming of 3D printing itself, but the fact that every 3D printing is preceded by 3D modelling. IT technology is an integral part of 3D printing, as all printed products are in fact materialized digital designs created using modeling software. The 3D printer will not be able to handle the wrong 3D model and will print it incorrectly. This wastes material, energy, time and money. At best, it doesn't even print such a model. Therefore, the models must always be thoroughly checked, or their control or the entire modeling left to professionals. Behind each component is a dedicated team of engineers and technicians and that is why skilled workforce is really necessary (Table 3).

3.2.3. *Small production volume and limited dimensions of printed products*

Depending on the quality and size of the printers as well as the material and printing technology that used, printing can take several hours or even days to process. In the case of electron beam printers (EBM), the printing process itself takes place in vacuum chambers. To some extent, such a size of the printed product is limited. For larger models, which the 3D printer is not able to print in one piece, it is necessary to print divided parts of the whole one by one and then join them.

3.2.4. *Rising unemployment*

Any application of automation, innovative technology means an increased unemployment rate. The machine replaces the human factor and replaces several original jobs. The structure of the economy is thus changing with changes in labour demand due to the introduction of new machines, time-saving technology and improved production methods.

Table 3: Assessment of identified weaknesses. Source: Authors.

	Efficiency <1-5>	Weight (0-1)	Calculated Value	Maximal value
Expensive technology	5	0,55	2,75	2,75
The need for a skilled workforce	3	0,1	0,3	0,5
Small production volume and limited dimensions of printed products	4	0,20	0,8	1
Rising unemployment	0	0,15	0	0,75
SUM	**-**	**1,00**	**3,85**	**5**

3.3. Analysis of Opportunities

The opportunities of additive production technology in air transport consist of the persistence of the achieved positive results of 3D printing as a production process, with the assumption of further progress. The high potential of 3D printing can be expected in a term of long-term CO_2 reduction due to aviation operations and increasing aviation safety (Tab 4). However, the ambition of 3D printing goes much further. The primary goal remains to rapidly reduce the costs related to the material and energy security of the printing process. The absolute culmination of 3D printing in the aviation industry is the premise of the application of 4D printing, which, compared to its predecessor, is supplemented by the so-called smart materials. These are capable of changes or other properties that are triggered by an external energy source such as a change in temperature, humidity or pressure. The 4D printing technology could also be used in the military aviation or space sector.

Table 4: Assessment of identified opportunities. Source: Authors.

	Efficiency <1-5>	Weight (0-1)	Calculated Value	Maximal value
Long-term reduction of the share of air transport in CO_2 production	5	0,3	1,5	1,5
Increasing level of air transport safety	4	0,3	1,2	1,5
Cost reduction	3	0,25	0,75	1,25
4D printing	5	0,15	0,75	0,75
SUM	**-**	**1,00**	**4,2**	**5**

4. Analysis of Threats

The only factors that can theoretically endanger the high position of 3D technology in the aerospace industry are the findings of a negative effect on the health of workers who are physically involved in the printing process. So far, no negative effects of this technology on the health impact of the workers involved have been demonstrated. The only risk of 3D printing is the arrival of competitive technology on the market. In the foreseeable future, however, the only hypothetical competitor is the 4D printing technology (Table 5). It is basically just an improved modification of 3D printing, and therefore cannot be understood as its direct threat.

Table 5: Assessment of identified threats. Source: Authors.

	Efficiency <1-5>	Weight (0-1)	Calculated Value	Maximal value
Demonstrable negative impact on human health	1	0,7	0,7	3.5
The arrival of new competitive technology on the market	0	0,3	0	1,5
SUM	-	**1,00**	**0,7**	**5**

5. Evaluation of the SWOT analysis

$$\sum \boldsymbol{S} - \sum \boldsymbol{W} = \mathbf{4,8 - 3,85 = 0,95} \quad (1)$$

$$\sum \boldsymbol{O} - \sum \boldsymbol{T} = \mathbf{4,2 - 0,7 = 3,5} \quad (2)$$

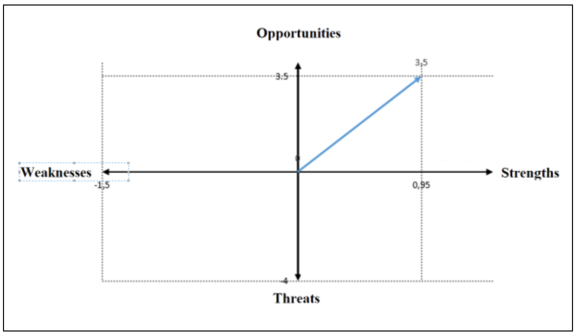

Figure 3: The result of the SWOT analysis. Source: Authors.

The result of the SWOT analysis (Figure 3) placed 3D printing technology in aviation in the quarter of the offensive strategy, which means that the technology makes sufficient use of its strengths and also has a high potential for development and further wider application in the aviation industry (Figure 4). 3D printing as such has an ideal position to become the number one choice, whether in the field of production or maintenance services of airlines.

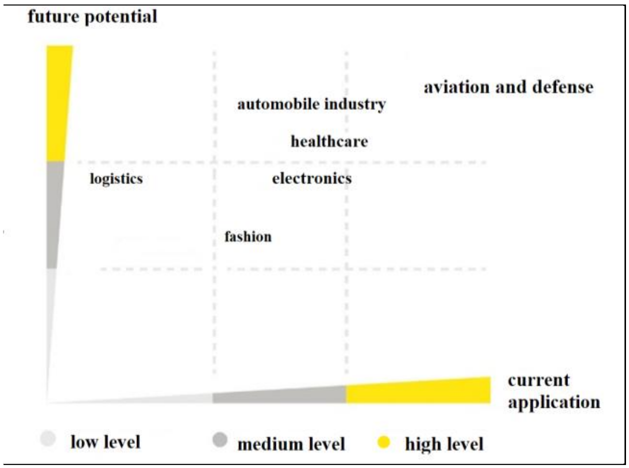

Figure 4: Current application and potential of 3D printing in industry. Source: Authors.

6. Expected future appearance of space industry involving 3D printing technology

It is aeronautics and space research that have become the driving force behind the development of 3D printing technology, which has taken on a new dimension in the possibilities of worldwide travel and space research. Over the next few years (forecast time interval 2020-2026) it is estimated that 3D printing in the aerospace and defense (military) market will register an annual compound growth rate of more than 20% (Figure 4). The Compound Annual Growth Rate (CAGR) is an indicator that describes the rate at which an investment would grow if it grew at the same rate each year and the profit reinvested at the end of each year. A key aspect of the rapid growth of industrial aviation 3D printing is the additional permission of the Federal Aviation Administration (FAA) as well as the European Aviation Safety Agency (EASA) to use more 3D printed parts for commercial jet airliners. The largest increase is projected for the North American region, as can be seen in the forecast below (Figure 5) (Mordorintelligence.com, n.d.).

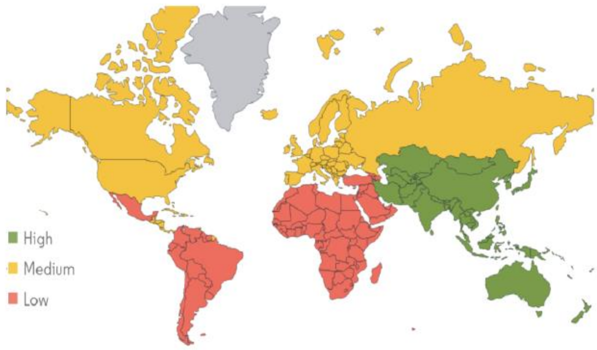

Figure 5: 3D printing in Aerospace and defence Market (2020-2025). Source: Mordorintelligence.com.

The increase in this area is largely due to the companies that operate in this area and have a dominant position in the market. These are companies such as GE (General Electric), Pratt & Whitney or Boeing Company, which clearly excel not only in the activity of additive manufacturing but also its necessary equipment (Figure 5).

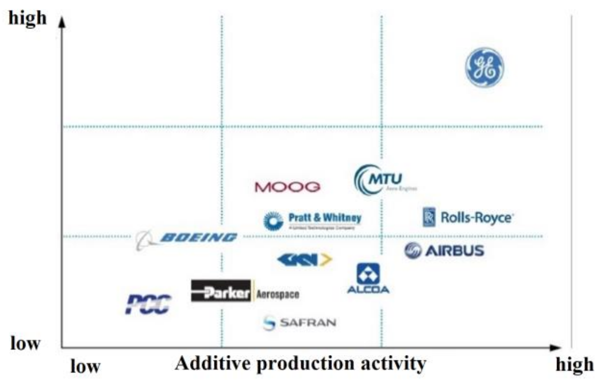

Figure 6: Activity map of selected companies. Source: Langerfeld (2013).

Many airlines and AMO (Approved maintenance organisations) s rely on externally supplied spare parts imported over long distances. The whole process is expensive, time consuming and represents a lost profit for the company. With 3D printing, it is easy to manufacture some parts saving time and money. The prices of 3D printers are falling and will continue to fall due to the greater number of companies using this technology, so a rapid decline in "outsourced" products can be expected. Areas where 3D printing should grow more progressively should be unmanned aerial vehicles (Figure 6) and experimental aircraft, as they require a lower degree of regulatory control.

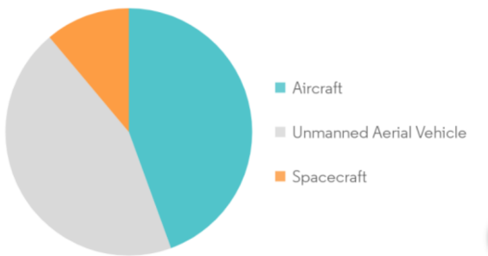

Figure 7: 3D printing in Aerospace by application in aircraft, UAV, and spacecraft segment. Source: Mordorintelligence.com.

7. Conclusion

Based on the performed SWOT analysis and subsequent analysis of statistics related to the integration of additive production as part of the production process in aviation industry, it can be concluded that the current position of AM is more than favourable. For its benefits, it is currently an unquestionably unrivalled method of aircraft production and maintenance. It provides flexibility in creating aircraft components of very complex geometries that are sometimes impossible to create by conventional technology processes. AM rapidly reduces the weight of components, while in no way degrading the mechanical properties of the material and maintaining the level of safety in full. From an ecological point of view, the post-processing process generates a minimum amount of waste, which is to some extent reusable in selected AM technologies. These are usually cases of powder-based systems where unconsumed powder can be used repeatedly.

To translate the position of additive manufacturing into the language of numbers, the values clearly speak in favour of 3D printing as the most efficient technological choice of production (average values): total cost savings in the range of 30-50%, maximum waste after post-processing 10%, time saving up to 64%, component weight reduction 30-65%. However, the most important indicator of all the above is the buy-to-fly ratio, which reached an incredible 1:1.

The statistics and analyses clearly identify AM as a leader in aerospace technology, and the position is expected to be as positive in the next 5 years. Despite the fact that the expected progress in North America is more pronounced due to the geographical situation of the leaders of the aviation industry, Europe will not remain stagnant. The growing use of AM in the maintenance may also lead to some degree of economic progression. However, many AM and aerospace experts agree that real and full use of the potential of 3D printing, which can add another dimension to the world, is still ahead of us.

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References

3D Printing.com. n.d. What is 3D Printing?. [online] Available at: <https://3dprinting.com/what-is-3d-printing/> [Accessed 6 September 2021].

Additive- X. n.d. 3D Printing Aircraft Tools, Fixtures, and Prototypes with Royal Netherlands Air Force and Ultimaker. [online] Available at: <https://www.additive-x.com/blog/3d-printing-aircraft-tools-fixtures-and-prototypes-with-royal-netherlands-air-force-and-ultimaker/> [Accessed 9 October 2021].

Bugaj, M., Urminský, T., Rostáš, J., Pecho, P. 2019. Aircraft maintenance reserves - New approach to optimization. Transportation Research Procedia, 2019, 43, pp. 31–40.

Coykendall, J, 2014. 3D opportunity for aerospace and defense. [online] Deloitte Insights. Available at: <https://www2.deloitte.com/us/en/insights/focus/3d-opportunity/additive-manufacturing-3d-opportunity-in-aerospace.html> [Accessed 12 September 2021].

Galierikova, A., Materna, M., Sosedova, J. 2018. Analysis of risks in aviation. Transport Means - Proceedings of the International Conference, 2018, 2018-October, pp. 1427–1431.

Iljaszewicz, P., Lusiak, T., Pastuszak, A., Novak, A. 2020. Aerodynamic analysis of the aircraft model made with the 3D printing method. Transportation Research Procedia, 2020, 51, pp. 118–133.

Kloski, L. - kloski, N. 2017. Začínáme s 3D tiskem. 1. vyd. Brno: Computer Press, 2017. s. 216. ISBN 978-80-251-4876-1

Langefeld, B. 2013. Additive Manufacturing. Roland Berger (2013) [online]. Available at: <https://www.rolandberger.com/de/Publications/Addi

tive-Manufacturing.html> [Accessed 3 September 2021].

Leandri, A. 2015. 7 3D Printing Pluses for Aerospace - 3D Printing Industry. [online] 3D Printing Industry. Available at: <https://3dprintingindustry.com/news/7-key-improvements-3d-printing-brings-to-the-aerospace-industry-49823/> [Accessed 7 September 2021].

Materialise. n.d. Whitepaper: Buy-to-Fly Ratio, Cutting Costs with Metal 3D Printing. [online] Available at: <https://www.materialise.com/en/manufacturing/whitepaper-buy-to-fly-ratio-cutting-costs-metal-3d-printing> [Accessed 12 September 2021].

Mordorintelligence.com n.d. 3D Printing in Aerospace and Defense Market | 2021 - 26 | Industry Share, Size, Growth - Mordor Intelligence. [online] Available at: <https://www.mordorintelligence.com/industry-reports/3d-printing-in-aerospace-and-defense-market> [Accessed 3 September 2021].

Pecho, P., Ažaltovič, V., Kandera, B., Bugaj, M. 2019. Introduction study of design and layout of UAVs 3D printed wings in relation to optimal lightweight and load distribution. Transportation Research Procedia, 2019, 40, pp. 861–868.

TCT Magazine. 2014. EOS and Airbus Group Innovations join forces on study for 3D printing in aerospace. [online] Available at: <https://www.tctmagazine.com/additive-manufacturing-3d-printing-news/eos-and-airbus-group-innovations-join-forces-on-study-for-3d/> [Accessed 1 September 2021].

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MULTI-CREW COOPERATION TRAINING MANUAL FOR AIR TRAINING AND EDUCATION CENTRE

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Abstract

The main goal of the training manual is to create a study material for the theoretical and practical part of the multi-crew cooperation training course, which is provided by the Air Training and Education Centre of the University of Žilina since 2007. At the same time, the purpose of the training manual will be to contribute to the quality of education, streamlining the multi-crew cooperation training course and to provide a comprehensive study material for pilots in training that reflects on the changes made from 2007 to the present. The reason which stimulated the elaboration of the training manual is mainly the already existing study material which has now proved to be outdated and insufficient for the needs of the training course. The training manual will reflect the legislative changes made, the modifications to the flight and navigation procedures trainer and some training elements, which are currently emphasized in the training process and will meet all the currently required criteria. The content of training manual which is based on valid and effective regulations, on the airplane flight manual of Beechcraft Super King Air B200 / B200C, inspired by internal operation manuals of the airline operators, internal manuals of the Air Training and Education Centre and is also based on the already existing study material. At the same time, it will be possible to implement some parts of the training manual into the internal manuals of the Air Training and Education Centre. Expected date of issue of training manual is May 2022.

Keywords

Multi-crew cooperation, Training, Manual, Air Training and Education Centre

1. Introduction

Flying in a multi-member crew has undergone considerable development, especially by reducing the number of flight crew members in the cockpit. The main reason was the technological development of airplanes. Automation and instrumentation of airplanes literally replaced some members of the flight crew. Despite the reduction in the number of flight crew members in the cockpit, safety requirements are still increasing. The main priority in the aviation is undoubtedly the safety that can be achieved not only by the multi-crew cooperation training course itself, operations manuals, but also on the basis of training and applying of the principles of crew resource management. The 1980s of the last century were significant for the development of crew resource management which has proven to be another factor playing a role in air accidents.

Training manual will describe the historical development of the multi-crew cooperation, crew resource management and will contain a basic skills of CRM that will be applicable to the flight crew members during the training. The main objective of the training manual is to develop a new, current study material for multi-crew cooperation training course provided by the Air Training and Education Center of the University of Žilina. The Training manual will be applicable solely on the flight and navigation procedures trainer of Mechtronix Ascent FNPT II MCC with the FSTD SK.002.A qualification certificate in the Beechcraft King Air B200 (generic) configuration.

MCC training manual will be based on the Air B200 / B200C aircraft flight manual and on the internal operations manuals of the Air Training and Education Centre. Furthermore, it will be inspired by internal operations manuals of air operators and corrects already existing study material, but mainly amends its absent elements that are currently necessary part of a multi-crew cooperation training course.

The basis for creation of training manual is also knowledge and experience I have gained within an integrated flight training course in the Air Training and Education Centre of the University of Žilina.

The training manual will bring a comprehensive study that will contain a detailed manual for a modified flight simulator, defining new normal and emergency checklists, memory items, standard operating procedures and will be supplemented by theoretical preparation for the multi-crew cooperation training course.

2. Current status analysis

Flight and Navigation Procedures Trainer Mechtronix ASCENT FNPT II MCC is a flight simulation training device (FSTD) which was installed in the Air Training and Education Center of the University of Žilina in 2005. Since 2007 multi-crew cooperation training course is provided on this flight simulator. In the same year a study material entitled *Metodika pilotného výcviku na letovom simulátore* was published. This methodology, and especially the part focused on the MCC training course was created in accordance of previous valid regulation JAR-FCL. As well as the flight simulation training device was certified in accordance of JAR-STD 3A regulation. Both of these regulations are not actual anymore.

Since 2005, a few significant changes have been made that prompted this proposal of training manual and has also stimulated the need for new study material.

The first significant change occurred in legislation. In particular, the change concerns the legislative, according to which the flight simulation training devices are certified nowadays and which regulates the multi-crew cooperation training courses.

The Civil Aviation Authority certify flight simulation training devices according to CS-FSTD (A) and Subpart FSTD, Part ORA of Commission Regulation (EU) No 1178/2011.

MCC training course is currently undertaken by FCL.735.A.

Significant changes for MCC training:

- Definition of performance-based navigation (PBN) instrument rating privileges,
- Replacement in terminology for 2D and 3D instrument approach operation,
- Change of the flight crew member label from pilot not-flying (PNF) to pilot monitoring (PM). (European Commission 2016 & ED Decision 2017)

The second change is the transition from FTO to ATO in 2013.

The third change is the modification of the Mechtronix ASCENT FNPT II MCC simulator that has been performed in 2019. The content of the modification was the installation of the Garmin GTN 650 device (Skvarekova et al., 2020), which replaced the Bendix / King 165 and (COMM / NAV), installing a new instrument panel backlight (Brezonakova et al., 2019) and new control switch for warning transparent.

3. Introduction to the CRM and MCC

3.1. Historical development

Human factor belongs to the main causes of air incidents and accidents in aviation. Represents more than 70% of air accidents. Air accident investigators have already knew about the possibility of errors caused by human factor. In the framework of prevention, emphasis was primarily on improving operation manuals, pilots training, pilot space ergonomics, reducing cabin noise and others. However, it has absented one important factor that has not been emphasized and whose existence has not been discussed thoroughly, although it was always present when flying in a multi-member crew. It was a factor that concerns the activities and relationships of the flight crew itself. The breakthrough was a year 1979, since we date the emergence of a new area called crew resource management (CRM) as we know it today. In particular, the creation of this area was caused by air accidents where the main cause was especially a human factor (Pružina, 2009).

Table 1: Air accidents related to crew resource management
Source: Munk (2010); NTSB (1973, 1979); ALPA (1978).

Date of accident	Place of accident	Flight number	Air operator	Type of aircraft
29. 12. 1972	Miami	401	Eastern Air Lines	Lockeed L-1011-1 TriStar
27. 3. 1977	Tenerife	4805	KLM	Boeing 747-206B
		1736	Pan Am	Boeing 747-121
28. 12. 1978	Portland	173	United Airlines	DC-8-61

Air accident of DC-8 can be considered key to the creation of CRM. The first airline that was interested in implementing CRM to the syllabus of flight training was United Airlines. United Airlines with cooperation of NASA and NTSB proposed the possible scheme of CRM to the flight training to optimize crew cooperation in the cockpit. The original CRM name was Cockpit Resource Management. At the birth of CRM was NASA psychologist, John Lauber, who dealt with communication processes in cockpit. CRM, which emphasizes the role of the human factor, passed in the 1980s and in the 1990s of a few phases of development. In the 1986, CRM was renamed to the Crew Resource Management. (Pružina, 2009 & Munk, 2010)

In particular, the reason for renaming was found that the flight crew is only one part of the team involved in the process during the flight. Based on this findings, the CRM was introduced in to the training for cabin crew members. In the 1990s, CRM training has been fully used in many airlines. Some airlines have implemented joint CRM training for flight crew and cabin crew, referred to as Joint CRM training.

CRM does not only concern flight crew and cabin crew, but also other company workers such as ground personnel, airline company management and others. For this reason, we can also meet the so-called Total Company Resource Management (TCRM), which also includes other company employees. Another development of CRM is EM - Error Management. EM deals with managing of unprepared situation and errors. The aim is to detect error and subsequent response of the crew. (Pružina, 2009)

The next step that includes EM is Loft - Line Oriented Flight Training. Loft is a type of training that contains realistic simulations of full flight focusing on communication and leadership. The last degree is TEM model - Threat and Error Management. The TEM model describes the possible external risks in service and consists of internal and external threats and errors. (Pružina, 2009)

4. Flight Simulator Mechtronix Ascent FNPT II MCC

Flight Simulator Mechtronix Ascent FNPT II MCC with SK.002 approval number and SN-FFT-2068 identification number from the Canadian manufacturer Mechtronix Systems is a device designed for training of flight and navigation procedures. Flight simulation training device (FSTD) is certified in accordance with Commission Regulation (EU) No 1178/2011, complies with requirements set by Part ORA, Subpart FSTD and meets the certification specification CS-FSTD (A). Air Training and Education Centre (LVVC) has been using this device since 2005 to train pilots who are applying for IR(A) instrument qualifications and since 2007 also provides training focused on multi-crew cooperation. The flight simulator is of almost 100% identical to the aircraft Beechcraft King Air B200 regarding dimensions, ergonomics and even an instrumentation. It can be reconfigured into the following types of airplane:

- Beechcraft King Air B200 (generic) – Multi-engine turboprop,
- Piper Seneca V (generic) – Multi-engine piston.

The visualization system of flight simulator offers visual display at 180° horizontally and 37.5° vertically. On the equipment it is possible to make simulations of the day, night, dusk, but also meteorological conditions in various flight levels. The simulator also allows you to perform the CAT Category I approach to the decision height of 200 feet, including a possibility to use autopilot for approach.

Table 2: Instrumentation of flight simulator device. Source: Author.

Number of devices	Equipment
2	Mechtronix Synthetic Instrument Display (SID) panel
1	Bendix/King KDI 572 Digital DME Indicator
1	Bendix/King KT 79 Transponder
1	Bendix/King 165 A (COMM/NAV 2)
2	Bendix/King KR 87 ADF
1	Bendix/King KAS 297 Altitude Pre-Selector
1	Bendix/King KFC 200 Flight Director/Autopilot System
1	Bendix/King KMA 24H Audio Control Panel
1	Garmin GTN G650 (COMM/NAV 1)

The instructor has two monitors available through which can create normal or emergency situations, changes in meteorological conditions, affect the technical condition of the airplane, monitor the operation and response of pilots and others. The instructor also has information about the vertical and horizontal airplane position in real-time. The Flight Simulator Mechtronix Ascent has also a two-sided radio connection between the crew and the instructor.

5. Cockpit ergonomics of the flight simulator in Beechcraft King Air B200 (Generic)

This chapter will include explanation and detailed photos of all flight simulator controls, switches and instruments along with a description. It is necessary for the pilots to be familiarized with the cockpit environment for succesful achievement of tasks.

Figure 1: Cockpit ergonomics of the flight simulator in Beechcraft King Air B200 (Generic). Source: Autor.

6. Theoretical preparation for MCC training

The theoretical preparation will consists of theoretical knowledge for individual phases of flight in chronological order as well as standard operating procedures for normal, abnormal and emergency situations. Theoretical preparation for MCC training consists of:

6.1. Normal procedures

- General normal procedures
- Preliminary cockpit preparation,
- Pushback / towing,
- Engine start-up,
- Taxi,
- Take-off,
- Climb,
- Cruise,
- Descent,
- 3D approaches,
- 2D approaches,
- Go-around, missed approach procedures,
- Landing.

6.2. Abnormal and emergency procedures

- General abnormal and emergency procedures,
- Engine shut-down procedures,
- Rejected take-off to the V1,
- Emergency engine shut-down / engine fire after V1,
- Emergency engine shut-down during the flight,

- Engine fire during the flight,
- Emergency descent,
- Evacuation.

7. Conclusion

The training manual will provide a comprehensive field of study for the theoretical and practical part of the multi-crew cooperation training course, which meets the current criteria. Training manual will contain a historical development of the multi-crew cooperation and the crew resource management. The chapter of CRM will be extended and will involve detailed description of each skills which are applicable to the fight training.

New memory items and checklists for normal and emergency situation will be created, based on the Beechcraft Super King Air B200 / B200C aircraft flight manual and will be adapted to be fully executable on a given flight simulator type. Checklists can be later implemented as a new revision.

The training manual will includes corrected and amended new standard operating procedures that are the basis for the successful execution of a multi-crew cooperation training course. The aim of the course is to get a knowledge, habits and understand basic philosophy which is required in a multi-crew aircrafts but it is also a part of the internal operations manuals of each air operators.

References

Air Line Pilots Association: Aircraft Accident Report – Pan American World Airways, Boeing 747, N737PA; KLM Royal Dutch Airlines, Boeing 747, PH-BUF; Tenerife, Canary Islands, 27/03/1997. Available at: http://archives.pr.erau.edu/ref/Tenerife-ALPAandAFIP.pdf

Annex I to ED Decision 2017/022/R, AMC/GM to Part-FCL – Amendment 3. Available at: https://www.easa.europa.eu/sites/default/files/dfu/Annex%20I%20to%20ED%20Decision%202017-022-R%20%E2%80%94%20AMC-GM%20to%20Part-FCL%2C%20Amendment%203.pdf

Brezonakova, A., Skvarekova, I., Pecho, P., Davies, R., Bugaj, M., Kandera, B. 2019. The effects of back lit aircraft instrument displays on pilots fatigue and performance. Transportation Research Procedia, 2019, 40, pp. 1273–1280.

COMMISSION IMPLEMENTING REGULATION (EU) 2016/1185 of 20 July 2016. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R1185&from=SK

COMMISSION IMPLEMENTING REGULATION (EU) No 923/2012 of 26 September 2012. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02012R0923-20200719&qid=1617475537703&from=SK

COMMISSION REGULATION (EU) 2016/539 of 6 April 2016. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0539&from=BG

COMMISSION REGULATION (EU) No 1178/2011 of 3 November 2011. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02011R1178-20200622&qid=1617472495800&from=SK

Easy Access Rules for Aeroplane Flight Simulation Training Devices (CS-FSTD(A)). Issue 2. Available at: https://www.easa.europa.eu/sites/default/files/dfu/easy_access_rules_for_aeroplane_flight_simulation_training_devices_csfstda_iss2.pdf

Easy Access Rules for Flight Crew Licencing (Part-FCL). Available at: https://www.easa.europa.eu/sites/default/files/dfu/Easy_Access_Rules_for_Part-FCL-Aug20.pdf

Kříž, J. a kol. 2007. *Metodika pilotného výcviku na letovom simulátore*. 1. vyd. Žilina: EDIS ŽU, 2007. ISBN 978-80-8070-793-4.

Munk, T. 2010. Vícečlenné posádky dopravních letadel: diplomová práca. Brno: VÚT, 2010.

National Transportation Safety Board: Aircraft Accident Report – United Airlines, Inc., McDonnell-Douglas, DC-8-61, N8082U, Portland, Oregon, 28/12/1978. Available at: https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR7907.pdf

National Transportation Safety Board: Aircraft accident report – Eastern Air Lines, Inc., L-1011, N310EA; Miami, Florida, 29/12/1972. Available at: https://libraryonline.erau.edu/online-full-text/ntsb/aircraft-accident-reports/AAR73-14.pdf

Pružina, V. 2009. *Létání vícečlenných posádek (MCC+CRM)*. 1. vyd. Praha: ČVUT, 2009. ISBN 978-80-01-04406-3.

Skvarekova, I., Azaltovic, V., Pecho, P., Kandera, B. 2020. Eye Track Technology in Process of Pilot Training Optimization. NTinAD 2020 - New Trends in Aviation Development 2020 - 15th International Scientific Conference, Proceedings, 2020, pp. 206–210, 9379071.

https://doi.org/10.26552/aer.C.2021.2.4

ANALYSIS OF THE EARTH'S SURFACE INFLUENCE ON THE ACCURACY OF NON DIRECTIONAL BEACON IN MOUNTAIN TERRAIN

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Abstract

This paper deals with the measuring and checking of the Non Directional Beacon using flying laboratory AeroLab 1 at University of Zilina. It is based on the most simple radio navigation concept: a ground-based radio transmitter (the NDB) sends an omnidirectional signal that an aircraft loop antenna receives. Our practical measurement shows that the NDB satisfies ICAO standards and can be used in industrial part of urban area and is functional in spite of the interference. The paper concentrates on the measuring of the Non Directional Beacon (NDB) which is installed close to industrial part of the city. The ADF/NDB navigation system is one of the oldest air navigation system still in use today. One of the paper's goals is to familiarize the aviation public with the practical measurement of this urban area phenomenon in terms of flight safety, which is common in mountainous nations such as Slovakia. The article's other purpose is to educate professionals in the area about this occurrence in terms of its nature as a physical rule, in order to develop solutions to improve the navigation system's measurement accuracy.

Keywords

Measuring, Flight Inspection, NDB, GNSS.

1. Introduction

In aeronautical radio navigation that uses the NDB/ADF system, the main role is played by the radio station - Non-Directional Beacon (NDB). The NDB transmitter has an antenna that transmits a radio signal non-directionally but symmetrically on all sides. The NDB itself does not generate radial aiming information to this navigation point, as is the case with the VOR/DME beacon (Bean & Dutton, n.a.) The pilot's navigation information is the directional bearing angle to the radio station (Bearing). The on-board Automatic Direction Finder generates this bearing information (ADF). It employs the concept of non-directional - circular radiation of the wave front, which is always perpendicular to the radiation source – NDB antenna at any point in the vicinity of the NDB transmitter (Zarihan & Zhang, 2001).

The Non Directional Beacon (NDB) systems provide a navigation capability to suitably equipped aircraft and therefore shall comply with the Standards and Recommended practices (SARPs) in ICAO Annex 10 Volume 1, Chapter 2 (General Provisions for Radio Navigation Aids) and Chapter 3 Section 3.4 (Specification for non-directional radio beacon). A NDB is a low or medium frequency radio beacon that operates in the frequency range 190 to 1,750 kilohertz (kHz). A radio beacon used in conjunction with an Instrument Landing System (ILS) marker is called as Compass Locator (Ahmed & Sharma, 2005).

Under the terms of Act. N. 143/1998 Z. z., 2th April 1998 (Aviation Act) Transport Authority, all civil Medium Frequency (MF) Non-Directional Beacon installations, intended for use in the provision of an Air Traffic Service in the Slovakia, require approval by the Transport Authority. University of Zilina (UNIZA) is able to provide a number of compliant services to assist NDB operators to demonstrate that they meet these SARPs. The following measurements are required to demonstrate compliance with the ICAO SARPs:

- Field Strength.
- Centre Frequency.
- Modulation Depth.
- Morse Ident Transmitted.
- Modulation Frequency.

2. Airborne equipment components for measuring NDB system

The AT-940 Flight Inspection System (FIS) main equipment consists of small and lightweight modules that are easily installed and removed from the aircraft. The airborne modules and related equipment are listed below:

- Host Computer and WinFIS software.
- Avionics Sensor Unit (ASU).
- Signal Processing Unit (SPU).
- Interface cables.
- Optional external avionics sensor(s).

2.1. Required Aircraft Equipment Provisions

In order to operate the AT-940 FIS certain equipment provisions must be installed in the aircraft. The exact provisions required will depend on the system configuration and the end user's specific mission requirements. ATI can prepare an Interface Control Document (ICD) for the end user to ensure the appropriate provisions are specified (Luo & Chen, 2012). The typical required provisions to be installed in the aircraft for operation of the AT-940 are:

- 28 VDC power source for the FIS including appropriate power control switch, circuit
- Breaker, wiring and connectors.
- Dedicated FIS Antennas.
- Attitude and Heading Reference System (AHRS) and Magnetometer.
- Pilot Event switches.
- Interface to aircraft L-Band suppression bus.
- Means of securing the FIS main equipment modules in the aircraft.
- FIS connector interface panel.

2.2. Avionics Sensor Unit (ASU)

The AT-940 ASU contains a Honeywell RNZ-850 Multimode Receiver (MMR) and Garmin G420 TSO GPS receiver with VHF communication. The MMR receives the RF signals and converts them to a format that can be used by the SPU for measurement, display and recording in the WinFIS™ software (Shan & Chen, 1994).

The front panel of the ASU has the MMR cover, under which there is access to the MMR, and the Garmin G420 GPS unit. Please see the manufacturer's operation manuals for information (Thürey et al., 2005; Sukop et al., 2005).

Four volume knobs are also located on the front panel alongside headset jacks and PTT switch. These allow the user to listen to the ident/tones on the individual navigation aids being monitored for NAV, DME, ADF and MKR. The rear panel of the ASU contains six circuit breakers which allow isolation of the individual receivers within the MMR and ASU. The AT-940 GRS contains a DGPS receiver, theodolite interface circuitry, a microprocessor and a telemetry modem. The GRS GPS receiver is positioned over a known point on an airfield, which is entered into the GRS during configuration, and sends DGPS corrections through an RF telemetry link to the SPU in the aircraft. If failure occurs of the DGPS a digital theodolite can be connected and used to track the aircraft (Zhang et al., 2010; Chen et al., 2018).

2.3. Signal Processing Unit (SPU)

Airfield Technology's terminology for the FIS real time computer is Signal Processing Unit (SPU). The SPU does the real-time data acquisition of all flight inspection data. It receives and processes the signals from all the sensors in the FIS. The unit synchronizes and combines the data from the avionics sensors and position reference equipment and transmits it to the host computer (Chen et al., 2018; Ji et al., 2019).

2.4. Position Reference Equipment

Telemetry Receiver. The Telemetry receiver is used to receive Differential Global Positioning System (DGPS) corrections from the Ground Reference Station (GRS). The RS-232 serial data output from the Telemetry receiver is converted to LVTTL prior to being input to the DGPS receivers. The telemetry RS-232 output is input to COM5 on the Serial board for monitoring the status of the telemetry link from the GRS (Jiang et al., 2017).

GPS Antenna Splitter. An active GPS antenna splitter is used to allow all the GPS receivers in the system to share a single antenna on the aircraft. Depending on the specific SPU configuration supplied the GPS splitter may be installed either inside the SPU or externally in the aircraft. Refer to the specific SPU technical manual and/or Interface Control Document for more information (Kazda et al., 2020; Kraus, 2016).

DGPS Receivers. Two independent DGPS receivers are used in the SPU to provide highly accurate and redundant aircraft position data to the system. The receivers receive DGPS corrections from the Ground Reference Station through the Telemetry receiver in the SPU. The RS-232 output from the Telemetry receiver is converted to LVTTL prior to being input to the DGPS receivers. The outputs from the receivers are input to COM6 and COM7 on the Serial board. The pulse-per-second (PPS) signals from the receivers connect to digital inputs on the A/D boards. These are 10 Hz timing signals, which are used by the system as the primary timing reference. Kirschenstein et al., 2018; Myler, 2015).

External AHRS and Magnetometer. The system uses data from the externally mounted AHRS and magnetometer for antenna coordinate transformations (lever arm corrections), antenna pattern compensation and ADF differential bearing error calculation. The AHRS interfaces with the magnetometer through a direct RS-422 connection. Serial RS-232 data from the AHRS is input to the system through COM8 on the Serial board (Sobiech et al., 2017; Ji et al., 2019).

3. Methodology of measuring individual parameters of NDB ZL

Identification check is performed by listening to a Morse code during a circling flight to verify NDB coverage. The identification must be clearly audible. Keying must be accurate and clearly audible throughout the coverage range. The identification must also be correctly coded.

The power drop during identification shall not exceed 0.5 dB and for NDB devices with a required power of 50 NM or more shall not exceed 1.5 dB.

The control of the voice quality is performed during the circling flight. The voice channel must be clearly audible and free of interference throughout the coverage range.

3.1. Rated coverage

Rated coverage, as defined, is a means of determining the actual operation of the NDB in a measurable manner. When checking the rated coverage at its required range, the signal strength must be at least 70 µV/m. However, this intensity value shall not be exceeded by more than 2 dB. In general, a minimum value of 120 µV/m is sufficient, although this value is not sufficient in areas with very high fault levels. However, it should be noted that the minimum specified field strength values may be insufficient, as they are set only on the basis of a simple comparison of faults in different areas and may be influenced by other factors than will be explained below (Lu et al., 2020; Labun et al., 2020)

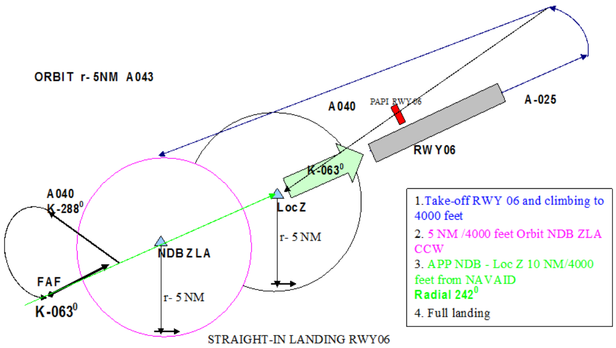

Figure 1: Flight measurement scheme for NDB ZLA, horizontal profile for RWY 06. Source: Authors.

3.2. Effective coverage

Effective coverage is defined as the space surrounding the NDB in which we can obtain real information at a given time. (see Figure 1) When checking the actual coverage, the minimum signal strength is 70 µV/m in the required coverage area. Aiming errors cannot exceed ± 10°. Actual coverage is thus a measure of NDB's performance under normal conditions (Novák et al., 2017).

3.3. Track alignment errors

When checking track alignment errors, the alignment error shall not exceed ±10°. If the alignment errors are of oscillation character, they may exceed this value for less than 8 seconds. When checking approach alignment errors, the alignment error must not exceed ±5°. If the alignment errors are of oscillations nature, they may exceed this value for less than 4 seconds. When checking for alignment errors on hold, the alignment error must not exceed ±5° (Chen et al., 2018; Sobiech et al., 2017).

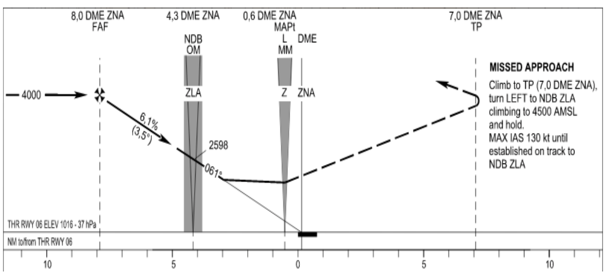

Fig. 2 Flight measurement scheme NDB ZLA, vertical descent profile fo RWY 06. Source: Authors based on Kraus (2016).

4. Practical measuring and testing parameter for ndb zla and NDB ZLA

The ground aid NDB ZLA (identification) is installed in the industrial part of the city Bytča. Installation of test facilities is within the boundaries of the city at the GPS position: LAT: 491210,3N, LON 0183037,6E, and use of the frequency 404 kHz and identification ZLA.

The ground aid NDB Z (identification) is installed in the industrial part of the city Dolný Hričov. Installation of test facilities is within the boundaries of the city at the GPS position: LAT: 491339,4N, LON 0183540,7E, and use of the frequency 508 kHz and identification Z.

4.1. Testing Procedures

1. Take-off from airport Dolný Hričov (LZZI): departure from RWY 06, climb straight ahead via ZLA NDB to 4 000 ft AMSL.
2. At the minimum sector altitude fly two circles (a radius 5 NM, center in NDB ZLA) anti-clockwise (CCW) at an altitude of 4 000 ft. (see Fig. 1)
3. At the minimum sector altitude fly two circles (a radius 5 NM, center in NDB Z) anti-clockwise (CCW) at an altitude of 4 000 ft. (see Fig. 1)
4. Departure within 10 NM from the NDB aid, measurement of back course and checking the aid range identification (Identification marks ZLA). (see Fig. 1)
5. Measurement the NDB approach from FAF (K063) via NDB ZLA and NDB Z full landing runway 06.

4.2. Result from measuring NDB ZLA

The following next four graphs depict dependence of the field strength on the distance or angle. The first phase of flight checking NDB ZLA was the measurement the track in direction ZLA - Z. The measuring flight was conducted at an altitude of 4,000 feet with a gradual descent to an altitude of 4,500 feet. The total length of the measured track was 10 NM including overflying of the NBD ZLA. The voice facility identification test was carried during the flight, identification was clearly identifiable throughout the measured flight path. The measurement sample rate was 10 Hz. The result is in the Fig. 3. The largest recorded facility error was measured in close proximity to the NDB ZLA at a distance 3.37 NM (the error was 13.47°) and was caused by flying over mountains, which are near the NDB ZLA facility.

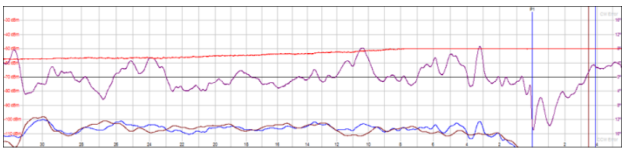

Figure 3: The graphs represent measured values of the first flight segment ZLA – Z. Source: Authors.

The second phase consisted of measurement during the two circuits around the aid at a distance of 5 NM, and of testing the aid. The purpose of the measurement was to check the horizontal cover and facility test in holding. During the test the checking of aid voice identification was executed, see the result in Fig. 4

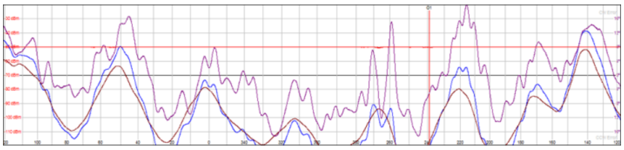

Figure 4: The graphs represented measured values of the second flight segment, orbit 5 NM. Source: Authors.

In the third phase measurement the flight from the facility was using a back course, while the outbound flight was chosen for the existing track between FAF aid and point MAPt. During the testing, the maximum range and reaching of the threshold level of 70 µ/m should be monitored. It is obvious from our measurement that the aid reaches the required minim signal level at the end point of the measurement MAPt , wherein the signal level is -63.5 dBm, that represents 149 mV/m. The measurement result is depicted in the Figure 5.

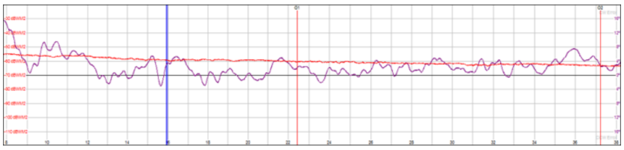

Figure 5: The graphs represent measured values of the third flight segment SLC – PATAC. Source: Authors.

5. Conclusion

Our testing measurement showed that the aid NDB ZLA placed at the test position LAT: 491210,3N, LON 0183037,6E can be used as a navigation aid in Air Navigation Services. It satisfies the requirements of Annex 10, Volume I, for the transmitted power, which cover the device should be at the level of cover 70 µV/m respectively 120 µV/m in areas where there is a big disturbance. Due to the antenna used and the frequency of the device is transmitted power in tolerance according with Annex 10, Volume I, Chapter 3.4. Also, in this case, the electromagnetic wave of the carrier radio navigation NDB signal propagates along the course axis towards the runway 06. If the direction of propagation of the radio wave is along the navigation course axis of the aerodrome, then the wave front of this radio wave is perpendicular to the course axis. The wave front is an imaginary line on which the wave has the same phase and thus the same amplitude. In terms of its principle, the ADF frame antenna shows a direction that is perpendicular to the wave front.

Since the course axis is formed by the NDB signal, this is the direction from which the radio wave is coming, i.e. the direction to the NDB navigation point. If anything affects the tilt of the wave front line, then the ADF will show the wrong direction of NDB alignment. This situation is illustrated on the left side of Fig. 5, where three different positions are marked - the inclinations of the wave front lines (brown) and the indication of the respective direction of the ADF's alignment on the NDB (black arrows). Once the alignment on the NDB is correct - 180º and twice the alignment is with an error of ±5º, i.e. 175º, 185º.

The paper deal with the topic of analyzes the unusual interaction of the electromagnetic waves of the NDB radio navigation signal with the relief of the earth's surface. It analyzes the major impacts, i.e. height changes of the terrain profile and changes in the electrical properties of the surface, which are represented by water surfaces. From the practical use point of view, the reverse targeting of the NDB ZLA is not used, as the NDB Z device is installed on the first kilometer on the approach axis of RWY 06.

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References

Ahmed, M. R, Sharma, S. D. 2005. An investigation on the aerodynamics of a symmetrical airfoil in ground effect Experimental Thermal and Fluid Science, Vol. 29, 2005, pp. 633-647.

Bean, B. R., Dutton, E, n.a. Radio Meteorology, Central Radio Propagation Laboratory, National Bureau of Standards, Boulder, Colorado.

Chen, S., Zhao, H., Huang, C. 2018. Impacts of GNSS radio occultation data on predictions of two super-intense typhoons with WRF hybrid variational-ensemble data assimilation. Journal of Aeronautics, Astronautics and Aviation, 50(4), 347-364. doi:10.6125/JoAAA.201812_50(4).02

Chen, Y., Zhan, X., & Tu, J. 2018. A SVM based GNSS performance assessment with reliable vulnerability degree model. Journal of Aeronautics, Astronautics and Aviation, 50(3), 301-314. doi:10.6125/JoAAA.201809_50(3).07

Ji, K., Zhou, H., & Fan, Y. 2019. GPS vector tracking loop enhancement using a robust cubature kalman filter. Journal of Aeronautics, Astronautics and Aviation, 51(4), 345-354. doi:10.6125/JoAAA.201912_51(4).01

Jiang, C., Chen, S., Chen, Y., Bo, Y., Wang, C., & Tao, W. 2017. Performance analysis of GNSS vector tracking loop based GNSS/CSAC integrated navigation system. Journal of Aeronautics, Astronautics and Aviation, Series A, 49(4), 289-297. doi:10.6125/17-0413-935

Kazda, A., Badanik, B., Tomova, A., Laplace, I., & Lenoir, N. 2013. Future airports development strategies. Komunikacie, 15(2), 19-24.

Kazda, A., Turiak, M., & Gőtz, K. 2020. Airport typology for lcc policy changes: A european perspective. Aviation, 24(3), 90-98. doi:10.3846/aviation.2020.12051

Kirschenstein, M., Ambroziak, R., & Tyburek, P. 2018. Practical use of approach systems for landing at rzeszów-jasionka airport. Paper presented at the Transport

Means - Proceedings of the International Conference, 2018-October 883-888.

Kraus, J. 2016. Determining acceptable level of safety of approach to landing. Paper presented at the Transport Means - Proceedings of the International Conference, , 2016-October 230-235.

Labun, J., Kurdel, P., & Novák, A. 2020. Analysis of the earth's surface influence on the accuracy of ADF. Paper presented at the Transportation Research Procedia, 51 333-341. doi:10.1016/j.trpro.2020.11.036

Lu, N., Zhu, F., Xiao, Y., & Li, X. 2020. The research on EMI of high-speed railway to NDB. IEEE Transactions on Electromagnetic Compatibility, 63(3), 692-701. doi:10.1109/TEMC.2020.3032133

Luo, S. C., Chen, Y.S., Ground effect on flow past a wing with a NACA0015 cross-section. Experimental Thermal and Fluid Science, Vol. 40, 2012, pp. 18-28.

Myler, H. 2015. Design for a source-agile automatic direction finder (ADF). Paper presented at the Proceedings of SPIE - the International Society for Optical Engineering, , 9474 doi:10.1117/12.2176429

Novák, A., Havel, K., & Janovec, M. 2017. Measuring and testing the instrument landing system at the airport zilina. Paper presented at the Transportation Research Procedia, ,28, 117-126. doi:10.1016/j.trpro.2017.12.176

Shan, X., Chen, H. 1994. Simulation of nonideal gases and liquid-gas phase transitions by the lattice Boltzmann equation. Physical Review E, Vol. 49, No. 4, 1994, pp. 2941-2948.

Sobiech, J., Kieliszek, J., Puta, R., Bartczak, D., & Stankiewicz, W. 2017. Occupational exposure to electromagnetic fields in the polish armed forces. International Journal of Occupational Medicine and Environmental Health, 30(4), 565-577. doi:10.13075/ijomeh.1896.00696

Sukop, M., C., 2005. Thorne JTD, Lattice Boltzmann Modeling. Germany: Springer-Verlag, 2005.

Thürey, N., Rüde, U., Körner, C. 2005. Interactive Free Surface Fluids with the Lattice Boltzmann Method, Technical Report 05-4, University of Erlangen-Nuremberg, Germany 2005.

Zerihan, J., Zhang, X. 2001. Aerodynamics of gurney flaps on a wing in ground effect. AIAA Journal, Vol. 39, No. 5, 2001, pp. 772-780.

Zhang, R. L., Di, Q. F., Wang, X. L., Gu, C.Y. 2010, Numerical study of wall wettabilities and topography on drag reduction effect in micro-channel flow by Lattice Boltzmann Method, Journal of Hydrodynamics, Ser. B, Vol. 22, No. 3, 2010, pp. 366-372.

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