МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
ФАКУЛЬТЕТ АЕРОНАВІГАЦІЇ, ЕЛЕКТРОНІКИ ТА ТЕЛЕКОМУНІКАЦІЙ
КАФЕДРА АЕРОНАВІГАЦІЙНИХ СИСТЕМ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д-р техн. наук, проф.
__________В.Ю. Ларін
« ___» _________2023 р.

ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА
ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«ОБСЛУГОВУВАННЯ ПОВІТРЯНОГО РУХУ»

Тема: Міська повітряна мобільність. Спільні прийняття рішень в аварійних ситуаціях

Виконавець: Яшан Ольга Василівна

Керівник: Шмельова Тетяна Федорівна

Керівники спеціального розділу
д.т.н. проф. Остроумов Іван Вікторович
д.т.н. проф. Шмельова Тетяна Федорівна

Нормоконтролер Аргунов Геннадій Вікторович

Київ 2023

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра аеронавігаційних систем

Навчальний ступінь «Магістр»

Спеціальність 272 «Авіаційний транспорт»

Освітньо-професійна програма «Обслуговування повітряного руху»

ЗАТВЕРДЖУЮ

Завідувач кафедри

д-р техн. наук, профессор

____________В. Ларін

« ___ »________2023 р.

ЗАВДАННЯ

на виконання дипломної роботи

ЯШАН ОЛЬГИ ВАСИЛІВНИ

1. Тема дипломної роботи: **«Міська повітряна мобільність. Спільні прийняття рішень в аварійних ситуаціях»** затверджена наказом ректора від «22» серпня 2023 р. № 1443/ст

2. Термін виконання роботи: з 23.10.2023 по 31.12.2023.

3. Вихідні дані до роботи: теоретичні дані керівних документів Міжнародної організації цивільної авіації та документів Державної авіаційної службиУкраїни.

4. Зміст пояснювальної записки: Аналіз міської повітряної мобільності; Методи дослідження процесу прийняття спільного рішення в нестандартній ситуації з БПЛА; Моделювання спільного прийняття рішення в умовах зіткнення птахів в польоті БПЛА на маршрути «Чернівці-Київ»; Спеціальний розділ; Охорона праці та охорона навколишнього середовища середовища при забезпеченні польотів пілотованих та безпілотних повітряних суден.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: рисунків, таблиць, формули.

6. Календарний план-графік

№ пор.	Завдання	Терміни виконання	Відмітка про виконання
1.	Підготовка та написання 1 розділу «Аналіз міської повітряної мобільності »	23.10.2023 – 31.10.2023	Виконано
2.	Підготовка та написання 2 розділу «Методи дослідження процесу прийняття спільного рішення в нестандартній ситуації з БПЛА »	01.11.2023 – 05.11.2023	Виконано
3.	Підготовка та написання 3 розділу «Моделювання спільного прийняття рішення в умовах зіткнення птахів в польоті БПЛА на маршрути «Чернівці-Київ» »	06.11.2023 – 15.11.2023	Виконано
4.	Підготовка та написання 4 розділу «Спеціальний розділ »	18.11.2023 – 22.11.2023	Виконано
5.	Підготовка та написання 5 розділу «Охорона праці та охорона навколишнього середовища при забезпеченні польотів пілотованих та безпілотних повітряних суден»	24.11.2023 – 30.11.2023	Виконано
6.	Підготовка презентації та доповіді	01.12.2023 – 08.12.2023	Виконано

7. Консультанти з окремих розділів

Розділ	Консультант (посада, П.І.Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
4.1. Автоматизована обробка аеронавігаційних даних великої розмірності	д.т.н, проф. Остроумов ІванВікторович	15.11.2023	18.11.2023
4.2. Ефективність авіаційних перевезень	д.т.н, проф. Шмельова Тетяна Федорівна	15.11.2023	18.11.2023

8. Дата видачі завдання: « 23 » жовтня 2023 р.

Керівник дипломної роботи Шмельова Тетяна Федорівна

(підпис керівника) (П.І.Б.)

Завдання прийняла до виконання Яшан Ольга Василівна

(підпис студента) (П.І.Б.)

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Міська повітряна мобільність. Спільні прийняття рішень в аварійних ситуаціях»: 94 сторінки, 27 рисунків, 24 таблиці, 33 використаних джерел.

Мета дипломної роботи – розробка моделі спільного прийняття рішення, яка дозволяє ефективно реагувати на потенційну загрозу від птахів для БПЛА та підвищує рівень безпеки польотів БПЛА в особливих випадках.

Об'єкт дослідження – технологія спільного прийняття рішень при виникненні особливого випадку в польоті БПЛА, такого як, напад птахів.

Предмет дослідження – моделювання спільного прийняття рішення у разі нападу птахів в польоті БПЛА .

Методи дослідження – метод експертних оцінок, моделювання прийняття рішень в умовах визначеності, невизначеності та ризику.

Актуальність – розроблена модель спільного прийняття рішення забезпечить безпеку повітряного простору та ефективну експлуатацію БПЛА, а також дасть змогу покращити підготовку під час управління повітряним рухом в аварійних та нестандартних ситуаціях авіадиспетчера, оператора БПЛА та пілота.

Результат дипломної роботи рекомендовано використовувати для спільного прийняття обґрунтованих рішень в умовах невизначеності, при виникненні особливого випадку в польоті БПЛА – напад птахів.

ОСОБЛИВИЙ ВИПАДОК, МІСЬКА ПОВІТРЯНА МОБІЛЬНІСТЬ, СПІЛЬНЕ ПРИЙНЯТТЯ РІШЕНЬ, НЕСТАНДАРТНА СИТУАЦІЯ, НАПАД ПТАХІВ.

АРКУШ ЗАУВАЖЕНЬ

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONIC AND TELECOMMUNICATION
AIR NAVIGATION SYSTEM DEPARTMENT

PERMISSION FOR DEFENCE
Doctor of Sciences (Engineering), prof.
Head of the Department
_______________Larin V.Y.
«_____»_____________2023р.

MASTER'S DEGREE THESIS
(EXPLANATIONARY NOTES)

GRADUATE OF THE MASTER'S DEGREE
BY EDUCATION PROGRAM
«AIR TRAFFIC SERVICE»

Theme: Urban air mobility. Collaborative Decision-Making in the emergency situations

Performer: Yashan O.V.

Head: Shmelova T.F.

Heads of special chapter
Doctor of Sciences (Engineering), prof. Ostroumov I.V
Doctor of Sciences (Engineering), prof. Shmelova T.F.

Standards Inspector Arhunov H.F.

Kyiv 2023

NATIONAL AVIATION UNIVERSITY
Faculty of air navigation, electronic and telecommunication
Air Navigation Systems Department
Specialty 272 « Aviation transport »
Educational program «Air traffic service »

APPROVED BY
Head of the Department
______________V.Y. Larin
«__»___________________2023

GRADUATE STUDENT’S DEGREE THESIS ASSIGNMENT
OLHA YASHAN

1. Topic of thesis: «**Urban air mobility. Collaborative Decision-Making in the emergency situations**» was approved by the Rector's order of № 1443/CT from 22.08.2023
2. The term of the work: from 23.10.2023 to 31.12.2023.
3. Initial data to the thesis: theoretical data of ICAO, UKSATSE, EUROCONTROL.
4. The content of the explanatory note (the list of problems to be considered): Analysis of urban air mobility; Research methods of collaborative decision-making process in an emergency with UAV; Modeling of collaborative decision-making in the conditions of bird strike in UAV flight on the route «Chernivtsi-Kyiv»; Special chapter; Labor protection and environmental protection at ensuring flight of manned and unmanned aircraft.

5. The list of mandatory graphic (illustrated) materials: graphs of results data, tables, formulas.

6. Calendar timetable

№	Completion stages of Degree Thesis	Stage completion dates	Remarks
1.	Preparation of chapter 1: «Analysis of urban air mobility »	23.10.2023 – 31.10.2023	Completed
2.	Preparation of chapter 2: «Research methods of collaborative decision-making process in an emergency with UAV »	01.11.2023 – 05.11.2023	Completed
3.	Preparation of chapter 3: «Modeling of collaborative decision-making in the conditions of bird strike in UAV flight on the route «Chernivtsi-Kyiv» »	06.11.2023 – 15.11.2023	Completed
4.	Preparation of chapter 4: «Special chapter »	18.11.2023 – 22.11.2023	Completed
5.	Preparation of chapter 5: «Labor protection and environmental protection at ensuring flight of manned and unmanned aircraft »	24.11.2023 – 30.11.2023	Completed
6.	Preparation of report and graphic materials	01.12.2023 – 08.12.2023	Completed

7. Consultants from individual chapter

Chapter	Consultant (position, name)	Date, signature	
		Issued the task	Accepted the task
4.1. Automated processing of aeronautical data of large dimensions	Doctor of Sciences (Engineering), prof. Ostroumov I.V.	15.11.2023	18.11.2023
4.2. Efficiency of air transport	Doctor of Sciences (Engineering), prof. Shmelova T.F.	15.11.2023	18.11.2023

8. Assignment accepted for completion «23» Octovber 2023

Supervisor Shmelova T.F

Assignment accepted for completion Yashan O.V.

ABSTRACT

Explanatory note to the graduation work «Urban air mobility. Collaborative Decision-Making in the emergency situations» contains 94 pages, 27 figures, 24 tables, 33 sources used.

The purpose of the work - development of collaborative decision-making model that allows effective response to the potential threat from birds to UAVs and increases the level of safety of UAV flights in special cases.

The object of the research - the technology of collaborative decision-making in the event of a special case in the flight of a UAV, such as a bird strike.

The subject of research - modelling of collaborative decision-making in the conditions of a bird strike in a UAV flight.

Methods of research – Expert Judgment Method, modeling of decision-making in conditions of certainty, uncertainty and risk.

Actuality - the developed collaborative decision-making model will ensure the safety of the airspace and the efficient operation of UAVs, as well as make it possible to improve the training of the air traffic controller, UAV operator and pilot during air traffic control in emergency and non-standard situations.

The result of the thesis is recommended to be used for CDM in conditions of uncertainty, in the emergency situation in the flight of a UAV - a bird strike.

EMERGENCY SITUATION, URBAN AIR MOBILITY, COLLABORATIVE DECISION-MAKING, NON-STANDARD SITUATION, BIRD STRIKE

CONTENTS

LIST OF ABBREVIATION

AAM - Advanced Air Mobility

ADS-B – Automatic Depend Surveillance

ANS – Air Navigation Service

ATC – Air Traffic Controller

ATM/ANS – Air Traffic Management/ Air Navigation Service

ATS – Air Traffic Service

CDM – Collaborative Decision-Making

EASA – European Union Aviation Safety Agency

EJM – Expert Judgment Method

EUROCONTROL – The European Organization for the Safety of Air Navigation

FAA – Federal Aviation Administration

GNSS – Global Navigation Satellite System

ICAO – International Civil Aviation Organization

IFR – Instrument Flight Rules

NAS – National Air System

NOTAM – Notice to Air Missions

PSU – Provider Services of UAM

SDSP – Supplemental Data Service Provider

UAM – Urban Air Mobility

UAV - Unmanned Aerial Vehicle

WHO – World Health Organization

INTRODUCTION

Urban air mobility (UAM) is an emerging topic that is currently attracting the attention of both industry and researchers. UAM opens up the possibility of fast and efficient mobility in urban areas with the help of small unmanned aerial vehicles that can act as vehicles, such as means of responding to emergency situations. The UAM concept includes a set of rules, procedures and technologies that ensure the air movement of cargo and passengers in urban conditions. UAM is a part of the Advanced Air Mobility (AAM), a joint initiative of the FAA, NASA, and the industry to develop an air transportation system that moves passengers and cargo with new electric (i.e. green) air vehicles in various geographies previously underserved by traditional aviation [1]. It involves the development of air transport systems that use new electric aircraft to transport passengers and cargo. Today, unmanned aerial vehicles (UAVs), also known as drones, are used for:

- Recreation
- Traffic monitoring;
- Natural disasters monitoring;
- Fire detection;
- Infrastructure inspection;
- Mapping;
- Forestry, agriculture, and;
- Other civilian purposes.

Such operations are usually limited to certain geographical areas and do not pose a significant risk to the daily operations of the National Air System (NAS). However, proposed urban, suburban and extra-urban air services may present operational and safety issues that could materially affect the NAS. The proposed operations will probably be carried out by manned and unmanned aerial vehicles with electric vertical take-off and landing. Unlike conventional helicopters, the new aircraft will be cheaper, quieter and more efficient, using multiple engines, propellers, electric motors and lightweight materials. They are expected to cover both urban and rural areas.

Since unmanned aerial vehicles have become an integral part of modern airspace both in urban areas and outside their borders, along with the growing popularity and use of UAVs, a new risk has appeared - bird attacks. Bird attacks on UAVs can have different causes and consequences. Some birds react aggressively to approaches to their nests or territories. Others may see UAVs as a threat to their security and direct attacks to scare or drive them away. In urban areas, where birds have adapted to the environment, this problem can be even more urgent.

Since UAVs have become an integral part of modern airspace in urban and suburban areas, along with the growing popularity and use of UAVs, a new risk has appeared - bird attacks on UAVs.

Bird attacks on UAVs can have different causes and consequences. In urban areas, where birds have adapted to the environment, this problem is more urgent. Because some birds may react aggressively when drones approach their nests or territories. Other birds may perceive UAVs as a threat to their safety and direct attacks to scare them away.

The most frequent consequences of a bird attack on a UAV, for example, are:

- Damaged equipment;
- Loss of stability and controllability of the UAV;
- Data loss.

Whereas, according to the European Union Aviation Safety Agency, in the first quarter of 2021, the number of bird strike in Europe increased by 205%, compared to the same quarter of 2020; in the third quarter of 2021, the number of collisions with birds increased by more than 18%, compared to the same quarter of 2019, to 240.8 per million flights [2], so it is an important aspect to create measures to prevent and minimize the risks of bird strikes on UAVs. We can take several measures such as:

1) To plan UAV flights in such a way as to avoid the place and time when bird activity is highest;

2) To climb to a higher altitude where birds are less likely to be;

3) To use acoustic repellants that emit sounds to scare away birds;

4) To use a beacon light on the UAV that can scare away birds, especially at night;

5) UAV operators must be trained to recognize potential bird threats and be able to respond in the event of strike;

6) To use monitoring and tracking systems to detect approaching birds and avoid them.

Today, a key factor in ensuring flight safety is solving the problem of organizing Collaborative Decision-Making (CDM) by all operational partners - air traffic controllers, pilots, UAV operators. CDM allows operators and controllers to actively collaborate in real time to detect a threat and take measures to prevent it.

The thesis will consider the organization of Collaborative Decision-Making by the ATC and UAV operator when birds strike UAVs in flight in urban and non-urban areas. Such emergency situations, along with a strict time limit for making a collaborative decision and the tense psychophysiological state of the UAV operator and ATC, are characterized by a high level of uncertainty and incomplete information. That is why the task of evaluating possible options for collaborative solutions is relevant, which allows the operator and the air traffic controller to choose a strategy of actions with a minimum level of potential losses.

CHAPTER 1. ANALYSIS OF URBAN AIR MOBILITY

1.1. The operational concept of UAM and its relevance in modern condition

A UAM operation transports people and cargo from one airport to another. UAM corridor construction, UAM procedures, information sharing, and UAM performance criteria allow for increased operational speed and minimized impact of ATM and UTM operations without the need for tactical UAM isolation services.

Aircraft operating in the UAM corridor must meet the requirements for the characteristics and attendance of the UAM environment. Performance and attendance requirements in the UAM corridor may vary depending on what process is being performed or taking place in the UAM corridor. ATC do not participate in strategic disruptions and tactical separations occurring in the UAM corridor. UAM aircraft operating outside the UAM corridor must comply with the operating rules and procedures applicable to the relevant airspace.

This concept supports the development of a regulatory framework, the development of operational rules and performance requirements to meet operational requirements, data sharing to support UAM and FAA operator responsibility, and UAM uses a common technical environment similar to UTM, for which the operator is responsible. coordinate, perform and manage operations as well as monitor CBR. This networked exchange of information provides the basis for stakeholders to plan, manage, execute and oversee UAM operations. The public interest and other interested parties have access to general operational information of the UAM.

Urban Air Mobility is a relevant and innovative concept that can transform the way we move around cities, improve transport accessibility and contribute to the sustainable development of urban environments. Many companies and governments are now investing resources in the study and implementation of UAM, making it one of the most important initiatives for the future of urban mobility.

I will give several reasons why the concept is becoming more and more relevant:

1) In urban areas, UAM can be a revolutionary step in easing traffic congestion and reducing travel time;

2) UAM reduces emissions of harmful gases and improves air quality;

3) UAM can be most effective in emergency situations;

4) UAM industry creates new jobs and can be a source of economic growth for cities;

5) UAM concepts can minimize noise in urban environments.

The ever-increasing demand for approval of UAS operations for humanitarian, professional and commercial purposes requires an effective regulatory framework to safely manage this growth. It also requires support in the implementation of regulations, as well as adequate training capabilities to ensure that the oversight of operators and operations can be carried out effectively and efficiently.[3]

In order to establish foundations for the safe, secure and sustainable integration of unmanned aviation in the global air transport system, an increasing number of coordination activities have been initiated or pursued involving a broad range of aviation disciplines. Work has been conducted in the areas of air navigation services and airport economics, including to identify cost-recovery mechanisms for providing air navigation services to UAS. [3]

Regarding the physical infrastructure needed to support the projected growth of urban air mobility/advanced air mobility (UAM/AAM) operations using vertical take-off and landing (VTOL) capabilities, ICAO has started to work on the development of technical requirements for vertiports.[3]

1.2. Roles and Responsibilities

1.2.1. Air Traffic Controller

The main purpose of ATC is to prevent collisions involving aircraft operating as part of the NAS. Air traffic control may advise other aircraft on uam operation depending on the allowable workload. Thus, to ensure the safety of aircraft receiving ATC services, ATC should have additional access to operational uam data. ATC may request information from participants and receive automatic notifications as required. The task of ATC to ensure the operation of the UAM is as follows:

1) Establish the availability of the UAM corridor in accordance with the work plan;

2) Advise uam on working with other aircraft depending on the permissible workload;

3) If necessary, supports non-standard UAM operations.

ATC can review any pertinent information from UAM operations.

1.2.2. UAM operator

UAM operators can conduct their activities in the form of regular or on-demand services. They are responsible for complying with all established regulatory requirements and all aspects of performing tasks related to the UAM system.

The UAM operator receives up-to-date information from PSU and SDSP services, such as environmental data, situational assessment, UAM aerodrome availability and supplementary data. This information is used by the UAM operator to determine its operational plans, such as determining the departure location, route and desired flight time.

UAM operators must submit to the PSU information regarding their flight intentions and operational data necessary to operate a flight within or through UAM corridors. Functions performed by the operator UAM:

1) Notifies other operators of upcoming operations within the UAM corridor to increase safety and general awareness.

2) Ensures strategic conflict avoidance.

3) Assists in the identification and dissemination of known airspace limitations and restrictions for intended areas of operation.

4) Transmits up-to-date advice, weather conditions and other important data related to space and time.

5) Supports shared partition management services.

The UAM operator also strategically plans for contingencies, including analysis of possible alternative landing sites and airspace classes adjacent to the UAM corridor(s) for operations. Upon completion of such operations, the UAM operator notifies the PSU.

1.2.3. PIC (Pilot in command)

The PIC in the UAM system is the person who has overall responsibility for the performance and safety of the flight on board. This is the person who analyzes all potential risks, makes decisions and ensures safe and efficient delivery of passengers or cargo. The PIC's primary task is to determine the flight path and navigate to ensure the accuracy and efficiency of the UAV movement in and out of urban airspace.

1.2.4. PSU and SDSP

PSU is an organization that supports UAM operators in meeting operational requirements that ensure safe, efficient and reliable use of airspace. The PSU performs the following duties:

1) Provides communication between all UAM participants in order to ensure the ability of the UAM operator to meet regulatory and operational requirements for UAM operations;

2) Provides the UAM operator with information collected from network PSUs regarding scheduled UAM operations within the UAM corridor;

3) Confirms the intent to fly to the PSU network;

4) Disseminates operational data and guidance provided by the FAA, weather information, and additional data;

5) Determines the status of the use of the UAM corridor;

These core functions allow the PSU to provide joint management of UAM operations without direct FAA involvement in each individual flight.

UAM and PSU operators use the SDSP to access additional information, including location information, obstructions, aerodrome availability and special meteorological conditions. SDSP can be accessed through the PSU network or directly by UAM operators.

1.3. Organization of air transportation in and around urban areas

Air transportation with the help of UAVs in urban and suburban areas is one of the most relevant innovations in the field of transport. Unmanned aerial vehicles make it possible to realize the ideas of urban air mobility, which have the potential to solve many problems of transport in cities. UAVs are used effectively in both military and civil aviation, including emergency and disaster response, as well as agriculture, aerial photography, communications relaying, weather, air, and water quality monitoring, and many other potential uses [4].

Remotely piloted aircraft system (RPAS) - a remotely piloted aircraft, its associated remote pilot station, the required command and control links, and any other components. The challenge now is to integrate RPAS safely and effectively into the highly regulated and well-established manned aviation industry. New interfaces (Figure 1.1) with direct link from the RPAS to Air Traffic Controller (ATC), as system interfaces, by ICAO in RPAS Concept of operations (CONOPS) for international Instrument flight rules (IFR) operations in single airspace proposed.[4]

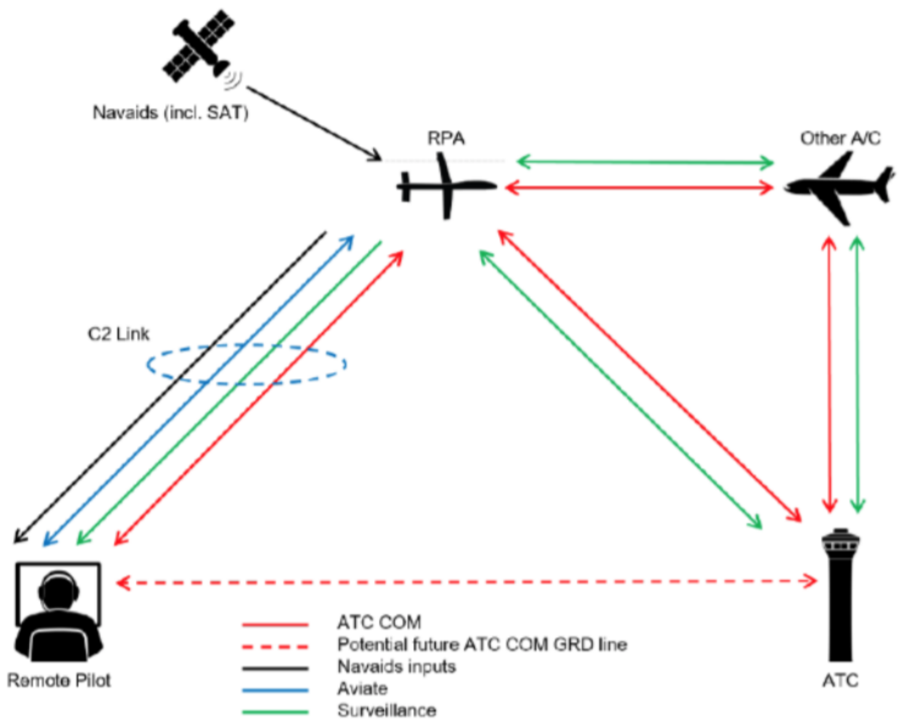


Figure 1.1 – Interfaces with direct link from the RPAS to Air Traffic Controller (ATC) proposed ICAO [5]

The roles of RPA will continue to expand as technologies and performance characteristics become better understood. Long flight durations, covert operational capabilities, and reduced operational costs serve as natural benefits to many communities such as law-enforcement, agriculture and environmental analysis.[6]

The German Aerospace Center (DLR), Institute of Aerospace Medicine and Institute of Flight Guidance conducted the research. The main task of this study was to understand how people relate to UAVs and their use in the concept of mobility.[7] They got the following results (Figure 1.2)

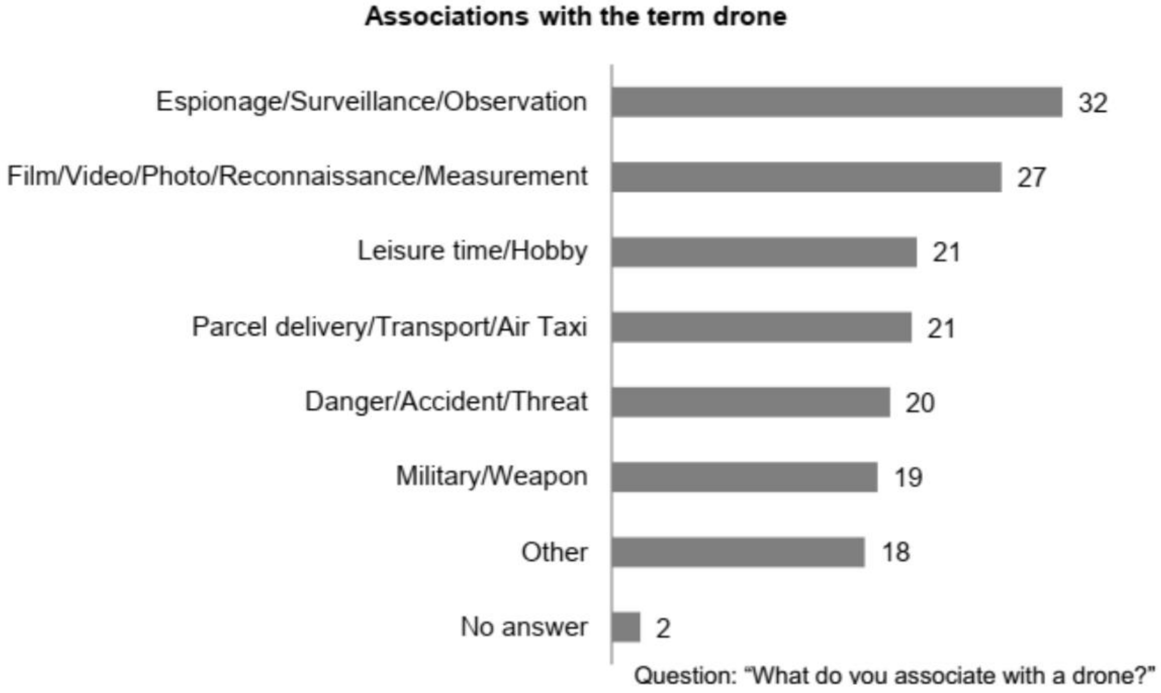


Figure 1.2 – People's associations with drone missions[7]

UAVs have both advantages and disadvantages when performing air transportation. Some of them are listed in the table 1.1.

Table 1.1 – Advantages and disadvantages of UAVs

№	Advantages	Disadvantages
1.	*Safety and risks:* The use of UAVs reduces the risk of potential harm to the crew and passengers, increases the safety margin for flight operations, and reduces the risk of accidents due to human error	*Safety and risks:* Unmanned aerial vehicles have a detrimental effect on the environment. Noise pollution is one example of how drones affect the environment. Another illustration is the risk of unmanned aerial vehicles crashing or malfunctioning, causing damage to ecosystems

		and habitats. Also drones can be manufactured using potentially hazardous substances and chemicals, and disposal of old or broken drones can lead to e-waste that fills landfills and causes pollution.
2.	*Cost and efficiency:* UAVs are more affordable than conventional methods because they operate remotely, so there is no need for expensive equipment and manpower, and they cover large areas quickly, increasing efficiency.	*Cost and efficiency:* Larger UAVs are more difficult to control and may become less maneuverable when remotely piloted. Also, their inability to deliver large or bulky items is one illustration of their low carrying capacity. This means that they may not be able to take the place of conventional freight transport methods such as trucks or ships in some sectors of the economy.
3.	*Performance and capabilities:* UAVs may also fly at lower altitudes and slower speeds, and are equipped with a variety of sensors and cameras enabling the collection and processing of more precise data.	*Performance and capabilities:* Most drones have limited battery life, resulting in short flight times that may not be sufficient for certain tasks. The range of drones is limited by their communication and battery capabilities, which limits their range.

The term "smart city" has gained popularity in recent years. This term can be formulated as: "Smart city is a concept of development and organization of urban space, which is based on the use of advanced technologies, digital innovations, and approaches to sustainable development to improve the quality of life of city residents. UAM is aimed at optimizing management of urban resources, transport infrastructure, energy, communications and other aspects of the urban environment in order to ensure efficiency, safety, sustainability and equal availability of services for all citizens of the city."

Figure 1.3 – «Smart city» concept view[8]

The use of UAVs within the framework of the concept of a smart city can contribute to solving the following tasks:

– Monitoring the intensity of traffic and preventing the formation of traffic jams;

– Ensuring rapid response of emergency services in emergency situations;

– Carrying out search and rescue operations to find and provide assistance to those in need;

– Implementation of video surveillance and photography to monitor various aspects of the urban environment;

– Creation of mobile Wi-Fi relay points to provide communication and access to the Internet in different parts of the city;

– Provision of cargo delivery and movement services, which can be useful for efficient logistics and supply of the city.

For the effective implementation of air transportation using UAVs, certain factors must be taken into account, such as the presence of infrastructure facilities, buildings, roads, recreation areas, natural areas, and the presence of prohibited and dangerous areas. In order to ensure safe flights, obstacle maps were drawn up in and around the urban area. Google Maps, Maps.me, Google Earth Pro were used to obtain a map of obstacles [4]. To assess the risks of obstacles, it can be used EJM and Fuzzy logic. Risk assessments can range from very low to very high risk. For example, assessment of infrastructure objects: this is an enterprise and institution of such industries as energy, chemical industry, transport, banks, information technologies and telecommunications, food, health care, communal economy, which are strategically important for the functioning of the economy and security of the state, society and the population. The potential risk of flying over such objects is very high.

1.4. Statistic of world civil UAS market

The foundations are being laid for the rapid growth of the civil UAS market. The UAS market is promising. In terms of aerospace, the market for civil UAS promises to be one of the most dynamic growth sectors for the next decade, emerging from a $5 billion annual market in 2019 to almost triple to $14.5 billion by 2028 (Figure 1.4).[9]

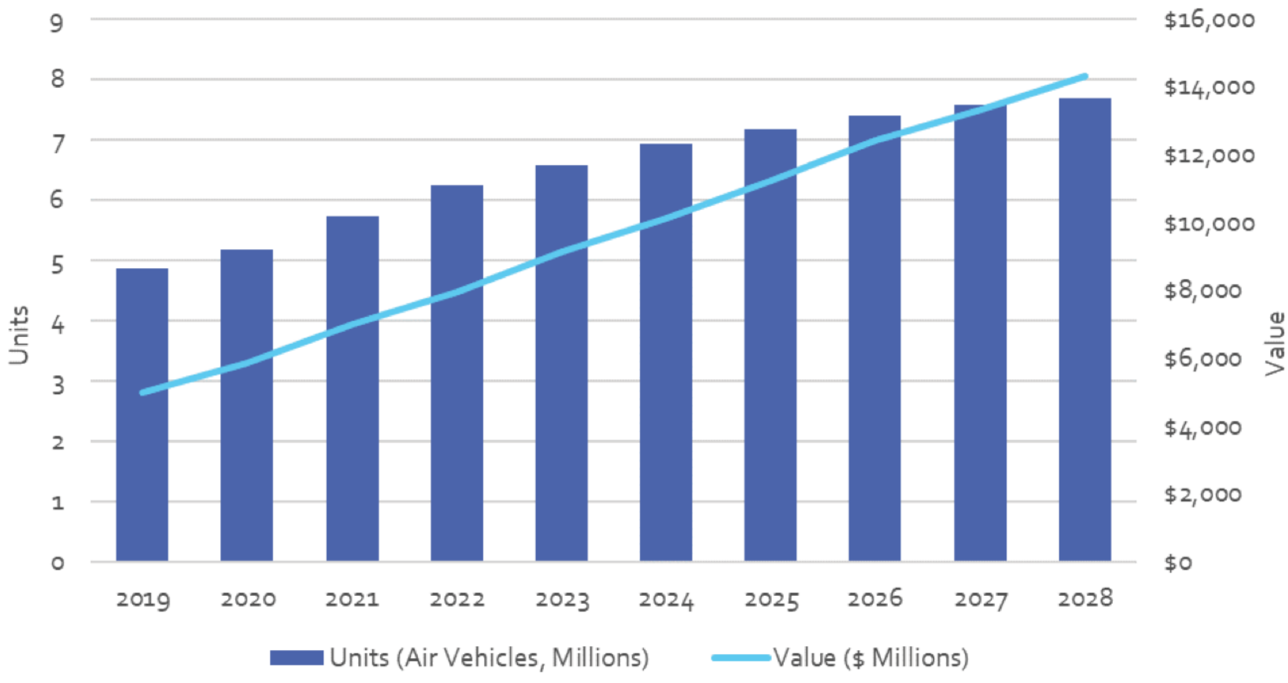


Figure 1.4 – World civil UAS production forecast[9]

That represents a 12.5% compound annual growth rate in constant dollars. Over the next 10 years the market totals $97.6 billion. Although consumer systems represent slightly over 55% of the overall market through the decade, the fastest growth comes from commercial systems, which surpass consumer systems by annual value in 2023 and continue to widen the lead throughout the rest of the forecast period (Figure 1.5).[9]

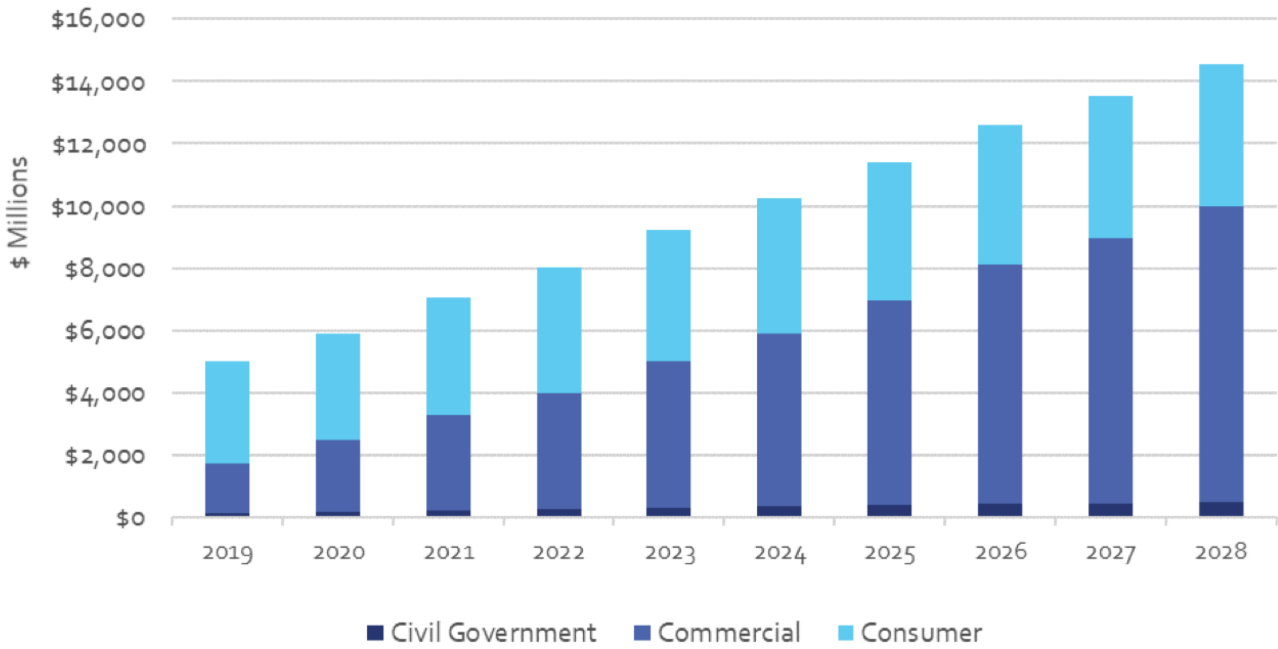


Figure 1.4 – World civil UAS production value forecast by sector[9]

Commercial markets are beginning to develop. Many companies are currently doing proof of concept work that creates the foundations for widespread deployment of drones. They are working to prove cost savings and make sure data provided can be integrated into the business' work-flow.[9]

Construction, insurance and energy promise to grow quickly in coming years. Large enterprises will de- ploy fleets of systems. Agriculture, which is currently the largest market thanks to the value of unmanned spraying systems, will grow more slowly due to the currently depressed profitability of the sector and the diffuse nature of decision-making. Delivery eventually promises to be a very large market but will develop first in narrow niches such as delivery to very remote areas such as is- lands or ships or delivery of high- value, time-sensitive products such as medical supplies.[9]

As the commercial market develops, it mostly will be based on inexpensive prosumer and mini UAVs and will be much more price sensitive than the governmental market. Even local law enforcement agencies will be buying mainly prosumer and inexpensive mini-systems rather than much costlier larger UAVs.[9]

While the unit numbers of these UAVs purchased to serve the commercial market promise to be substantial, their value will be a small fraction of that of the costly, sophisticated systems that dominate the military market such as Global Hawk and Predator.[9]

Consumer UAS will continue to grow but its most explosive growth is behind it. It is a much more mature market that has lost some of its novelty and technological innovations that will attract buyers are becoming fewer. Still, the market will continue to expand thanks to new technological developments and a wider range of product offerings. Moreover, there promises to be considerable crossover between the consumer and the commercial UAS markets. Some consumer drones are used for lowend commercial tasks such as real estate. Consumer drone manufacturers are also moving up the value chain to create more capable, complex systems able to take on more demanding commercial work.[9]

With the promise offered by the explosive market growth in coming years for commercial UAS systems, substantial venture capital funding is going into the civil UAS industry.[9]

1.5. The causes and consequences of bird strikes in urban airspace. Guidance for ATC and operator of UAVs in an emergency.

The US Federal Aviation Administration's Migratory Bird and Wildlife Sensitive Areas Report [10] states that the risk of bird strikes becomes more frequent in March/April and August/November, with over 90% of strikes occurring at 3,000 feet and lower. The FAA's 1990–2021 Wildlife Strike Report [11] indicates that 15,556 bird strikes occurred in 2021 alone.

Figure 1.6 – The bird strike on UAV in the flight

Birds are often considered an important element of a city's ecosystem, but their interaction with UAVs can have negative consequences. Here are some reasons why birds may attack UAVs in urban areas:

– Nesting season: at this time, birds may be more aggressive towards UAVs that approach their nests, protecting the chicks or eggs in the nests;

– Foraging: Birds may mistake UAVs for a food source such as insects or other prey;

– Noise: UAVs generate various sounds and vibrations that can irritate birds and they may react aggressively to these irritants;

– Specificity of the territory: urban areas have different avian fauna, which can be particularly aggressive;

– Territory defense: Birds may view UAVs as a potential threat to their territory or nests. Therefore, they try to drive away UAVs and cause damage or loss of control over them.

By analyzing these reasons, it is possible to indicate what consequences are expected in the event of a bird attack on a UAV. One of the main consequences of bird attacks on UAVs is physical damage to the drones. Most often, propellers, cameras and sensors are damaged. While this leads to the loss of expensive equipment and inappropriateness in the performance of tasks. Due to physical damage to drones, the quality of recordings and images may deteriorate or lead to the loss of important video and photo material. In more serious situations, bird strikes can damage the UAV so severely that it cannot be repaired and this will lead to the loss of the UAV. Also, the consequences of bird strike pose a threat to people and property on earth, and to the birds themselves. A fall of the drone may result in personal injury or property damage. And the birds themselves can be injured or even die. To prevent this it can be recommended to use of additional security measures, such as the installation of a bird detection system, or the development of flight strategies that avoid areas where bird strikes are most likely to occur, may be recommended.[12]

For controllers, there is a guidance of what to expect from an aircraft that has suffered the consequences of a collision with birds. These instructions will allow the controller to not only provide maximum support to the aircraft in question, but also to maintain the safety of other aircraft in the vicinity. This also applies to bird monitoring and control concepts and service provision in general. There is no set of ready-made standard rules that should be followed everywhere. As in any unusual or emergency situation, dispatchers must use their best judgment and experience when dealing with the obvious consequences of a dangerous bird strike.

Eurocontrol suggests that ATC adhere to the best practices laid down in the ASSIST [13] principle. ATC use this principle in case of an unforeseen situation, since the ASSIST code is the most convenient and understandable in case of emergency situations. Depending on the situation, the options for expected actions are different, but the ASSIST assistance algorithm remains unchanged.

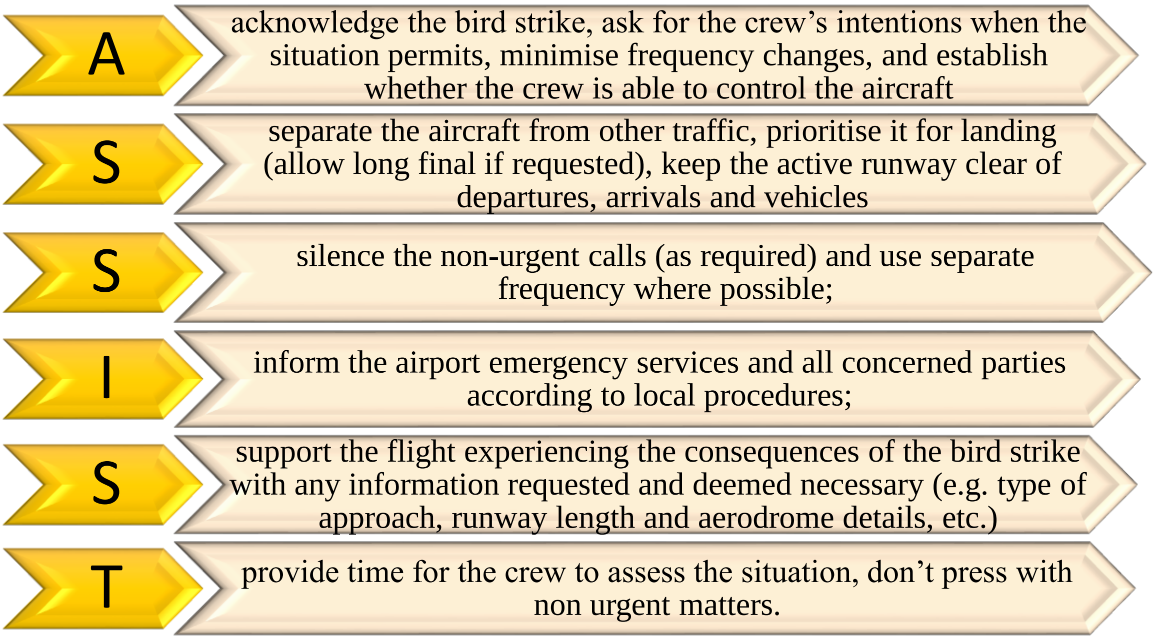
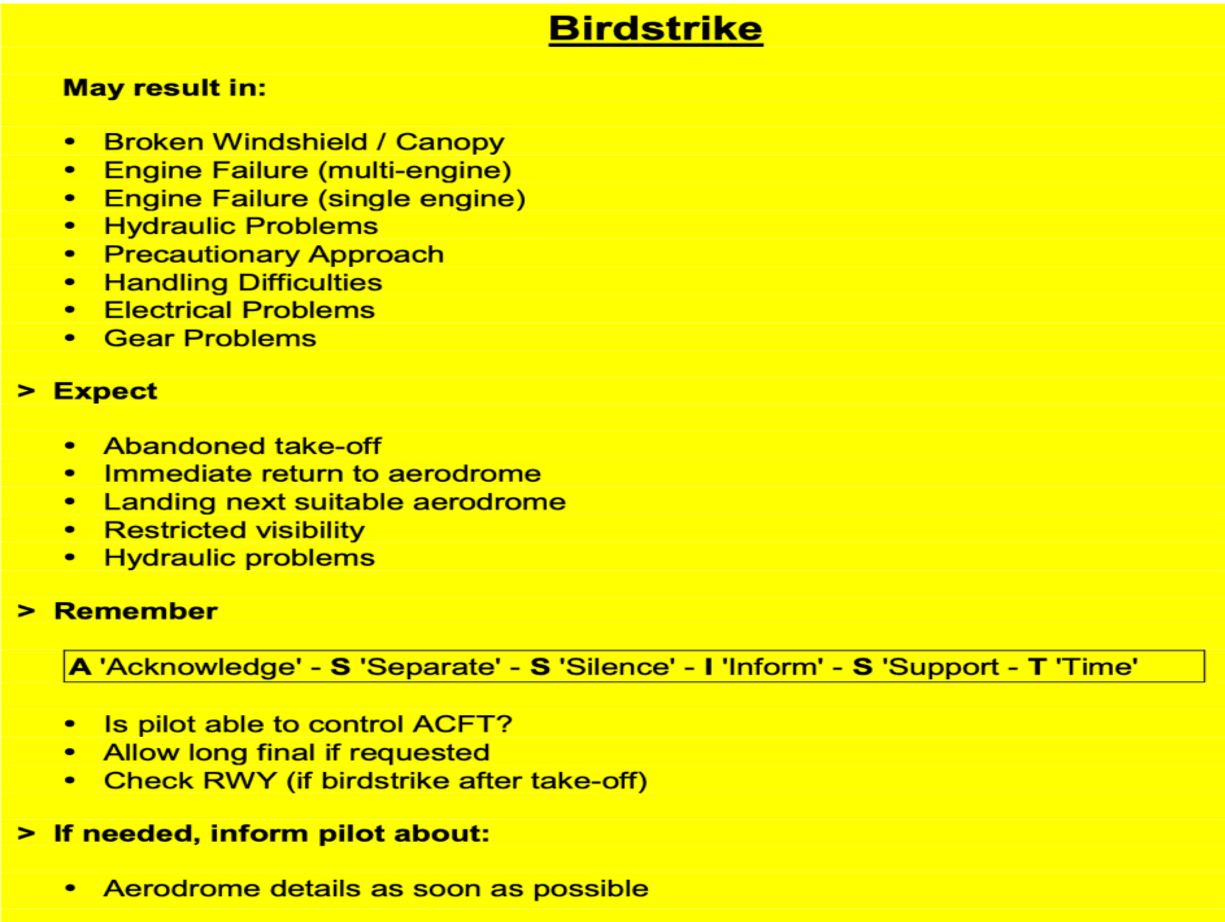


Figure 1.7 – Operating procedures ASSIST

A checklist [13] is proposed for use in order to ensure proper handling of any incident which requires controller action. ATC can use checklist booklet og emergency situation № 2 "Bird strike":



Birdstrike

May result in:

- Broken Windshield / Canopy
- Engine Failure (multi-engine)
- Engine Failure (single engine)
- Hydraulic Problems
- Precautionary Approach
- Handling Difficulties
- Electrical Problems
- Gear Problems

> Expect

- Abandoned take-off
- Immediate return to aerodrome
- Landing next suitable aerodrome
- Restricted visibility
- Hydraulic problems

> Remember

A 'Acknowledge' - **S** 'Separate' - **S** 'Silence' - **I** 'Inform' - **S** 'Support - **T** 'Time'

- Is pilot able to control ACFT?
- Allow long final if requested
- Check RWY (if birdstrike after take-off)

> If needed, inform pilot about:

- Aerodrome details as soon as possible

Figure 1.8 – Checklist booklet[13]

Depending on where a bird strike occurs on aircraft, the incident can range from a minor nuisance to an emergency. The first thing the UAV operator/pilot should do is to inform the dispatcher about the situation. This information should include the condition, location of the aircraft, size and number of birds. The next step is to fill out an FAA Wildlife Strike Report which is Appendix 1 in the Aeronautical Information Manual. And finally, the last step will be to help FAA recognize the bird species. The following measures can help reduce the risk of bird impact or mitigate the consequences [14]:

- Bird proofing, that is, the process of making vulnerable surfaces more resistant to bird impact. This includes multiple iterations of designing and then testing various parts until satisfactory results are achieved, it is demonstrated that safe landing can be achieved after being struck by a bird anywhere on the structure, at normal operating speeds. The process is similar to the one used for manned aircraft and is mostly suitable for larger UASs which are normally also subject to stricter regulations.
- Loss of control link can be mitigated by adding an autonomous program that is activated in such scenarios and performs a safe landing and/or flight to a suitable location.
- Avoiding bird locaions, such as feeding grounds, and taking account of seasonal behaviour could be an option. UASs normally have more options for take off and landing as opposed to large commercial aircraft.
- If feasible, planning the flights early in the morning reduces the chances of encounter as birds are generally less active at this time. This approach can sometimes be feasible in case avoiding bird locations altogether is not possible.
- Smaller UASs can be considered as a threat or prey by birds, therefore keeping a safe distance or flying away when approached by birds is the best option.[14]

Conclusion to chapter 1

The concept of air mobility and the use of unmanned aerial vehicles (UAVs) in urban areas is becoming increasingly relevant. This innovative technology opens up new opportunities for fast and efficient transportation of passengers and cargo, as well as for the provision of emergency medical care and other tasks.

At the same time, the importance of the role and responsibility of air traffic controllers, UAV operators and pilots in ensuring safety, coordinating flights and performing various tasks is growing. Air traffic controllers play a key role in airspace control and management, ensuring flight safety and conflict avoidance. UAV operators have a great responsibility for the proper operation and monitoring of drones, as well as for ensuring safety in urban environments. They must be prepared to respond to various situations and comply with all regulatory requirements. In the event of a special case in flight, the actions of the air traffic controller, operator and pilot may differ from the established algorithm of necessary actions. At the same time, there is a need for immediate readiness to provide assistance and make decisions depending on the situation, showing independence, own experience, knowledge and initiative.

Implementing the concept of air mobility and UAV air transportation in urban areas requires teamwork, a strong focus on safety and compliance with regulatory requirements.

CHAPTER 2. METHODS OF RESEARCHING OF COLLABORATIVE DECISION-MAKING PROCESS IN AN EMERGENCY SITUATION WITH UAV

2.1. Decision-making in conditions of uncertainty, certainty and risk

The professionals of ANS are involved in the provision of safety during the manned and unmanned flight in the integrated air space. There are flight crews, remote pilots, air traffic controllers, flight dispatchers, maintenance staff, ground handling personnel, etc. Each of them plays a major role at different stages, as the safe flight starts not only from manned and unmanned aircraft departure. They are strictly following the manuals and legal documents approved in the field of their professional activity [15]. The pilot of the aircraft bears full responsibility for the flight and compliance with all regulations and procedures in case of emergency or non-standard situations. At that time, the air traffic controller is responsible for maintaining separation between aircraft in established airspace corridors and assisting crews and remote pilots in emergency situations, acting in accordance with established instructions. Specialists ANS participate in ensuring general safety in the airspace. Each of them contributes to flight safety.

In the case of collaborative decision-making conditions, there are methods of decision-making under conditions of certainty, risk, uncertainty and conflict.

2.1.1. CDM under conditions of conflict

Risk conditions arise when, during decision-making, it is necessary to take into account random factors with a priori known laws of probability distribution. The task of choosing decisions under conditions of risk is reduced to the task of making statistical decisions under simple or complex alternative hypotheses. One-dimensional or multidimensional utility theory methods are also used to solve these problems.

Under conditions of risk, the air traffic controller’s decision-making algorithm looks like this:

1) Structural analysis of the situation – determination of decision stages k, stage time t, additional risk at stage R_{add}: {t}, {C}.

2) Determination of alternatives at each stage: {A}.

3) Definition of probabilities for each alternative: {P} (EJM).

4) Definition of results: {u} (EJM).

5) Building a decision tree.

6) Calculation of the optimal solution using the criterion of the expected value and the method of dynamic programming.

7) Result R_{min}/R_{max} (Formulas 2.1-2.2)

$$R_{ij} = \min\{t_i(\sum_{j=1}^{n} p_j\ u_j) + C_i\} + min\ R_{i-1},$$

$$R_{ij} = \max\{t_i(\sum_{j=1}^{n} p_j\ u_j) - C_i\} + max\ R_{i-1}.$$

2.1.2. CDM under conditions of certainty

Under conditions of certainty, the decision-making algorithm looks like this:

1) Determination of special case in the flight according to the ASSIST list.

2) Determination of the air traffic controller's, UAVs operator's and pilot's procedure in the event of special case in the flight.

3) Decomposition of the order of operational procedures: ai, where I = 1..n.

4) Construction of a block diagram of the air traffic controller's, UAVs operator's and pilot's action algorithm.

5) Determination of time ti, where I = 1..n using the EJM;

6) Determination of the opinion of the group of experts: $t_{gr} = t_{avr}$

a) Determination of the coordinated opinion of a group of experts for t_i,

where I = 1..n;

b) The variance for each factor is D_j;

c) Root mean square deviation – σ_j;

d) Coefficient of variation for t – v_j.

7) Determining the time to perform operational procedures and building a structural time table of actions.

8) Construction of a network schedule of the actions of the air traffic controller, UAVs operator's and pilot's in special case.

9) Determination of the critical time of execution of actions – T_{gr};

10) Determination of the critical path of DM.

2.1.3. CDM under conditions of uncertainty

Modelling the possible further development of the situation in the event of an emergency is characterized by a high level of insufficient information and uncertainty of the situation, and is possible precisely with the help of decision-making methods under conditions of uncertainty.

Decision-making methods under uncertainty are the most common and universal. Decision-making under uncertainty, like risk, involves alternative actions, the payoffs of which depend on random factors. The algorithm of the collaborative decision-making in flight emergency [16]:

1) Building of individual DM matrix with the alternative solutions {A};

2) Alternative solutions A = {A_1 , A_2 ,…A_i , …, A_n);

3) Factors {λ} influencing on DM for each operator {λ} = {λ_1 , λ_2 …, λ_j , …, λ_m }, where λ m – are the original or identical factors;

4) Outcomes {U} = u_{11}, u_{12}, ..., u_{ij}, ..., u_{nm}, outcomes of DM matrix depend on factors that influence the actions of operators.

5) Formation of the individual matrixes of solutions for each operator.

6) Choosing the methods of DM under uncertainty with maximum safety.

To choose the optimal alternative under conditions of uncertainty, appropriate criteria are used, namely:

• Wald criterion☹maximin – the choice of the alternative that, of all the unfavourable options for the development of events, acquires the largest of the minimum values);

$$A^* = \max_{A_i}\left\{\min_{\lambda_j} u_{ij}\left(A_i, \lambda_j\right)\right\}$$

• Laplace criterion : (maximax – the choice of the alternative, which of all the most favorable situations of the development of events has the most of the maximum values);

$$A^* = \max_{A_i} \left\{ \frac{1}{m} \sum_{j=1}^{n} u_{ij} \left(A_i, B_j\right) \right\}$$

B_j – factor of set of factors { λ }

• Hurwicz criterion: (the “optimism-pessimism” criterion, built on the interaction of the maximax and maximin rules, connecting the maximum of the minimum values of the alternatives).

$$A^* = \max_{A_i} \left\{ \alpha \max_{B_j} u_{ij} \left(A_i, B_j\right) + \left(1 - \alpha\right) \min_{B_j} u_{ij} \left(A_i, B_j\right) \right\}$$

α – optimism-pessimism coefficient, £ α 3 1, 0 – extreme of pessimism and 1 – extreme of optimism.

2.2 Expert Judgment Method

In the aviation industry, every mistake made can cost lives, so new or improved methods and approaches to ensure the safety and reliability of flights are constantly launched in this industry, for example, the Expert Judgement Method (EJM). The EJM is a process of interviewing a qualified group of experts (4–8 people) to analyze and assess possible situations or risks.

Such a method is effective for analyzing events or accidents to investigate and determine causes and effects. Qualified experts can assess the risks that may occur on a specific route and on a specific flight, and reduce these risks by applying rules and procedures accordingly. EJM makes it possible to choose the criteria for the optimal decision options in emergency situations.

The availability of sufficient knowledge of the expert in the research topic and the ability to give correct and quick answers is a necessary condition for the application of expert evaluation methods. A good expert is considered to be a person who is in a relevant position or has a scientific degree, as well as a long experience in a specific field. Such characteristics will help create a group of specialists with extensive practical experience.

There are 7 stages and conducting analysis and obtaining results based on EJM:

1. The goals and object of the research are determined.
2. A group of qualified experts is created
3. It is determined how the survey will be conducted and according to what criteria.
4. Creating a survey questionnaire.
5. Conducting a survey.
6. Summary and analysis of results received from experts.
7. Summarizing the results and choosing the best solution option to achieve the goal.

The questionnaire method is a method in which experts are provided with a questionnaire with questions to which experts must answer in writing. Although this method is quite convenient to use, it also has disadvantages. For example, an expert may not understand a question, give an unclear answer, or even not express his opinion.

The EJM is one of the methods of solving multi-criteria problems. There is an algorithm for EJM:

1. Matrix of group preferences Rij, I = 1, ... m, j = 1, n
2. Determine the opinion of the group of experts – Rgrj:

$$R_{grj} = \frac{\sum_{i=1}^{m} R_i}{m}$$

3. Determine the coordination of the opinion of experts:

a) Dispersion:

$$Dj = \frac{\sum_{i=1}^{m} \left(R_{grj} - R_i\right)^2}{m-1}$$

b) Square average deviation:

$$\sigma_j = \sqrt{D_j}$$

c) Coefficient of the variation:

$$\nu_j = \frac{\sigma_j}{R_{gri}} \bullet 100\%$$

If during calculations we get a coefficient of variation of less than 33%, then the opinion of the experts is agreed, and if it is more than 33% - the opinion of the experts is not agreed. In this case, you need to calculate the Kendall concordance coefficient.

4. Kendall's coefficient of concordance:

$$W = \frac{12S}{m^2(n^3 - n) - m\sum_{j=1}^{m} T_j}$$

$$S = \sum(\sum_{i=1}^{m} R_{ij} - \bar{R})^2$$

$$T_j = \sum(t_i^3 - t_i),$$

Where S – is generalized dispersion, T_j – is the number of the same ranks in the j-th row, and fixed the j-th expert.

Kendall's coefficient of concordance has the limit. It should be within the limit 0,7<W≤1. If W is less then 0,7 it needs repeated questioning.

5. Compare the system of advantages R_{gr} and R_i using the rating correlation coefficient R_s (Spearman coefficient):

$$R_{si} = 1 - \frac{6\sum_{j=1}^{n}(x_{ij} - y_{ij})^2}{n(n^2 - 1)}.$$

6. Value of calculations:

Criterion – χ^2

$$\chi_f^2 = \frac{S}{\frac{1}{2}m(n+1) - \frac{1}{12(n-1)}\sum_{j=1}^{m} T_j} > \chi_t^2$$

Where χ_f^2 – factual value of variable, χ_t^2 – table value of variable.

The significance of the calculations R_s for using Student's t – criterion:

$$t_{critical} = r_s \sqrt{\frac{n-2}{1-r_s^2}} > t_{st}$$

7. Weight coefficient w_j of the complexity of the j-zone:

$$w_j = \frac{C_j}{\sum_{j=1}^{n} C_j}; \sum_{j=1}^{n} w_j = 1$$

8. Graphic representation of weighting factors.

The survey procedure, in which experts provide their results for processing and their reasoning, encourages experts to critically rethink their conclusions. During the survey, the anonymity of experts' answers is ensured.

Conclusion to chapter 2

In this chapter, research methods of collaborative decision-making in conditions of certainty, risk and uncertainty were considered. These methods are used in various industries, so their use will be appropriate and effective. By applying these methods, the UAV operator and ATC can quickly find a correct solution to the existing problem.

The method of EJM, as a method of group decision-making, was also considered. This method makes it possible to evaluate all the opinions of qualified experts and form the right decision based on their results.

CHAPTER 3. MODELING OF COLLABORATIVE DECISION-MAKING IN THE CONDITIONS OF A BIRD STRIKE IN FLIGHT OF UAV ON THE ROUTE «CHERNIVTSI-KYIV»

3.1 Modeling of CDM under conditions of certainty using a network graph

In case of an in-flight emergency with a UAV, such as a bird strike on a UAV, the actions of the air traffic controller and the UAV operator must be carried out strictly according to the established work algorithm, although in some cases these actions may vary. Taking into account ASSIST, a list of necessary actions of the air traffic controller, given in the Table 3.1.

Table 3.1 – List of necessary actions of ATC

№	Operating procedure	Description of the procedure
1.	A_1	Receive a bird strike message from the UAV operator
2.	A_2	Confirm receipt of information
3.	A_3	Establish whether the UAV operator is capable of operating an unmanned aerial vehicle
4.	A_4	Separate the UAV from other vehicles, determine its priority for landing
5.	A_5	Establish a corridor for UAVs for emergency landing in the event of a bird strike
6.	A_6	Inform the UAV operator about the nearest suitable place for landing
7.	A_7	Inform the landing aerodrome
8.	A_8	Support the operator controlling the UAV that encountered the bird with any information requested and necessary
9.	A_9	Notify other ATS authorities about the emergency situation
10.	A_{10}	Regularly check the presence of birds near the landing place
11.	A_{11}	In case of persistent bird activity, the controller should raise the NOTAM and cancel when the threat has passed

Using data from Table 3.1 on the actions of the air traffic controller in the special situation of a bird strike, it can be build a block diagram of the algorithm of actions, which is presented in the Figure 3.1.

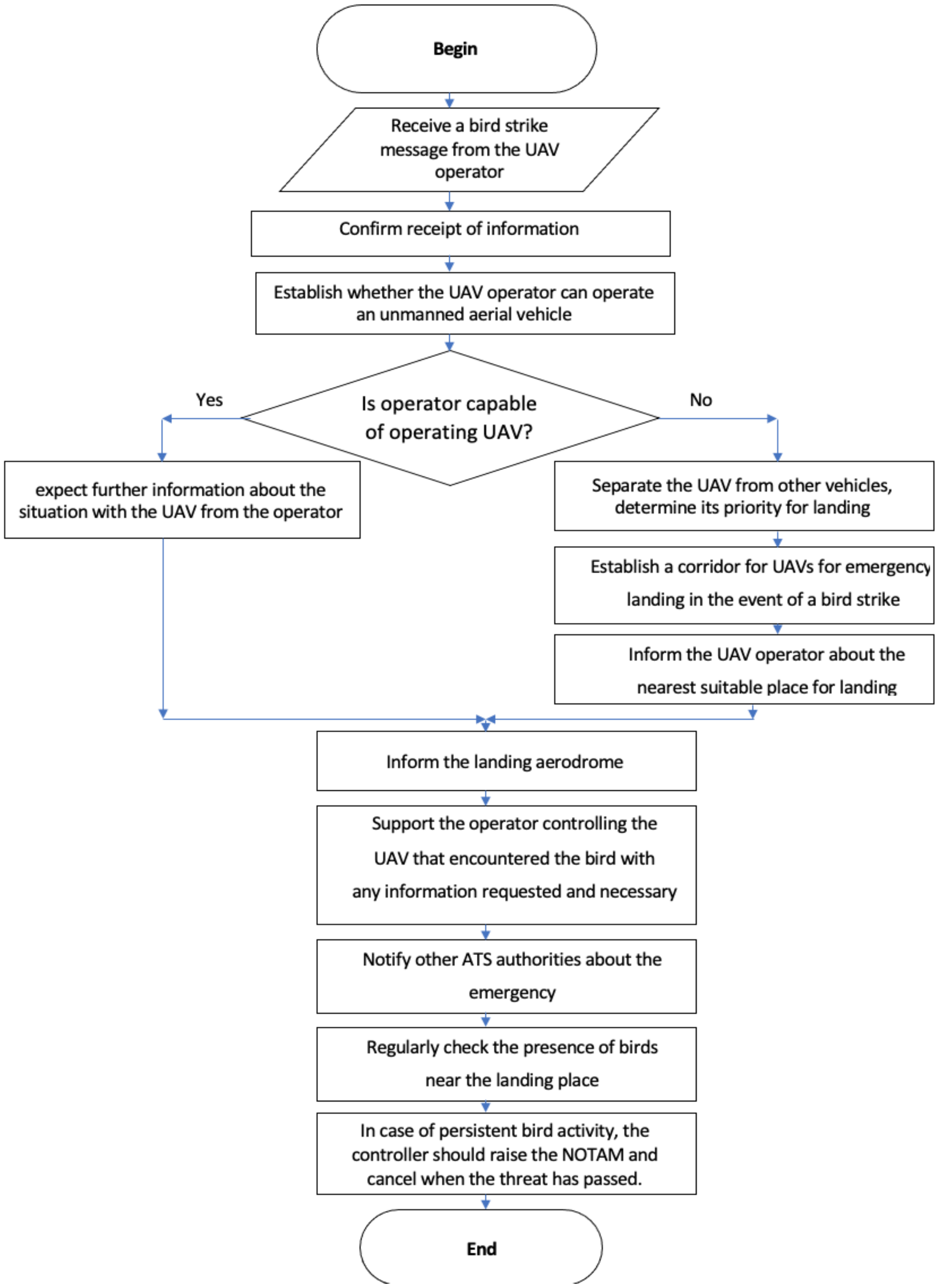


Figure 3.1 – Block diagram of the algorithm of actions ATC during bird strike

It is also necessary to pay attention and consider the technology of the necessary actions of the UAV operator in the event of a bird strike (Table 3.2).

Table 3.2 – List of necessary actions of UAV operator

№	**Operating procedure**	**Description of the procedure**
1.	A_1	To determine the type of emergency – bird strike
2.	A_2	To determine the type of UAV
3.	A_3	To evaluate critical time of flight
4.	A_4	To define UAV field range
5.	A_5	To check whether there is control over UAV
6.	A_6	To try to land UAV on any suitable place
7.	A_7	Transfer to the ATC unit place of UAV's crashing

Using data from Table 3.2 on the actions of UAV operator in the special situation of a bird strike, it can be build a block diagram of the algorithm of actions, which is presented in the Figure 3.2.

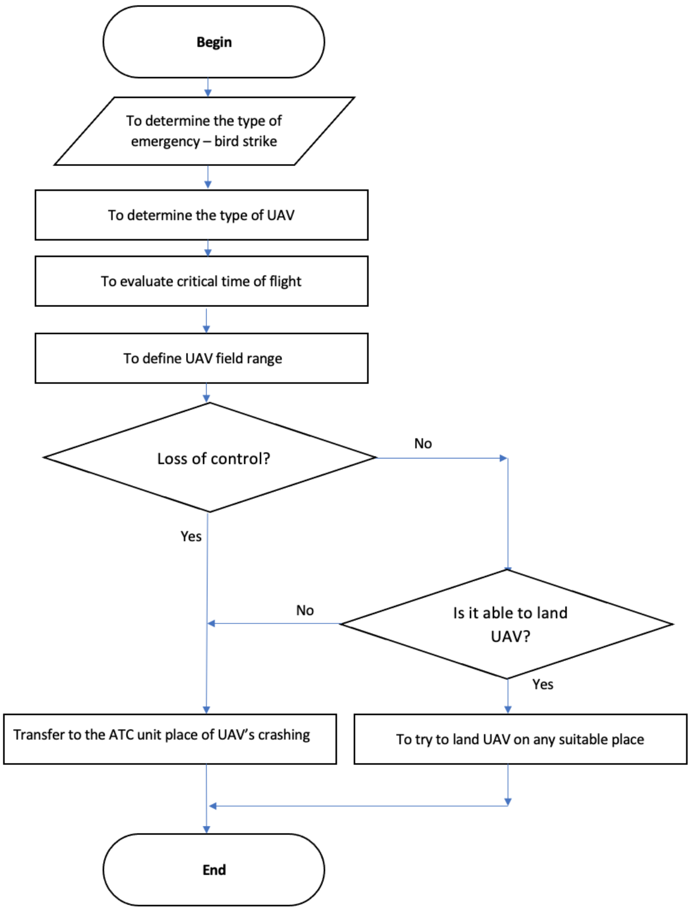


Figure 3.2 – Block diagram of the algorithm of actions UAV operator

In order to determine the time required to perform each procedure from the algorithm of actions of the air traffic controller and UAV operator in times of bird strike, EJM can be used. Having taken 5 qualified ATCs and 5 qualified UAV operators, will make a questionnaire according to EJM and determine the execution time of each action from the algorithms. The results of the questionnaire are entered in two structural Table 3.3-3.4.

Table 3.3 – Determining the duration of actions of ATC

Experts	**Duration of actions (sec)**										
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}
1.	14	10	11	10	10	8	10	13	9	11	13
2.	13	13	12	13	12	15	16	11	8	5	9
3.	11	11	13	12	8	9	9	7	10	9	10
4.	12	15	9	14	7	9	11	6	7	12	8
5.	9	9	12	9	9	8	7	9	9	8	9
R_{gr}	***11,8***	***11,6***	***11,4***	***11,6***	***9,2***	***9,8***	***10,6***	***9,2***	***8,6***	***9***	***9,8***

Table 3.4 – Determining the duration of actions of UAV operator

Experts	**Duration of actions (sec)**						
	A_1	A_2	A_3	A_4	A_5	A_6	A_7
1.	10	9	14	10	8	9	5
2.	9	7	7	9	12	14	10
3.	11	10	9	12	8	9	9
4.	12	13	11	8	10	10	10
5.	8	9	12	11	9	8	9
R_{gr}	***10***	***9,6***	***10,6***	***10***	***9,4***	***10***	***8,6***

After analyzing the results obtained from each group of experts (Table 3.3-3.4), it is possible to calculate the variance, the standard deviation and the coefficient of variation, which are placed in table 3.5-3.6.

Table 3.5 – The result of a survey of qualified ATCs

	Operating procedure										
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}
R_{gr}	11,8	11,6	11,4	11,6	9,2	9,8	10,6	9,2	8,6	9	9,8
D_i	3,7	5,8	2,3	4,3	3,7	8,7	11,3	8,2	1,3	7,5	3,7
σ_i	1,92	2,40	1,51	2,07	1,92	2,94	3,36	2,86	1,14	2,73	1,92
V_i, %	16,30	20,76	13,30	17,87	20,90	30,09	31,71	31,12	13,25	30,42	19,62

Table 3.6 – The result of a survey of qualified UAV operators

	Operating procedure						
	A_1	A_2	A_3	A_4	A_5	A_6	A_7
R_{gr}	10	9,6	10,6	10	9,4	10	8,6
D_i	2,5	4,8	7,3	2,5	2,8	5,5	4,3
σ_i	1,58	2,19	2,70	1,58	1,67	2,34	2,07
V_i, %	15,81	22,82	25,48	15,81	17,80	23,45	24,11

Since the correlation coefficient does not exceed 33%, we can conclude that the opinions of qualified experts are fully agreed. Structure-time tables 3.7-3.8 are given below with the time required to perform each action of ATC and UAV operator.

Table 3.7 – Structure-time table of actions of ATC

№	Description	Procedure	The sequence of the procedure	Duration, sec
1.	Receive a bird strike message from UAV operator	A_1	-	11,8
2.	Confirm receipt of information	A_2	A_1	11,6
3.	Establish whether the UAV operator is capable of operating an unmanned aerial vehicle	A_3	A_2	11,4

№	Description	Procedure	The sequence of the procedure	Duration, sec
4.	Separate the UAV from other vehicles, determine its priority for landing	A_4	A_3	11,6
5.	Establish a corridor for UAVs for emergency landing in the event of a bird strike	A_5	A_3, A_4	9,2
6.	Inform the UAV operator about the nearest suitable place for landing	A_6	A_3, A_4, A_5	9,8
7.	Inform the landing aerodrome	A_7	A_5, A_6	10,6
8.	Support the operator controlling UAV that encountered the bird with any information requested and necessary	A_8	A_7	9,2
9.	Notify other ATS authorities about the emergency	A_9	A_8	8,6
10.	Regularly check the presence of birds near the landing place	A_{10}	A_9	9
11.	In case of persistent bird activity, the controller should raise the NOTAM and cancel when the threat has passed	A_{11}	A_{10}	9,8

Table 3.8 – Structure-time table of actions of UAV operator

№	Description	Procedure	The sequence of the procedure	Duration, sec
1.	To determine the type of emergency – bird strike	A_1	-	10
2.	To determine the type of UAV	A_2	A_1	9,6

№	Description	Procedure	The sequence of the procedure	Duration, sec
3.	To evaluate critical time of flight	A_3	A_2	10,6
4.	To define UAV field range	A_4	A_2, A_3	10
5.	To check whether there is control over UAV	A_5	A_2, A_3, A_4	9,4
6.	To try to land UAV on any suitable place	A_6	A_5	10
7.	Transfer to the ATC unit place of UAV's crashing	A_7	A_5	8,6

Next step is to build two network graphs (Figure 3.3-3.4) in order to calculate the critical time required to perform actions by the air traffic controller and the UAV operator in an emergency – a bird strike.

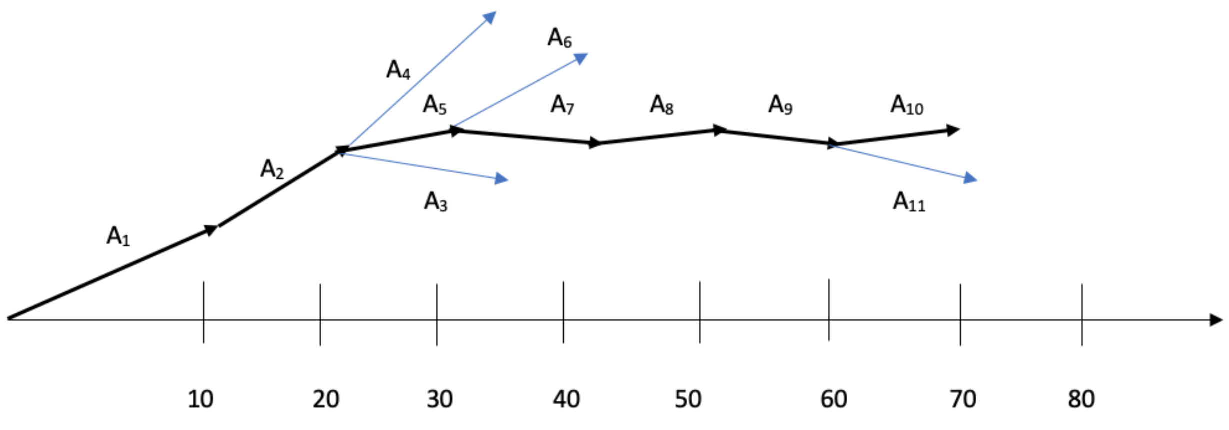


Figure 3.3 – Network graph of actions of ATC

From the received network schedule of actions of the air traffic controller, it can be determined that the critical time in the event of a bird strike is – 58,6 seconds. Critical path – A_1, A_2, A_5, A_7, A_8, A_9, A_{10}.

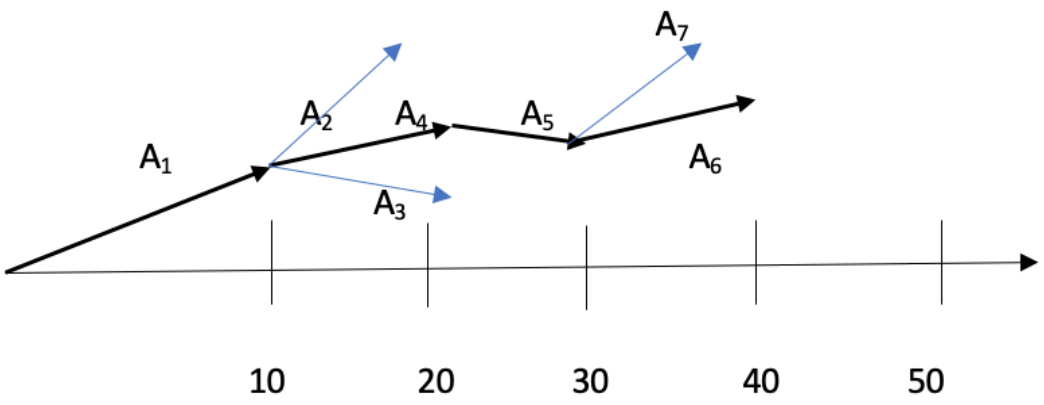


Figure 3.4 – Network graph of actions of UAV operator

From the received network schedule of actions of operator UAV, it can be determined that the critical time in the event of a bird strike is – 39,4 seconds. Critical path – A_1, A_4, A_5, A_6.

3.2. Modeling of CDM under conditions of uncertainty

The first step in order to illustrate the construction of CDM in the case of bird strike on the Chernivtsi (A_1)-Kyiv (Boryspil) (A_6) route is to identify alternative airports. I took alternative airports in such cities as:

1. Chernivtsi (UKLN) – A_1, landing at the airport of departure;
2. Khmelnytskyi (UKMH) – A_2;
3. Vinnitsa (UKWW) – A_3;
4. Zhuliany (UKKK) – A_4;
5. Bila Tserkva (UKBC)– A_5;
6. Boryspil (UKBB) – A_6, landing at the destination airport.

Target task: cargo delivery from Chernivtsi to Kyiv using UAV.

The route of flight from Chernivtsi to Boryspil in navigation map is presented on Figure 3.5. and is marked with blue line. All alternative airports are marked with red circles on this figure.

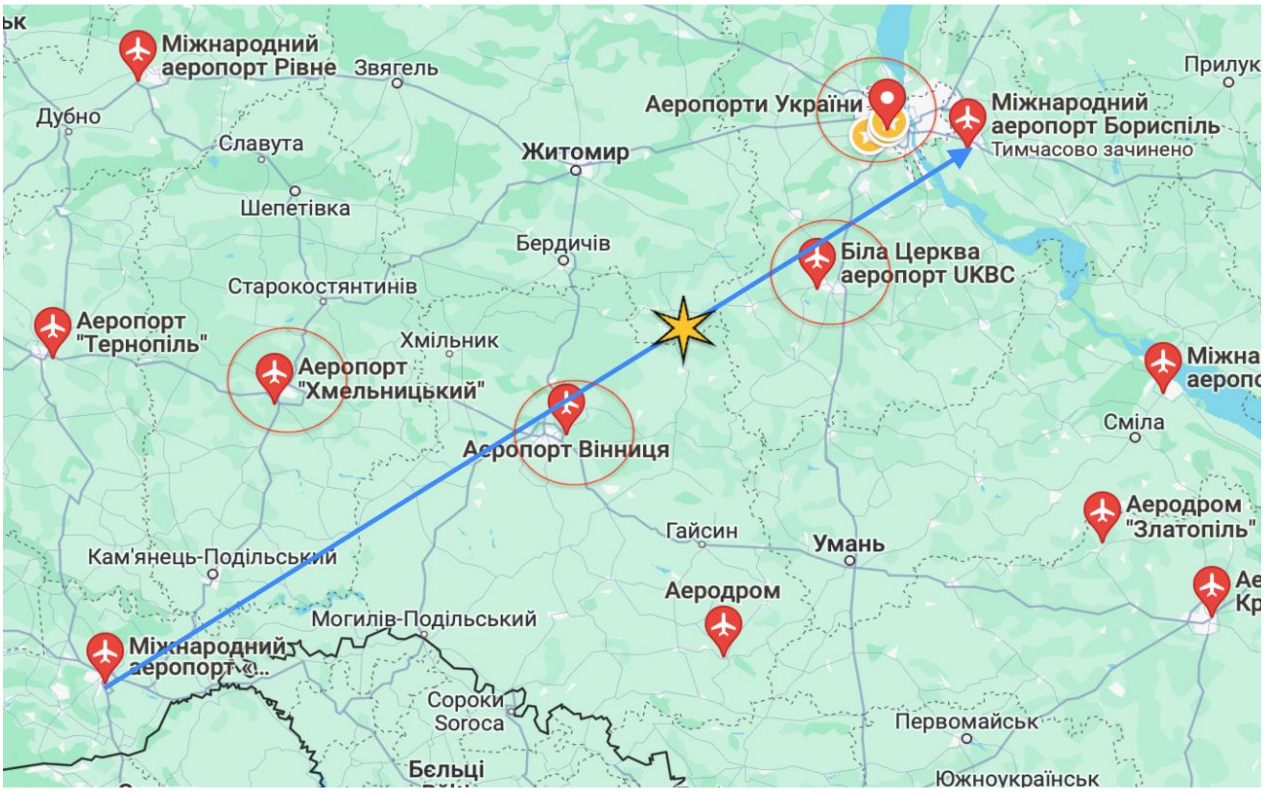


Figure 3.5 – Schematic presentation of flight route

In order to develop CDM, it will be simulate a non-standard situation in flight – a bird strike on a UAV traveling along the route Chernivtsi – Boryspil (collision between UAV and bird is marked with yellow icon).

For rational CDM, each operator has analyzed and considered the current situation. There are three operators in the CDM process: UAV operator (O_1), ATCO (O_2), pilot of the manned aircraft (O_3). Factors influencing DM for each operator:

- {f} – factors considered by operator O_1 (UAV operator);
- {l} – factors considered by operator O_2 (ATCO);
- {λ} – factors considered by operator O_3 (pilot of the manned aircraft).

Each operator has composed a matrix of decisions, where alternative solutions are alternative SA for the route Chernivtsi (A_1) – Boryspil (A_6), and each operator has taken into account the same factors in the current situation, but with different priorities. When choosing an optimal alternative, each operator is guided by the common factors:

- (f_1, l_1, λ_1 –meteorological conditions on ADep, ADest, SA;
- f_2, l_2, λ 2 – distance from UAV to ADep, ADest, SA;
- f_3, l_3, λ_3 – technical characteristics of ADep, ADest, SA;

- f_4, l_4, λ_4 – availability of fuel/energy onboard of UAV;
- f_5, l_5, λ_5 – reliability of C2 lines for connection with UAV;
- f_6, l_6, λ_6 – possibility of communication with ATC units;
- f_7, l_7, λ_7 – other factors (logistics, aeronautical fees, priority of UAV).[15]

These factors are objective. The DM matrixes for operators in emergency “Bird strike on the UAV” are shown in Tables 3.9-3.11. The results of decision-making by UAV operator (O_1) under conditions of uncertainty are shown in the Table 3.9.

Table 3.9 – The DM matrix in uncertainty for UAV operator (O_1)

Alternative Aerodrome {A}	**Factors influence DM for UAV operator**										
	f1	*f2*	*f3*	*f4*	*f5*	*f6*	*f7*	Wald	Laplac	Hurwi	Savag
A_1- Chernivtsi	8	3	0	8	5	8	7	0	5,5	4	8
A_2- Khmelnytskyi	3	5	8	4	9	2	5	2	5,1	5,5	9
A_3- Vinnitsa	3	9	1	7	4	3	3	1	4,2	5	9
A_4- Zhuliany	6	6	9	9	6	7	6	6	7	7,5	9
A_5- Bila Tserkva	5	6	8	7	2	4	10	2	6	6	10
A_6- Boryspil	4	3	7	5	8	7	5	3	5,5	5,5	8

The optimal alternative airport on the route Chernivtsi-Boryspil according to the UAV operators is Zhuliany airport (UKKK) - marked with blue color in the matrix- by Wald, Laplace and Hurwitz criterions, Bila Tserkva (UKBC) by Savage criterion.

The results of decision-making by ATC (O_2) under conditions of uncertainty are shown in the Table 3.10.

Table 3.10 – The DM matrix in uncertainty for ATC (O_2)

Alternative Aerodrome {A}	**Factors influence DM for ATC**										
	f1	*f2*	*f3*	*f4*	*f5*	*f6*	*f7*	Wald	Laplac	Hurwi	Savage
A_1- Chernivtsi	4	6	2	8	8	6	1	1	5	4,5	8
A_2- Khmelnytskyi	5	6	7	4	8	4	4	4	6,1	6,5	8
A_3- Vinnitsa	5	4	3	8	5	4	2	2	4,4	5	8
A_4- Zhuliany	9	7	7	8	6	5	5	5	7,1	7	9
A_5- Bila Tserkva	10	5	8	8	9	7	5	5	7,8	7,5	10
A_6- Boryspil	5	7	4	3	9	5	3	3	5,7	6	9

The optimal alternative airport on the route Chernivtsi-Boryspil according to the ATC is Bila Tserkva (UKBC) by Wald, Laplace, Hurwitz and Savage criterions and Zhuliany airport (UKKK) by Wald criterion - marked with blue color in the matrix.

The results of decision-making by pilot of the manned aircraft (O_3) under conditions of uncertainty are shown in the Table 3.11.

Table 3.11 – The DM matrix in uncertainty for pilot of the manned aircraft (O_3)

Alternative Aerodrome {A}	**Factors influence DM for pilot**										
	f1	*f2*	*f3*	*f4*	*f5*	*f6*	*f7*	Wald	Laplac	Hurwi	Savag
A_1- Chernivtsi	4	7	3	8	4	6	1	1	4,7	4,5	8
A_2- Khmelnytskyi	8	9	10	7	8	8	9	7	8,4	8,5	10
A_3- Vinnitsa	4	5	3	7	5	7	7	3	5,4	5	7
A_4- Zhuliany	3	7	10	4	3	6	6	3	5,5	6,5	10

Alternative Aerodrome {A}	Factors influence DM for pilot										
	f1	*f2*	*f3*	*f4*	*f5*	*f6*	*f7*	Wald	Lapla	Hurwi	Savag
A_5- Bila Tserkva	7	8	8	9	9	9	9	7	8,4	8	9
A_6- Boryspil	5	6	3	2	7	8	8	2	5,5	5	8

The optimal alternative airport on the route Chernivtsi-Boryspil according to the pilot of the manned aircraft is Khmelnytskyi (UKMH) by Wald, Laplace, Hurwitz and Savage criterions and Bila Tserkva (UKBC) by Wald and Laplace criterion and Zhuliany (UKKK) by Savage criterion - marked with blue color in the matrix.

To determine the consistency of operators, collective matrixes were constructed, in which the factors in the decision matrixes for the operators (UAV operator (O_1), ATCO (O_2), pilot of the manned aircraft (O_3)) and are identical, the solutions of the operators and are taken from matrixes, presented in Tables 3.9-3.11. In the CDM matrixes, the subjective factors – opinions of operators are using. The optimal CDM for all operators is presented in Table 3.12. In this case, the optimal landing aerodrome is determined on both the objective and subjective factors.[14]

Table 3.12 – The CDM matrix for all operators

Alternative Aerodrome {A}	Operators/solutions															
	O_1	O_2	O_3	***W***	O_1	O_2	O_3	***L***	O_1	O_2	O_3	***H***	O_1	O_2	O_3	***S***
A_1- Chernivtsi	0	1	1	0	5,5	5	4,7	5	4	4,5	4,5	4,25	8	8	8	8
A_2- Khmelnytskyi	2	4	7	2	5,1	6,1	8,4	6,5	5,5	6,5	8,5	7	9	8	10	10
A_3- Vinnitsa	1	2	3	1	4,2	4,4	5,4	4,6	5	5	5	5	9	8	7	9

Alternative Aerodrome {A}	**Operators/solutions**															
	O_1	O_2	O_3	***W***	O_1	O_2	O_3	***L***	O_1	O_2	O_3	***H***	O_1	O_2	O_3	***S***
A₄- Zhuliany	6	5	3	3	7	7,1	5,5	6,5	7,5	7	6,5	7	9	9	10	10
A₅- Bila Tserkva	2	5	7	2	6	7,8	8,4	7,4	6	7,5	8	7	10	10	9	10
A₆-Boryspil	3	3	2	2	5,5	5,7	5,5	5,5	5,5	6	5	5,5	8	9	8	9

The optimal CDM in case of bird strike on the route Chernivtsi (A_1) – Boryspil (A_6) based on DM of UAV operator, ATC and pilot of the manned aircraft is as follows (red color in the matrix): by Wald criterion –Zhuliany (A_4); by Laplace criterion –Bila Tserkva (A_5); by Hurwitz criterion – Khmelnytskyi (A_2), Zhuliany (A_4) and Bila Tserkva (A_5); by Savage criterion - Khmelnytskyi (A_2), Zhuliany (A_4) and Bila Tserkva (A_5).

3.3. Modeling of CDM under conditions of risk

In order to carry out a structural analysis of this problem and find a correct alternative solution under risk conditions, and especially in the case of an emergency situation such as a bird strike on a UAV, it is necessary to depict the technology and sequence of actions of the air traffic controller and the UAV operator in the form of a decision tree.

To begin with, we determine all the stages of solving the situation in order to make a structural analysis. The first stage in solving this situation will be an emergency landing, the second stage will be the selection of an airfield, the third stage will be the selection of either an alternative or an airfield for an emergency landing, the fourth stage will be the selection of the nearest most suitable unequipped place for landing, and the final stage will be the selection of the nearest equipped airfield. The Table 3.13 shows data for building a decision tree.

Table 3.13 – Data for building a decision tree

Type of situation	**Probability of losses**			
	p_1=0,3		p_2=0,7	
Landing at the destination airport	U_{21}	9	U_{22}	4
Alternative airport	U_{31}	5	U_{32}	5
The nearest most suitable unequipped place	U_{51}	2	U_{52}	8
The nearest equipped airport	U_{61}	4	U_{61}	6

These data were obtained using EJM and based on them we will build a decision tree in accordance with our case - a bird strike on a UAV. The decision tree is shown in the Figure 3.6.

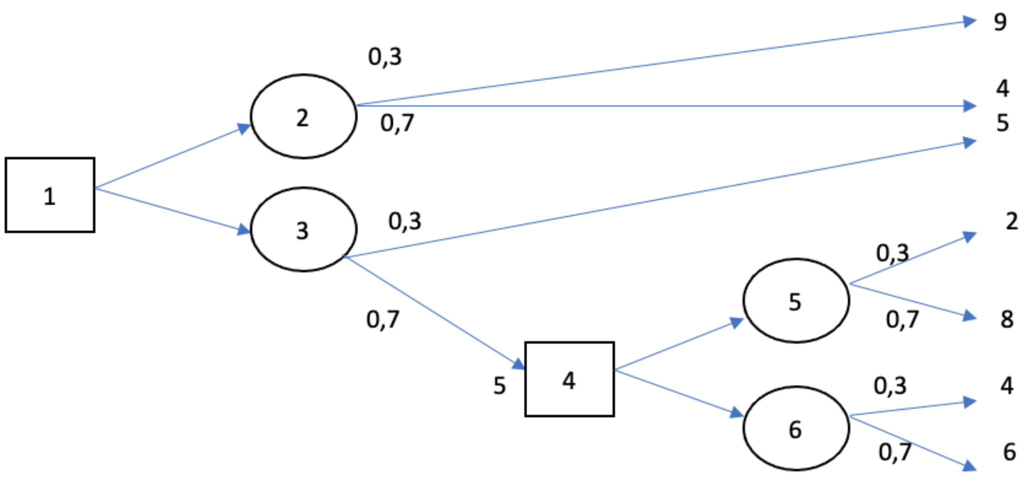


Figure 3.6 – The decision tree

Where:

2- Landing at the destination airport;

3- Alternative airport;

4- The nearest airport;

5- The nearest most suitable unequipped place;

6- The nearest equipped airport.

Knowing that p_1 is the probability that the landing will be successful, and p_2 is the probability of an emergency landing, and having determined using the *U* (loss) method, it can be calculated *R* (risks) based on the obtained results. For this, we will use the following formulas(3.1-3.4):

$$R_2=(p_1*U_{21})+(p_2*U_{22}); \qquad (3.1)$$

$$R_3=(p_1*U_{31})+(p_2*U_{32}); \qquad (3.2)$$

$$R_5=(p_1*U_{51})+(p_2*U_{52}); \qquad (3.3)$$

$$R_6=(p_1*U_{61})+(p_2*U_{62}). \qquad (3.4)$$

Using these formulas we can find R_2, R_3, R_5, R_6.

$R_2=(0,3*9)+(0,7*4)=5,5;$

$R_3=(0,3*5)+(0,7*5)=5;$

$R_5=(0,3*2)+(0,7*8)=6,2;$

$R_6=(0,3*4)+(0,7*6)=5,4.$

Since *A* is the optimal alternative solution in this situation, so determine that A_1-$R_3=5$ and A_4-$R_6=5,4$.

So, after analyzing the obtained data, I can conclude that the optimal solution with minimal losses in the event of a bird strike on a UAV is to land on the nearest equipped airport.

It can be created a new decision tree (Figure 3.7) and mark in red the optimal solution for the UAV operator/manned aircraft pilot in case of an emergency – a bird strike.

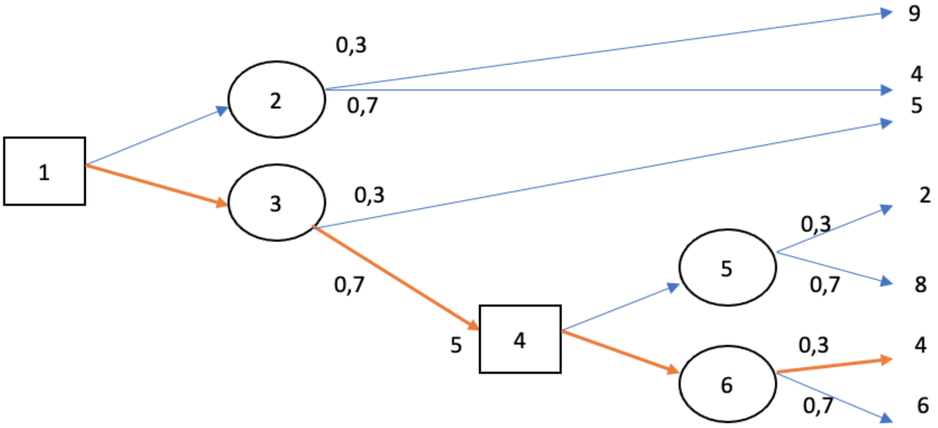


Figure 3.7 – The decision tree in case of emergency – bird strike

A feature of the remote pilot (operator UAV) activity is the low situational awareness of the external environment due to this absence on board the aircraft therefore he must intetact with both the ATCO and the pilots of manned aircraft.[17]

Conclusion to chapter 3

In this chapter, an analysis of collaborative decision-making by an air traffic controller, a UAV operator and pilot of the manned aircraft in an emergency situation - a bird strike - is carried out. The chapter describes the application of various collaborative decision-making methods and simulates an example of decision-making under conditions of certainty, uncertainty and risk. The technology of the actions of the air traffic controller and the UAV operator in the event of a bird strike has been developed. This technology was analyzed by the method of network planning. As a result, we found that the critical decision-making time for the air traffic controller is 58.6 seconds and the critical decision-making time for the UAV operator is 39.4 seconds.

Also, a system was developed and a decision tree was built to find the optimal solution for the UAV operator and the pilot of the manned aircraft to perform an emergency landing of the UAV in times of bird strike.

CHAPTER 4. SPECIAL CHAPTER

4.1. Automated processing of large-scale aeronautical data

Automated data processing is a typical task solved by modern air navigation systems. Processing of aeronautical data is provided both on board in certain avionics units and in ground computing complexes. Navigation parameters in modern systems are measured using a significant number of different sensors, which ensure the creation of a data archive, the processing of which requires the use of specialized statistical processing algorithms. Each sensor performs measurements with a certain amount of error, the effect of which cannot be excluded, but it can be reduced to an acceptable level. Therefore, the combined processing of data in the aeronautical system is performed taking into account the effect of the errors of each of the sensors. For this, confidence intervals are used, which guarantee finding a certain interval in the interval with a certain probability [18].

The most commonly used confidence intervals are the double root mean square value, which provides 95% localization of the measured values, based on the assumption of a normal distribution of errors.

Each unit of avionics in its structure is more similar to the architecture of a personal computer with the corresponding elements: processor, memory, analog-to-digital/digital-to-analog converters, which allows processing of measured data at the software level [19]. Sensor data is converted to digital form by sampling analog values. Measurement results are digitally stored in appropriate registers, variables, matrices or data archives.

Determining the exact location of an aircraft is one of the most important tasks of civil aviation [20-22]. The growing volumes of air transportation require a constant review of scheduling norms to meet the growing needs of air transport. The norms of echeloning of the aircraft determine the maximum permissible limits of separation of the aircraft in space in the vertical plane, lateral and longitudinal deviations. The only possible way to solve the issue of airspace congestion is to increase the capacity of a certain part of the airspace by reducing the safe distances between aircraft. In practice, this is implemented by introducing more precise requirements for determining the location of an aircraft in space. The introduction of more precise requirements for the positioning of the aircraft is possible only if there are appropriate systems capable of satisfying them. The functioning of civil aviation aircraft positioning systems is ensured by the field of aeronautical signals created in space by various systems.

As an example of large-dimensional data processing, we will consider the trajectory of the aircraft and perform its calculation using the MATLAB software.

4.1.1.Input data

A modern civil aviation aircraft is equipped with a whole group of various sensors that ensure the determination of the coordinates of the aircraft's location in space. According to the concept of Automatic Dependent Surveillance (ADS-B), airspace users must periodically report their location in space automatically. The most common airborne ADS-B equipment is the mode 1090ES aircraft transponder. The aircraft responder performs functions of automatic generation of digital messages in accordance with the system settings (standard settings ensure the emission of a signal with a frequency of 1 Hz) and performs their emission through omnidirectional antenna systems [23,24]. A shared digital message contains the aircraft's identification, location coordinates, barometric altitude, and other data. The coordinates of the aircraft are obtained from the flight computer system after selecting the optimal positioning system for a certain airspace based on the accuracy provided by the system and the specification requirements that apply in the airspace where the aircraft is located.

A terrestrial network of software-controlled receivers receives and decodes data transmitted according to the ADS-B concept. In particular, the aircraft identification code with location coordinates and barometric altitude is archived in global databases [25, 26]. In particular, computer clusters of Flightradar24 and Flightaware companies provide simultaneous processing of data from more than 30 thousand software-controlled receivers [27] of ADS-B signals located all over the planet (Figure 4.1).

Figure 4.1 – Global traffic map [27]

Access to global databases of trajectory data is open and provided on a commercial basis. The application programming interface allows us to easily get any segment of trajectory data for analysis.

As input, I use flight path data of NOZ555/DY555 (Norwegian Air Shuttle 555) operated by Norwegian Air Shuttle “Norsemann” for connection between Stavanger, Norway (SVG) and Gardermoen, Norway (OSL). Departure date is January 1, 2023 at 09:30PM (CET). Landing date is January 1 at 10:14PM (CET). The flight ended 11 minutes earlier than the scheduled landing time. This flight was performed by Boeing 737-800 (twin-jet) (B738). Table 4.1 shows all rows of flight path data.

Table 4.1 – Trajectory data of flight NOZ555 from January 1, 2023

Time	latitude	longitude	course	kts	mph	feet	Rate	Reporting facility
Sun 03:30:00 PM	**Left Gate (SVG)** @ Sunday 09:30:00 PM **CET** *Revised*							
Taxi Time: 8 minutes								
Sun 03:38:39 PM	**Departure (SVG)** @ Sunday 09:38:39 PM **CET**							FlightAware ADS-B (SVG / ENZV)
Sun 03:38:39 PM	58.8965	5.6374	↑ 360°	155	178	675	Level	FlightAware ADS-B (SVG / ENZV)
Sun 03:38:57 PM	58.9095	5.6372	↑ 360°	163	188	1,200	1,412 Climbing	FlightAware ADS-B (SVG / ENZV)

Sun 03:39:13 PM	58.9233	5.6369	↑ 359°	187	215	1,475	1,172 Climbing	FlightAware ADS-B (SVG / ENZV)
Sun 03:39:29 PM	58.9378	5.6367	↑ 359°	202	232	1,825	1,191 Climbing	FlightAware ADS-B (SVG / ENZV)
Sun 03:39:47 PM	58.9561	5.6367	↑ 360°	230	265	2,150	2,232 Climbing	FlightAware ADS-B (SVG / ENZV)
Sun 03:40:10 PM	58.9804	5.6365	↑ 2°	236	272	3,350	2,714 Climbing	FlightAware ADS-B (SVG / ENZV)
Sun 03:40:29 PM	58.9990	5.6521	↗ 39°	259	298	4,050	3,486 Climbing	FlightAware ADS-B (HAU / ENHD)
Sun 03:40:47 PM	59.0092	5.6891	→ 76°	246	283	5,500	4,425 Climbing	FlightAware ADS-B (HAU / ENHD)
Sun 03:41:09 PM	59.0104	5.7364	→ 89°	244	281	7,000	3,260 Climbing	FlightAware ADS-B (HAU / ENHD)
Sun 03:41:39 PM	59.0101	5.8048	→ 90°	268	308	8,325	2,739 Climbing	FlightAware ADS-B (BGO / ENBR)
Sun 03:41:55 PM	59.0103	5.8467	→ 89°	283	326	9,100	2,361 Climbing	FlightAware ADS-B (SVG / ENZV)
Sun 03:42:40 PM	59.0107	5.9692	→ 90°	333	383	10,725	2,396 Climbing	FlightAware ADS-B (SVG / ENZV)
Sun 03:43:02 PM	59.0134	6.0360	→ 80°	347	399	11,775	3,260 Climbing	FlightAware ADS-B (HAU / ENHD)
Sun 03:43:32 PM	59.0232	6.1283	→ 78°	352	405	13,550	3,075 Climbing	FlightAware ADS-B (HAU / ENHD)
Sun 03:44:02 PM	59.0329	6.2213	→ 79°	366	421	14,850	2,800 Climbing	FlightAware ADS-B (SVG / ENZV)
					…			
Sun 04:04:50 PM	59.9312	10.6663	→ 67°	268	308	7,100	-1,250 Descending	FlightAware ADS-B (OSL / ENGM)
Sun 04:05:20 PM	59.9442	10.7299	→ 68°	262	302	6,425	-1,450 Descending	FlightAware ADS-B (ENEG)
Sun 04:05:50 PM	59.9583	10.7971	→ 67°	262	302	5,650	-1,375 Descending	FlightAware ADS-B (OSL / ENGM)
Sun 04:06:20 PM	59.9726	10.8637	→ 67°	257	296	5,050	-1,000 Descending	FlightAware ADS-B (OSL / ENGM)
Sun 04:06:50 PM	59.9859	10.9260	→ 67°	247	284	4,650	-702 Descending	FlightAware ADS-B (OSL / ENGM)
Sun 04:07:07 PM	59.9954	10.9625	↗ 53°	239	275	4,500	-542 Descending	FlightAware ADS-B (ENKJ)
Sun 04:07:26 PM	60.0143	10.9809	↑ 10°	239	275	4,325	-500 Descending	FlightAware ADS-B (ENKJ)
Sun 04:07:43 PM	60.0321	10.9855	↑ 8°	233	268	4,200	-882 Descending	FlightAware ADS-B (ENKJ)
Sun 04:08:00 PM	60.0476	10.9942	↑ 18°	221	254	3,825	-1,455 Descending	FlightAware ADS-B (OSL / ENGM)

Sun 04:08:16 PM	60.0637	11.0044	↑ 16°	209	241	3,400	-1,213 Descending	FlightAware ADS-B (OSL / ENGM)
Sun 04:08:47 PM	60.0898	11.0191	↑ 16°	183	211	2,875	-1,065 Descending	FlightAware ADS-B (OSL / ENGM)
Sun 04:09:18 PM	60.1137	11.0327	↑ 16°	165	190	2,300	-1,206 Descending	FlightAware ADS-B (OSL / ENGM)
Sun 04:09:38 PM	60.1280	11.0409	↑ 16°	148	170	1,850	-812 Descending	Surface and Near-Surface
Sun 04:10:43 PM	60.1681	11.0642	↑ 16°	131	151	1,150	-667 Descending	FlightAware ADS-B (ENKJ)
Sun 04:10:59 PM	60.1770	11.0691	↑ 16°	135	155	950	-659 Descending	FlightAware ADS-B (OSL / ENGM)
Sun 04:11:24 PM	**Arrival (OSL)** @ Sunday 10:11:24 PM **CET**							FlightAware
Sun 04:11:24 PM	60.1918	11.0776	↑ 16°	136	157	700	-600 Descending	FlightAware ADS-B (OSL / ENGM)
Taxi Time: 8 minutes								
Sun 04:19:42 PM	**Gate Arrival (OSL)** @ Sunday 10:19:42 PM **CET**							Air shuttle

4.1.2. Visualization of trajectory data at specific software

Let`s import trajectory data of NOZ555 from 1th January 2023 into specialized software of MATLAB [28]. Results of trajectory data visualization for flight is represented in Figure 4.2 and vertical profile of flight is in Figure 4.3.

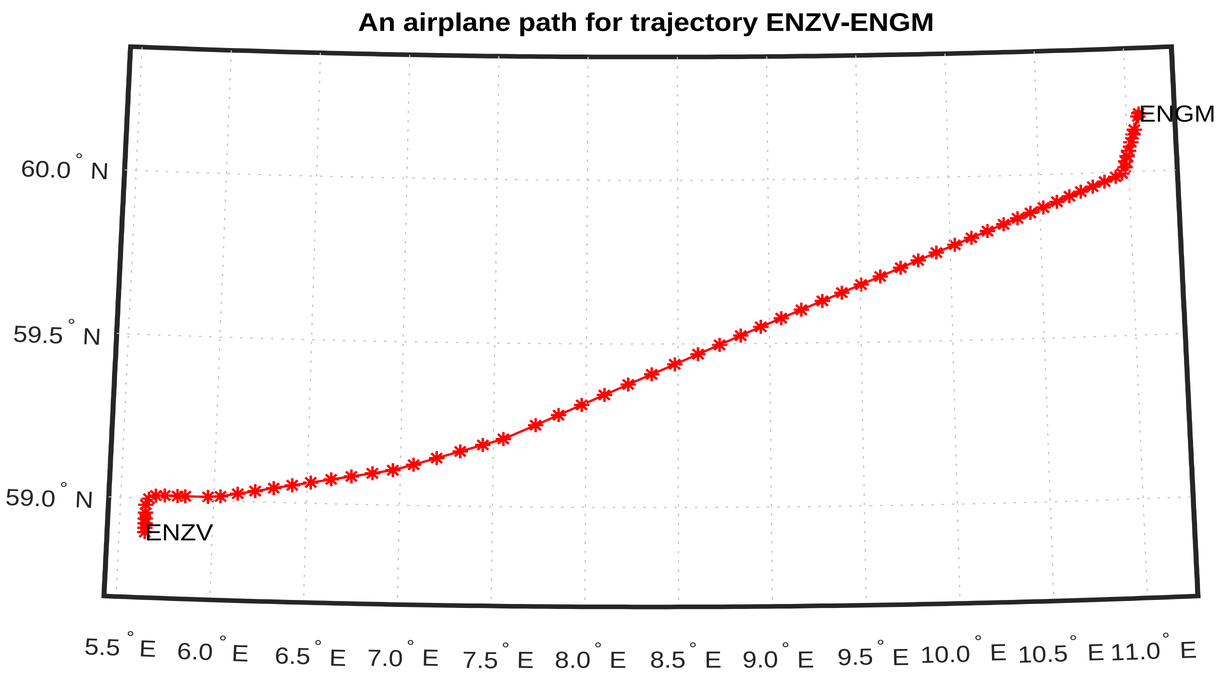


Figure 4.2 – Flight path of NOZ555 (1th January 2023)

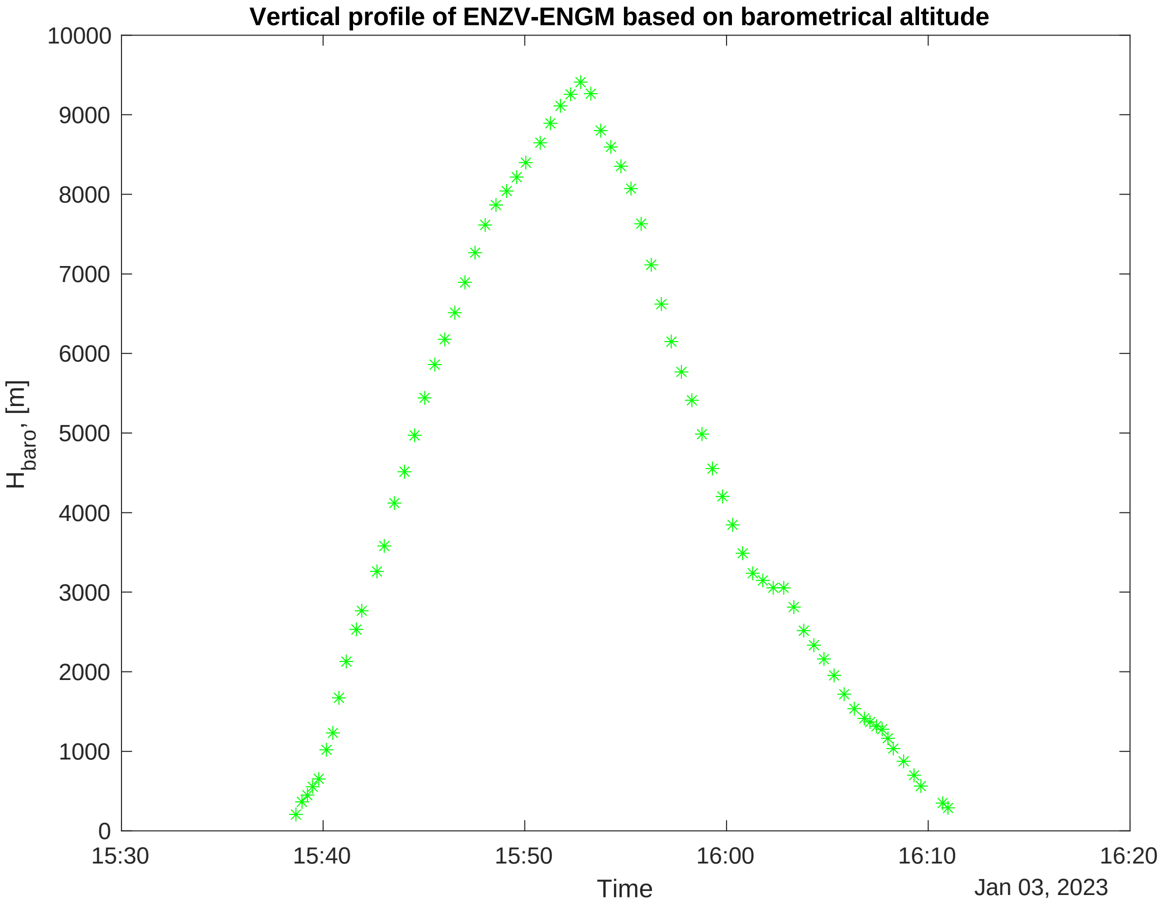


Figure 4.3 – Vertical profile NOZ555 (1th January 2023)

4.1.3. Trajectory data interpolation

The digital messages transmitted within ADS-B are not synchronized in time. A transmitter of each airspace user can be set to its frequency of digital message generation. In addition, it should be noted that the frequency of 1090 MHz is quite busy, since secondary radars, airborne collision and avoidance systems, and ADS-B use it. This leads to the fact that many digital messages may interfere with each other that destroy data transmitted inside of these messages. Therefore ADS-B trajectory data includes many gaps in the sequence and broken messages. At the stage of data processing usually, methods of data interpolation are used to solve this problem. The interpolating function can be polynomials or spline functions. The results of interpolation of input data at a frequency of 1 Hz are shown in Figure 4.4 – 4.6. All subsequent calculations will be performed with interpolated data. Let's display the data in the local NEU system. As the center of the system, we will use the coordinates of the first point of the trajectory. The results of visualization of the trajectory in the local system are shown in Figure 4.7 and Figure 4.8.

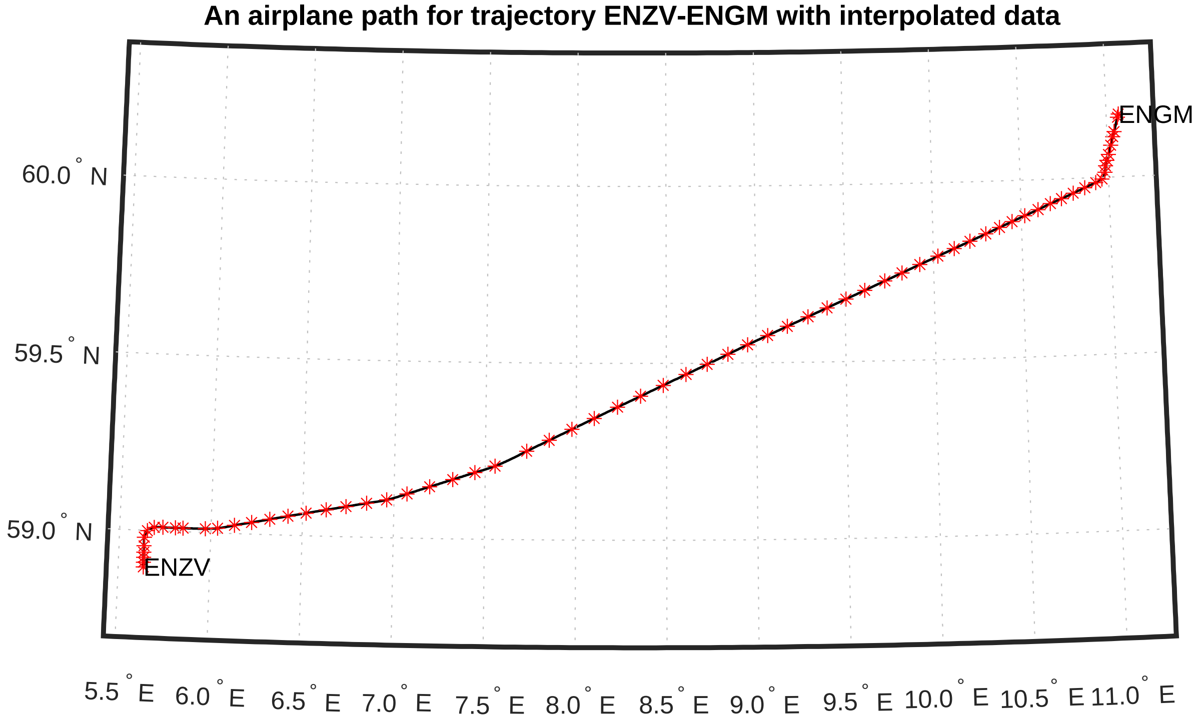


Figure 4.4 – Interpolated airplane trajectory of NOZ555

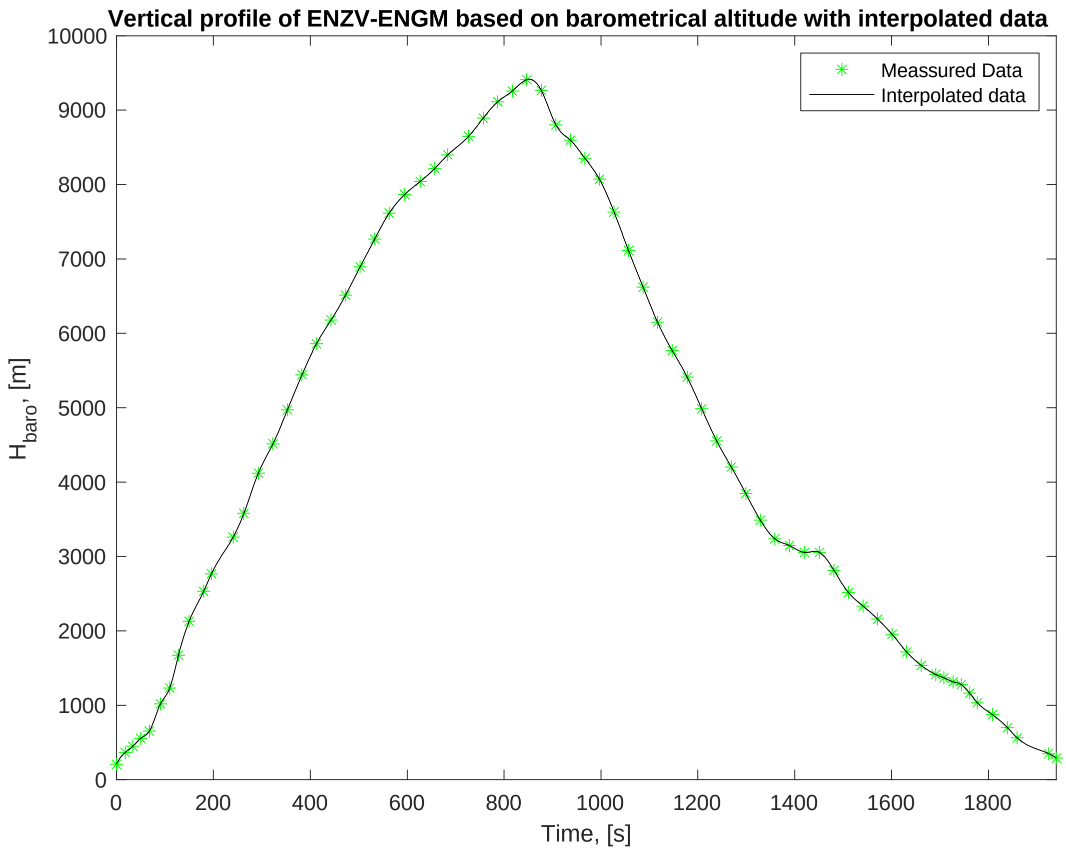


Figure 4.5 – Interpolated vertical profile of NOZ555

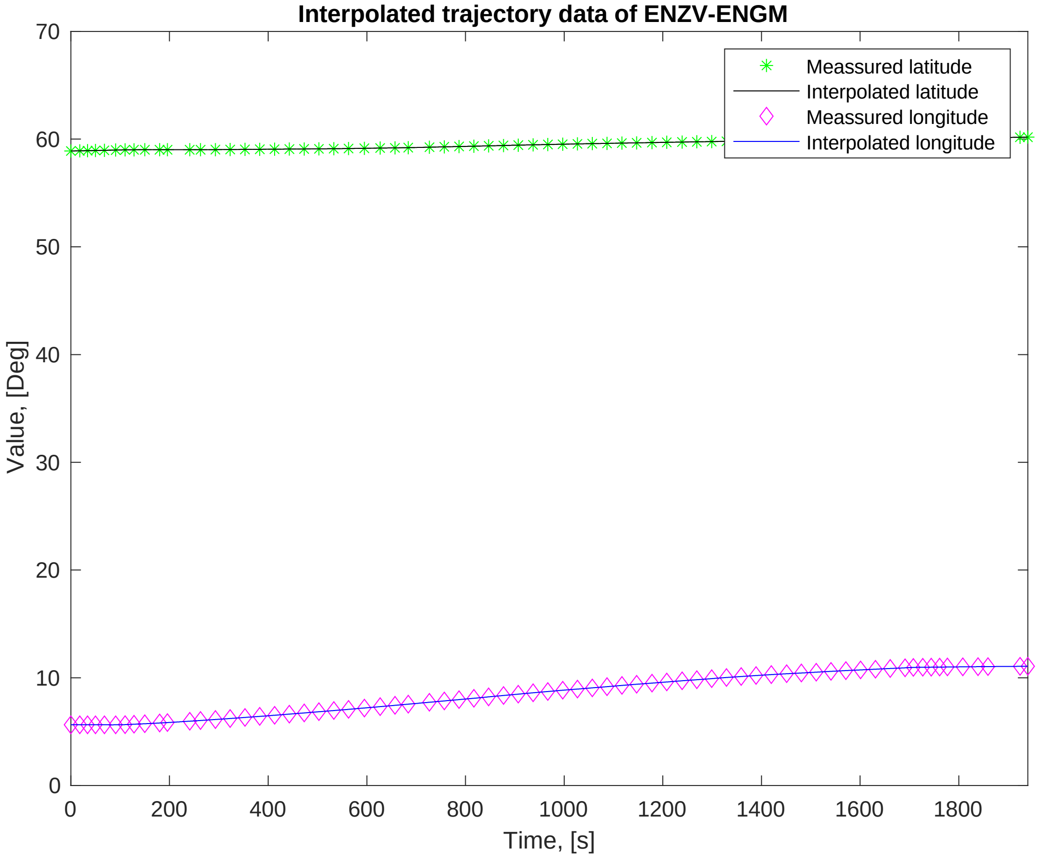


Figure 4.6 – Interpolated data for 1 Hz of NOZ555

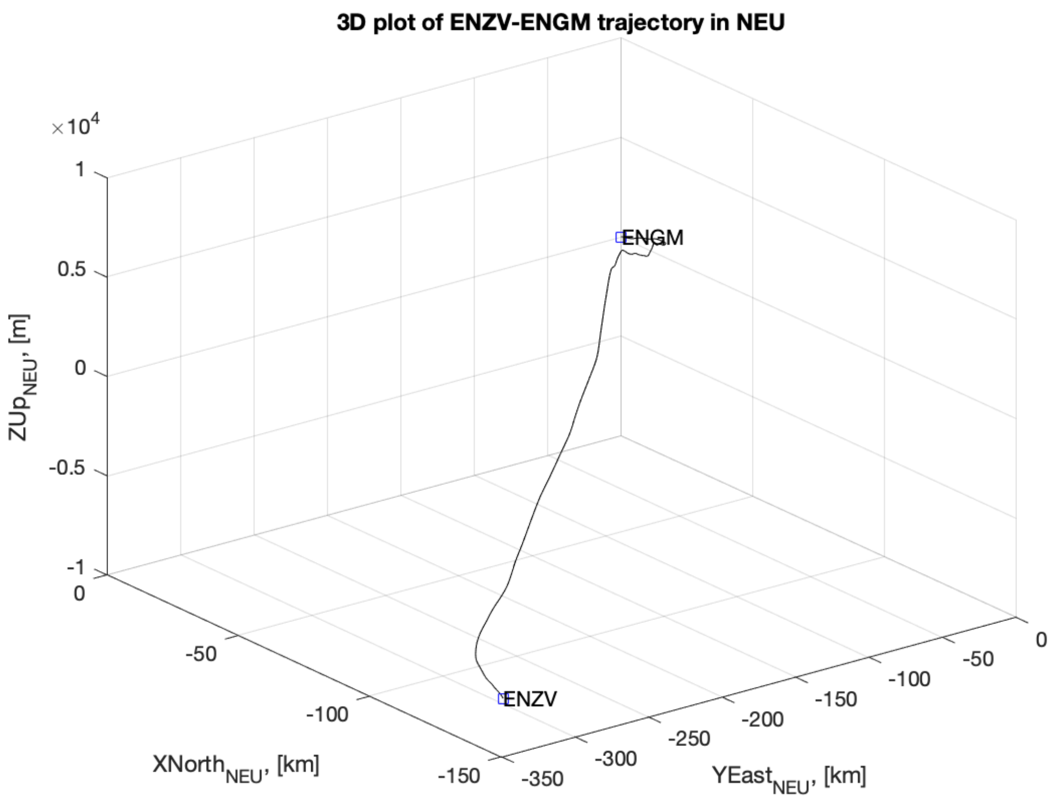


Figure 4.7 – 3D trajectory of NOZ555 in NED reference frame

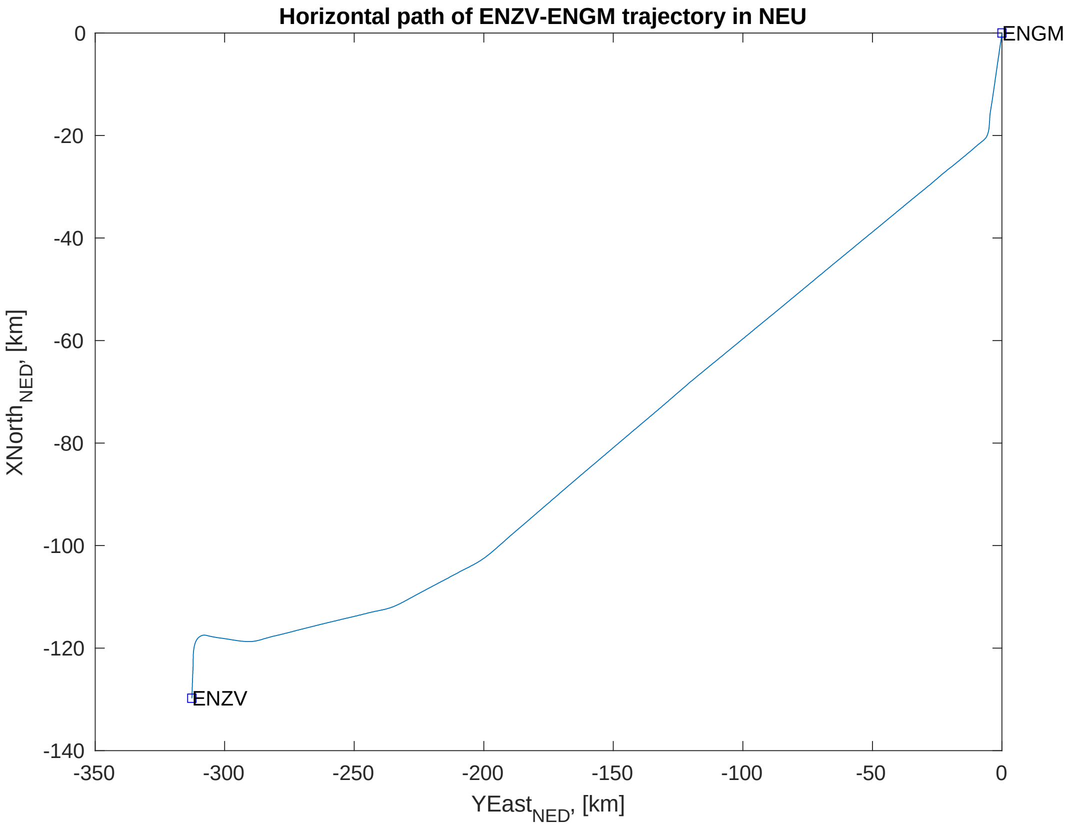


Figure 4.8 – Flight path of NOZ555 in local NED

4.1.4. Trajectory data calculation

Based on the data set of the three-dimensional movement trajectory, we will calculate the speed components. In particular, we calculate the full speed of an airplane, vertical, and horizontal components. The results of the speed calculation are shown in Figure 4.9, and the estimated course of the plane in Figure 4.10. Also, we calculate the total flight time and the length of the route and trajectory.

The total flight time of the flight NOZ555 from January 1, 2023 was 0 hours 32 minutes 20 sec. The length of the trajectory is 357,5 km, and the length of the route (horizontal projection) is 356,9 km.

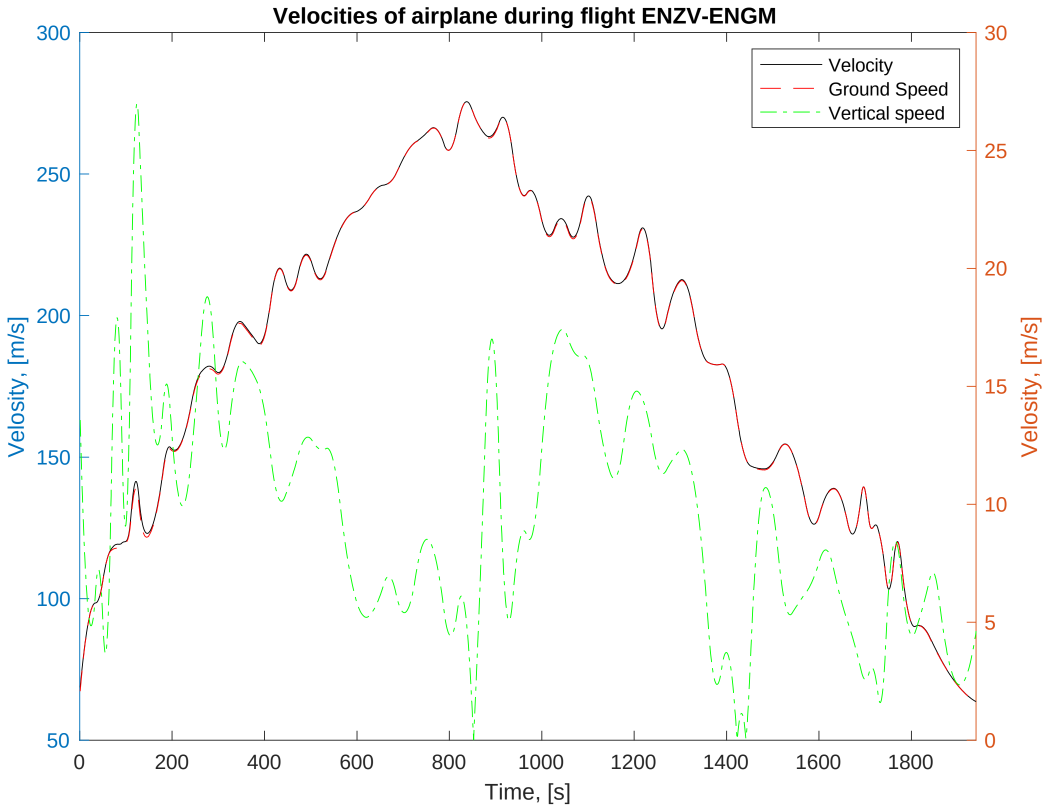


Figure 4.9 – Results of velocity estimation of NOZ555

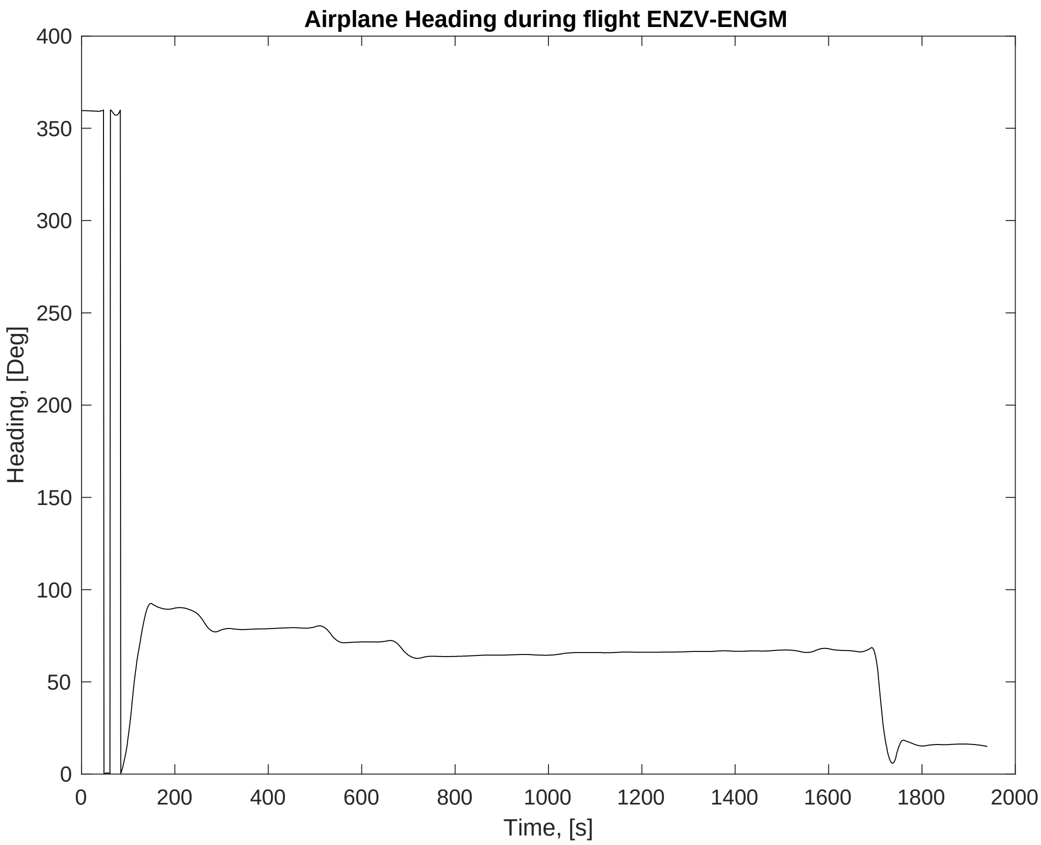


Figure 4.10 – Results of heading angle calculation of NOZ555

4.2. Efficiency of the aviation system

4.2.1. Forecasting the efficiency of passenger transportation

The year 2023 was no exception and continued the trends that arose in connection with the crisis in the world, COVID-19 and the military situation in several countries of the world, and in particular in Ukraine. The air transport market is affected by a large number of factors such as economic instability or weather conditions and the epidemic situation in the world. According to the results of the last two years, these factors significantly affected air transportation and led to a decrease in all main production indicators compared to previous years.

UAVs are used not only for passenger transportation, but also for cargo, medical, postal, and even agricultural needs. This diverse range of applications expands the capabilities of the aviation industry and attracts the attention of various sectors of the economy.

In particular, historical statistical data of the UAV air transportation from 2017 to 2022 are presented in Table 4.2.

Table 4.2 – Number of air transportation wit UAV from 2017 to 2022 years

Year	X- conventional time notation	Y- air transportation, in thousanc
2017	17	159
2018	18	246
2019	19	392
2020	20	634
2021	21	996
2022	22	1414

Using the method of correlation-regression analysis, I analyze number of the UAV air tarnsportation and forecast the next few years.

Correlation-regression analysis is a method used to predict the values of one variable based on another.

To make decisions in cases of forecasting events and in the case of identifying interdependencies with multidimensional parameters, use the method of correlation and regression analysis. The key indicators of correlation-regression analysis are correlation coefficients r and regression lines. The correlation coefficient has limits such as:

$$-1 \leq r \leq 1,$$

if $r = 0$, then there is no relationship between the investigated features;

if $r = 1$, a strong and direct relationship is observed;

if $r = 0.7...0.8$, the relationship is considered high;

if $r = -1$, we are talking about strong feedback.

Stages of correlation-regression analysis:

1. Collection of statistical data.
2. Correlation analysis. Using the correlation coefficient r, we determine the closeness of the connection and the nature of the connection.
3. Regression analysis. For a straight line, write analytic type of addiction:

   $y = b_0 + b_1 x$,

   where b_0 and b_1 - regression coefficients.
4. Determination of values of regression coefficients.
5. Determining the significance of the obtained values of correlation and regression coefficients using Student's and Fisher's tests.
6. Construction of the regression line.
7. Forecasting (extrapolation and interpolation)

Formulas should be used to calculate regression coefficients:

$$b_0 = (\sum y \sum x^2 - \sum xy \sum x)/(n\sum x^2 - (\sum x)^2);$$

$$b_1 = (n\sum xy - \sum x \sum y)/(n\sum x^2 - (\sum x)^2),$$

Where n – number of data.

$$r = \frac{\sum xy - (1/n)(\sum x)(\sum y)}{\sqrt{\left[\sum x^2 - (1/n)(\sum x)^2\right]\left[\sum y^2 - (1/n)(\sum y)^2\right]}}.$$

The value of the correlation coefficient shows how the variables x and y are related.

Based on theoretical data and with the help of MS Excel, a statistical analysis was made and a correlation-regression analysis was used to forecast the UAV air transportation until 2028. The results are shown in table 4.3.

After forecasting the UAV air transportation, we obtained a model for forecasting demand:

$$y = b_0+b_1x= -4244,3 + 250,48x$$

Table 4.3 – Forecasting the UAV market until 2028

Year	**X- conventional time notation**	**Forecast data, in thousands**	**Statistical data, in thousands**
2017	17	13,86	159
2018	18	264,34	246
2019	19	514,82	392
2020	20	765,3	634
2021	21	1015,78	996
2022	22	1266,26	1414
2023	23	1516,74	
2024	24	1767,22	
2025	25	2017,7	
2026	26	2268,18	
2027	27	2518,66	
2028	28	2769,14	

According to statistical and forecasted data, it is building Figure 4.11 for forecasting air transportation until 2028.

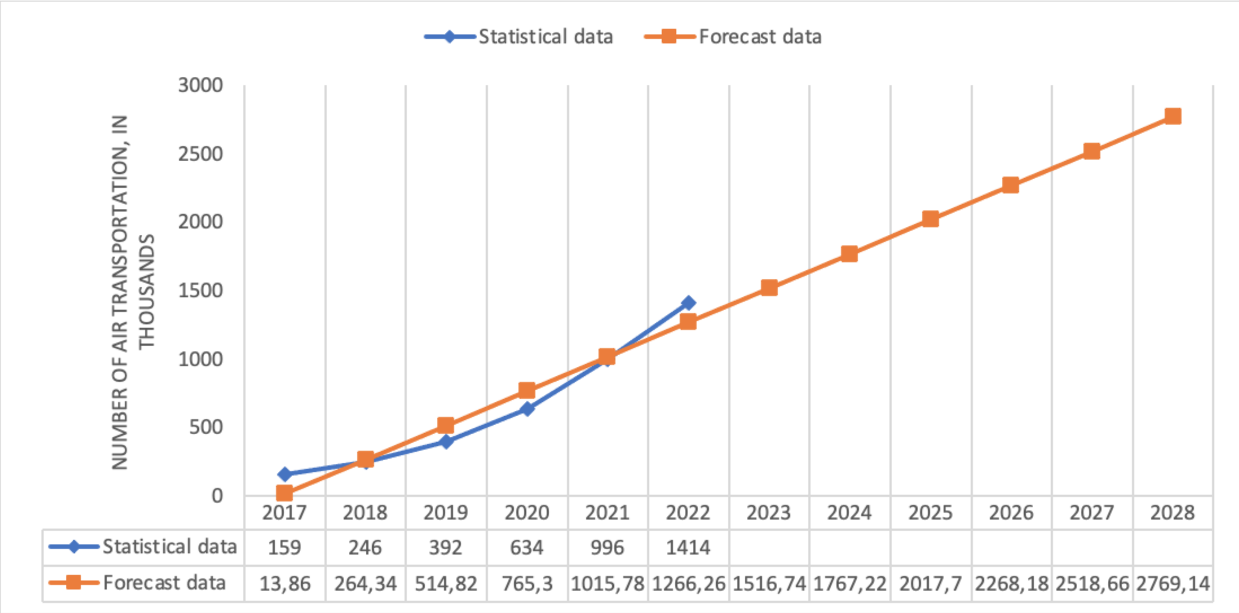


Figure 4.11 – Forecasting of number of air transportation with UAV

So, according to statistical data, in 2022 it was 1414 thousands air transportation wit UAV and in 2028 it is expected to be 2769,14 thousands.

4.2.2. Calculation of the efficiency of the use of cash income

The size of the global drone market is estimated to grow by 13,2% between 2022 and 2028. According to forecasts, the drone market could grow to 27 USD billion. The growth of the market depends on several factors, including the increase in the use of UAVs, the emergence of alternative inexpensive drones.

Based on theoretical data and with the help of MS Excel, a statistical analysis was made and a correlation-regression analysis was used to cash flow forecasting, which is presented in Table 4.4.

Table 4.4 – Market size of UAV from 2017 to 2022

Year	**CFt**	**Y**
2017	19,29 USD billion	19,7 USD billion
2018	19,93 USD billion	20,1 USD billion
2019	20,57 USD billion	20,5 USD billion
2020	21,21 USD billion	20,3 USD billion

2021	21,85 USD billion	22 USD billion
2022	22,49 USD billion	23,1 USD billion
r=0,91		

Where CFt - cash income, USD billion; Y- forecast value, USD billion.

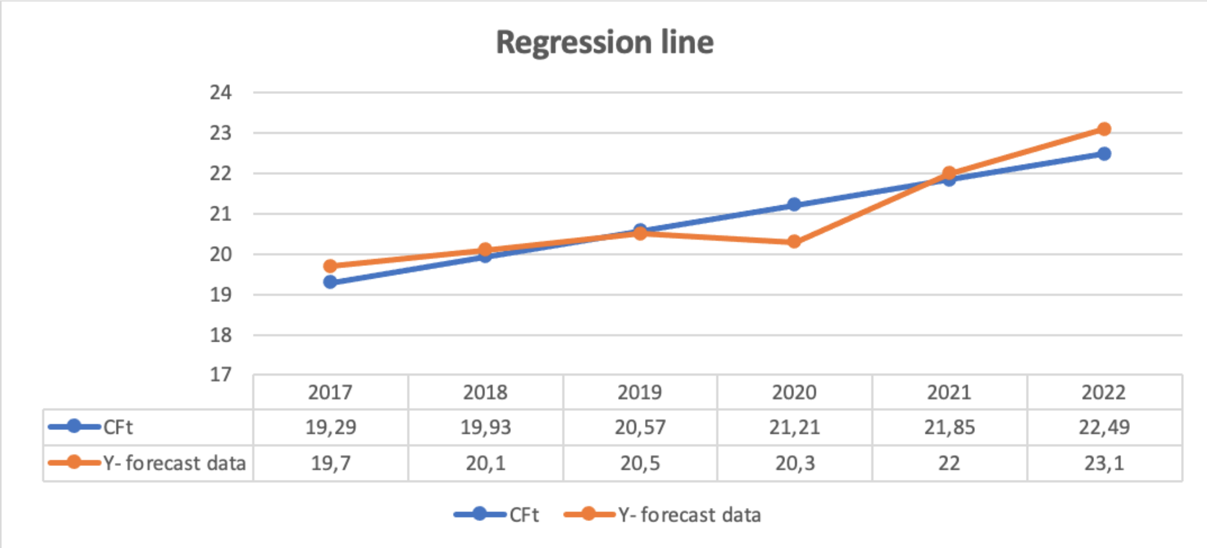


Figure 4.12 – Regression line

4.2.3. Business plan

- Accounting rate of return (ARR).

ARR = ((DACI – Depreciation)/II) x 100%,

where depreciation - the investment depreciation rate;

DACI - annual cash income taking into account discounting;

II - initial investments; Invest - investment amount.

- Program payback period (Payback Period - PVP).

РБР = II / DACI

- Reduced income (Net Present Value–NPV). The net present amount of income is an estimate of today's value of the stream of future income:

NPV = Σ (CFt / (1 + K)t) – II=ΣDASI - II

where CFt is cash receipts in time period t;

K is the discount rate.

- Profitability Index (Profitability Index - PI). The profitability index is a fraction of the sum of discounted income divided by the discounted value of expenses:

PI = Σ(CFt / (1 + K)t) / Invest=DASI/Invest

- Internal rate of return (Internal Rate of Return - IRR). The internal rate of return is calculated by determining discount rate at which the present value of the sum of future receipts is equal to the present value of expenses:

Σ(CFt / (1 + IRR)t) = Invest

The table 4.5 shows the initial data:

Table 4.5 – Initial data

Initial data		
II (Initial Investment)	II	20,5
CFt		
2021	Cf1	21,85
2022	Cf2	22,49
2021 & 2022	ΣCFt	44,34
SV (Salvage Value)	SV	
Cal (the cost of the tool)	Cal	13
Cd (asset depreciation)	Cd	5
SV (Salvage Value)=Cal-Cd	SV	8
Life - program term	t	2
K – discount rate, 20%	K	0,2

With the help of Microsoft Exel, it needs to make calculations on 5 points, which are shown in Table 4.6-4.10

Table 4.6 – Accounting rate of return

Depreciation = (II – SV)/Life		6,25
DACI = CFt / (1 + K)t, t=1	DACI2021	18,21
	DACI2022	18,74
	ΣDACI	36,95

ARR =((DACI – Depreciation)/II) x 100%,	ARR2021	58,33
	ARR2022	60,93
	ARRcep%,	59,63

Table 4.7 – Program payback period

PBP = II / DACI2021	PBP, years	1,13
PBP = II / DACI2022	PBP, years	1,09

Table 4.8 – Net Present Value–NPV

NPV = Σ (CFt / (1 + K)t) – II=ΣDASI - II	NPV	16,45

Table 4.9 – Profitability Index – PI

PI = Σ(CFt / (1 + K)t) / II=DACI/II	PI	1,80

Since PI>1, the program is cost-effective.

Table 4.10 – Internal Rate of Return – IRR

Σ(CFt / (1 + IRR)t) = Invest		
ΣCFt /(1+IRR)=II	IRR	1,162926829
IRR=CFt /II - 1	IRR,%	116,2926829

Since the IRR is greater than the standard level of desired profitability K, the program can be considered acceptable for investment. According to calculations of integrated indicators of investment effectiveness, it is clear that the chosen program is economically efficient.

Conclusion to chapter 4

This special section is divided into two parts. The first part of the special section deals with the automated processing of aeronautical data of the flight path NOZ555/DY555 (Norwegian Air Shuttle 555), provided by Norwegian Air Shuttle "Norsemann" with the connection Stavanger, Norway (SVG) and Gardermoen, Norway (OSL). Departure date January 1, 2023 at 09:30PM (CET). Landing date January 1 at 10:14PM (CET). The flight ended 11 minutes earlier than the scheduled landing time. The flight was performed on a Boeing 737-800 (twin-jet) (B738). As a result, we got the graphs shown in fig. 4.3 - 4.9. The total flight time of flight NOZ555 was also determined, which was 0 hours 32 minutes 20 c, the length of the trajectory is 357.5 km, and the length of the route (horizontal projection) is 356.9 km.

In the second part of the special section, the effectiveness of air transportation using UAVs was predicted. A statistical analysis of the UAV market was carried out and the number of UAV market until 2028 was predicted using correlation-regression, the obtained results are shown in Table 4.3. The calculation of the efficiency of the use of cash receipts was also carried out and an investment program was created, which turned out to be economically effective.

CHAPTER 5. LABOR PROTECTION AND ENVIRONMENTAL PROTECTION AT ENSURING FLIGHTS OF MANNED AND UNMANNED AIRCRAFT

5.1. Protection of the environment

Environmental protection is a system of measures for the rational use of natural resources, the preservation of particularly valuable and unique natural complexes, and the provision of environmental safety. This is a set of state, administrative, legal, economic, political and social measures aimed at the rational use, reproduction and preservation of the earth's natural resources, limiting the negative impact of human activity on the environment.

The main principles of environmental protection are (Article 3 of the Law)[29]:

- prioritization of environmental safety requirements, mandatory compliance with environmental standards, regulations and limits on the use of natural resources when carrying out economic, managerial and other activities;
- guaranteeing an ecologically safe environment for people's life and health;
- the preventive nature of the measures for the protection of the natural environment;
- greening of material production based on the complexity of solutions in matters of environmental protection, use and reproduction of renewable natural resources, wide implementation of the latest technologies;
- mandatory environmental examination;
- openness and democracy in decision-making, the implementation of which affects the state of the natural environment, the formation of the population's ecological outlook;
- scientifically based regulation of the impact of economic and other activities on the natural environment;
- compensation for damage caused by violation of legislation on environmental protection;

- establishment of environmental tax, fee for special use of water, fee for special use of forest resources, fee for use of subsoil in accordance with the Tax Code of Ukraine.

The legislation of Ukraine establishes standards for the use of natural resources and other environmental standards.

Environmental standards establish the maximum permissible emissions and discharges into the environment of polluting chemical substances, the levels of permissible harmful effects of physical and biological factors on it (Article 33 of the Law).[29]

Norms of maximum allowable concentrations of pollutants in the surrounding natural environment and levels of harmful physical and biological effects on it are uniform for the entire territory of Ukraine. Enterprises, institutions and organizations whose activities are associated with a harmful impact on the natural environment, regardless of the time of their implementation, must be equipped with facilities, equipment and devices for cleaning emissions and discharges or their neutralization, reducing the impact of harmful factors, as well as devices for controlling the amount and composition of pollutants and the characteristics of harmful factors (Article 51 of the Law).[29]

5.2. Analysis of the impact of UAVs on the environment.

Environmental protection is a very relevant problem, and on June 8, 2010, at the international conference Greener Skies Ahead 2010, the issue of reducing the environmental impact of aviation transport and reducing harmful emissions was raised. Most manufacturers of aviation equipment regularly deal with the issue of reducing the impact on the environment. There are four main areas with which manufacturers struggle, namely:

- reducing fuel consumption;
- reducing the emission of harmful gases;
- noise reduction;

- reducing the use of harmful materials and chemicals.

Environmental pollution is a significant factor in the environmental disaster in the world, which will lead to an increase in the risk of illness and even death. According to WHO statistics, approximately 12 million people die precisely because of poor environmental conditions.

The health of Ukrainians is most affected by polluted air. Every year, almost 17 million tons of harmful substances are in the Ukrainian atmosphere, which have a significant impact on the deterioration of people's health. UAVs, in particular, contribute to air pollution. The use of UAVs leads to emissions caused by burning fuel. The amount of emissions of CO_2, NO_x, and other air pollutants is increasing. Nitrogen oxides (NO_x) are substances in the form of solid suspended particles and are a key pollutant for the aviation industry, and this concern has led to improvements in the combustion chamber emissions performance of new aircraft engines as new NO_x standards have been adopted. Advances in technology have led to new aircraft engines with improved performance. This was done in order to create more environmentally friendly alternative engines that would reduce this negative impact.

Nitrogen dioxide (NO_2), which is part of nitrous oxide, is a greenhouse gas. It contributes to global warming, which in turn leads to climate change. NOx, which settles on land and water bodies, is harmful to vegetation and water resources. This can lead to a decrease in the fertility of Ukrainian soil and pollution of water bodies. NOx emissions are the greatest threat to the human respiratory system, causing lung disease. Children and people with respiratory diseases fall into the risk zone.

The impact of aircraft on the environment is manifested in the form of aircraft noise. Noise pollution of the environment is constantly increasing. This especially applies to large cities. A survey of city residents proved that noise bothers more than 50% of respondents. Moreover, in recent decades, the noise level has increased 10-15 times [30]. Therefore, today European countries have decided to set standards and restrictions on noise levels. These regulations and restrictions apply in urban areas and in other regions. In order to reduce noise pollution, organizations using UAVs are advised to comply with these regulations and restrictions.

Each take-off and landing of a UAV requires a plot of land - an airfield or a site. The use of valuable land plots for this purpose can have a negative impact on the flora and fauna, on the landscape. By developing land plots, it destroys the natural beauty, and also changes the purpose of the zone itself, for example, from agricultural to industrial. Therefore, when planning new infrastructure for UAVs, it is necessary to carefully study the environment and make an environmental assessment, as well as apply methods to reduce the impact on natural resources.

Moreover, each UAV has a lot of waste during production and maintenance. Such waste can include various materials and pollutants that are very dangerous for the environment. In an emergency situation, the amount of waste from an unmanned aerial vehicle can increase to 90%. And damaged UAV parts can be made of materials that do not decompose naturally. UAV maintenance itself is a very tedious process that requires a significant amount of resources, such as fuel or lubricants for parts inside the drone.

What can say about the impact of batteries and accumulators for UAVs on the environment. They have positive points, but no less negative ones. About the positive impact, we can say that the use of such UAVs on batteries reduces fuel emissions, and it also increases the efficiency of the UAV itself and the number of hours of operation. What about the negative impact? Batteries and accumulators contain liquid metals and require special measures for disposal. At the moment, batteries can be recharged, but they have a limited life, so they need to be replaced over time, which in turn leads to an increase in battery production. Materials such as lithium, nickel and cobalt are used for the production of batteries. These chemical elements can cause an irritating, general toxic effect on the blood, respiratory, cardiovascular and nervous systems in the human body. Despite this, electric batteries with such chemical compounds are considered the best and have high energy density and power, as well as a long service life.

5.3. Labor protection

According to the Law of Ukraine "On Occupational Safety" No. 2695-XII dated October 14, 1992, occupational safety is a system of legal, socio-economic, organizational-technical, sanitary-hygienic and medical-prophylactic measures and means aimed at preserving health I and the working capacity of a person in the process of work.

The employee is obliged to:

- to take care of personal safety and health, as well as the safety and health of surrounding people in the process of performing any work or while staying on the territory of the enterprise;
- to know and comply with the requirements of legal acts on labor protection, the rules for handling machines, mechanisms, equipment and other means of production, to use the means of collective and individual protection;
- undergo preliminary and periodic medical examinations in accordance with the procedure established by law.

The employee bears direct responsibility for the violation of the specified requirements.[31]

When performing work under an employment contract on remote work, on home work, the employee independently determines his workplace and is responsible for ensuring safe and harmless working conditions there, and the employer is responsible for the safety and proper technical condition of the equipment and means of production transferred to the employee for remote or home work. When performing work under an employment contract for home work, the workplace specified by the employee must be characterized by the presence of a fixed area, technical means (main production and non-production funds, tools, devices, inventory) or their combination, necessary for the production of products, provision of services, performance of works or functions , provided by the constituent documents (Article 14 of the Law).[31]

At the time of hiring and in the course of work, employees must undergo briefings, training on occupational health and safety issues, on providing first aid to victims of accidents and rules of conduct in the event of an accident at the expense of the employer.

Employees engaged in high-risk jobs or where there is a need for professional selection must undergo special training and knowledge testing of relevant regulations on labor protection every year at the expense of the employer (Article 18 of the Law).[31]

Employees, including officials, who have not undergone training, instruction and knowledge verification on labor protection are not allowed to work.[31]

If employees, including officials, are found to have unsatisfactory knowledge of occupational health and safety issues, they must undergo repeated training and a knowledge test within a month.

The study of the basics of labor protection, as well as the training and advanced training of labor protection specialists, taking into account the specifics of the production of the relevant economic objects, are provided by the central executive body, which ensures the formation of state policy in the field of education and science, in all educational institutions according to programs agreed with the central body of the executive power, which implements the state policy in the field of labor protection.

Employees and/or their representatives are provided with access to information and documents containing the results of workplace certification, preventive measures planned by the employer, results of investigations, registration and analysis of accidents and occupational diseases and reports on these issues, as well as to notifications, submissions and prescriptions bodies of state supervision over labor protection (Article 23 of the Law).[31]

5.4. Occupational health and safety instructions for the UAV operator

Persons at least 18 years old have the right to operate a UAV. Before using a UAV, these persons must undergo theoretical and practical training, a medical examination, as well as introductory and initial training at the workplace on occupational safety and work techniques, internship at the workplace and a test of knowledge of occupational safety requirements, as well as learn the rules of fire safety and electrical safety in the scope of job duties with the assignment of the 1st group.

The responsibilities of the UAV operator include knowledge and compliance with the following requirements:

– Rules and norms of labor protection and industrial sanitation;

- Rules and norms of environmental protection;
- Rules of the internal labor procedure;
- Fire and explosion safety requirements;
- The location of the first aid kit and the procedure for providing first aid;
- Procedures for emergency situations;
- UAV design, rules and norms of operation, maintenance.

During work, the UAV operator must undergo repeated training on occupational health and safety at the workplace once every 3 months, and once a year undergo a medical examination and check knowledge of occupational health and safety requirements once a year.

When working, the UAV operator can be affected by moving vehicles, sharp edges, burrs, roughness of the UAV surface or adverse weather conditions, electric current and physical stress. When the operator works in the dark, insufficient illumination of the work area can affect the efficiency of work.

Each employee must be provided with personal protective equipment in accordance with the current norms for issuing special clothing, special shoes and other personal protective equipment [32]. Special clothing, special shoes and personal protective equipment must correspond to the nature and conditions of work, ensure occupational safety, have a certificate of conformity or a declaration [32]. It is forbidden to use personal protective equipment and overalls for other purposes and if they do not have technical documentation and the expiration date is coming to an end.

The employee must know and follow the rules of personal hygiene. Eat, smoke and rest only in specially designated areas [32].The operator of the ground means of controlling an unmanned aerial vehicle at the workplace has no right to consume alcoholic beverages and drugs.

In an emergency situation at work or in the event of an accident with a colleague or other people, the operator must notify the manager. In the event of non-fulfillment of all the above-mentioned requirements and rules, the operator will bear responsibility in accordance with the current legislation of Ukraine.

5.5. Labor protection requirements during work of UAV operator

The UAV operator during operation must:

- Perform only the work for which training has been completed and occupational health and safety instruction has been received;
- Do not allow untrained and outsiders to work;
- Strictly comply with the safety requirements set forth in the operational documentation of the UAV manufacturer;
- To be attentive, not to be distracted from the performance of one's duties'
- Be polite, behave calmly and calmly, avoid conflict situations that can cause nervous and emotional tension and affect work safety.[32]

A UAV is an electronic device with a complex control system and can be a serious source of danger for the worker himself and others.

It is not recommended to use UAVs in places of mass gathering of people. The minimum safe distance from UAV to a person is at least 15 meters.It is recommended to use the UAV in open space.[32]

It is forbidden to operate the UAV at night, if it does not have LED navigation lights, as well as under any other circumstances in which visual control may be difficult.

It is forbidden to work with a technically defective UAV, in which structural, mechanism and device failures, as well as various problems in the process of using the electronic control system, including those caused by radio interference, have been detected.[32]

During operation, some elements, especially the contact group between the battery and the UAV, may heat up, so precautions should be taken to avoid burns.

Observe the following safety requirements when using the UAV battery:

- use only the charger supplied in the kit or recommended by the UAV manufacturer;

- charge the battery on a fire-resistant surface in a fire-safe and well-lit place and at a safe distance from equipment and vehicles;
- do not store or charge batteries in direct sunlight.

If the battery overheats during the operation of the UAV, it must be replaced with a new one.

Before long-term storage of the UAV, moving and assembly, disassembly of the UAV, the batteries should be removed.

The UAV operator must use batteries of the same type and manufacturer with the same charge level for the transmitter. Failure to comply with this condition may result in a complete loss of control of the UAV.

To avoid personal injury, the operator must not touch the propellers or other rotating parts.

Do not throw, protect the UAV and its control panel from impacts.

A dirty UAV should only be cleaned with a dry, clean, soft cloth with the battery removed.[32]

During work, being on the roadway or near it, the operator must pay special attention to moving vehicles, take his time.

The UAV operator needs to be attentive and monitor the change in the surrounding environment, especially in adverse weather conditions (rain, dew, snowfall, ice, etc.) and in the dark.

The UAV operator should remember that in conditions of increased street noise, sound signals and the noise of the running engine of an approaching car may not be heard.[32]

The operator should exercise caution and be attentive near areas of increased danger (when you are on the territory of active production, near electrical communications, etc.), as well as on the roadway, pay attention to unevenness and slippery places, obstacles (pipes, boxes and other objects) .

During the performance of work, the employee is prohibited from:

- to leave the workplace without the knowledge of the immediate supervisor;
- leave the UAV unattended;

- use open fire.

The UAV operator is prohibited from using random objects (boxes, boxes, etc.), equipment and devices for seating.

Also, the operator is prohibited from eating food at the workplace.

If you feel unwell, stop work, inform your manager and consult a doctor.[32]

5.6. Labor protection requirements in emergency situations

First, the UAV operator must notify the manager of the failure or failure of the UAV, if this threatens an accident at the workplace, and also stop operating the UAV. If the emergency situation threatens the lives of other people, then inform them about it and act according to the accident elimination plan.

It is not recommended to use water and foam fire extinguishers directly in the event of an accident. And to put out the fire, it is better to use carbon dioxide and powder fire extinguishers. If the UAV operator detects smoke and fire, he must immediately sound the fire alarm and call the fire brigade (phone number 101). Before the arrival of the fire brigade, you should take all measures to eliminate the fire and, of course, inform your supervisor about it.

In the event of an accident, the victim must be pulled away from the traumatic environment and call an ambulance (phone number 103). Before the ambulance arrives, give the victim first aid. If necessary, record the situation in which the accident occurred on a photo or video. The report of the supervisor and the labor protection specialist is mandatory.

The UAV operator has the right to leave the workplace immediately if his health is unsatisfactory, he cannot focus his eyes or focus on an object, he feels pain in his fingers and hands, and his heartbeat increases. He undertakes to inform his supervisor about this and seek medical attention.

Conclusion to chapter 5

In the chapter on environmental protection, various factors on human health and nature are considered. After all, today nitrogen oxides remain a key pollutant in the aviation sector. Nevertheless, ICAO continues to fight to reduce the impact of aviation on the environment and by mitigating the adverse effects of aviation on human health worldwide.

An analysis of dangerous and harmful factors at the air traffic controller's workplace, which have a direct impact on his work capacity and health, was carried out in the occupational health and safety division. As a result of the analysis, it was found that during work, the air traffic controller is exposed to a large number of harmful factors, such as - aircraft noise, high level of vibrations, adverse microclimate conditions, etc. The main measures for the organization of labor protection at the workplaces of air traffic controllers were also determined.

GENERAL CONCLUSIONS

In this thesis, a study and analysis of the problems of urban air mobility was carried out with an emphasis on the organization of an effective system of transportation in and around urban areas.

This thesis describes the concept of urban air mobility and analyzes the problems of urban air mobility with an emphasis on the organization of an efficient transportation system in and around urban areas. Urban Air Mobility is a relevant and innovative concept that can change the way of moving through cities, improve the accessibility of transport and contribute to the sustainable development of the urban environment. Air transport using UAVs in urban and suburban areas is one of the most relevant innovations in the field of transport, which allow the implementation of ideas of urban air mobility, which can potentially solve many problems of transport in cities. The results of the study indicate the relevance of transport infrastructure issues and the need to improve existing urban mobility systems.

Also, the process of collaborative decision-making by the air traffic control controller, the UAV operator and the pilot of the manned aircraft in the event of a special case in the flight of the UAV, namely bird strike, was considered in the course of the thesis. It was found that this problem can significantly affect the safety of citizens and the efficiency of transportation. Therefore, the technology of the actions of the air traffic controller and the UAV operator in the event of a collision with a bird was proposed, and the analysis of these actions was carried out by the method of network planning. By building a decision tree, I found the optimal alternative solution to this in-flight emergency and prevented the situation from developing into a wrong sequence of actions. As a result, the following recommendations and strategies may be important for improving urban air mobility safety and management systems.

The main goal of the thesis is to create a model of collaborative decision-making in order to ensure synchronization of decisions between participants of collaborative decision-making and timely exchange of information between them, effective balancing between security.

To simulate collaborative decision-making, I took as an example an emergency situation in a UAV flight - a bird strike - on the UAV route Chernivtsi-Kyiv (Boryspil). The main task was the need to choose the optimal UAV landing airfield, using a model of collaborative decision-making under uncertainty. In carrying out this task, the criteria of Wald, Laplace, Hurwitz and Savage were applied, as well as EJM. As a result, it received well-founded optimal solutions.

The results of this thesis can be used by air traffic controllers and UAV operators, pilots of manned aircraft to improve the efficiency of the collaborative decision-making process, increase the safety of UAV flights, and also to reduce the number of aviation events involving UAVs during bird strikes in and outside urban areas to a minimum.

REFERENCE

1. FAA, Urban Air Mobility (UAM), Concept of Operations. V1.0, US Department of Transportation. Office of NextGen, 2020.
2. Bird detection & mitigation technology for airports [Electronic resource]. URL: https://www.robinradar.com/bird-hazard-management-airports-guide
3. ICAO. Annual Report 2021. Emerging and Cross-cutting Aviation Issues. Increased use of unmanned aircraft systems (UAS). [Electronic resource]. URL: https://www.icao.int/annual-report-2021/Pages/emerging-and-cross-cutting-aviation-issues-increased-use-of-unmanned-aircraft-systems-uas.aspx
4. T.Shmelova, D.Kucherov, Y. Kovalyov, V. Stovba. Organization of a safe and efficient system of air transportation in and around an urban area using Unmanned Arial Vehicles. Proceedings of Conference: The 12 th IEEE International Conference on Dependable Systems, Services and Technologies, Greece, Athens, 2022.
5. Unmanned Aircraft Systems Traffic Management (UTM) – ACommon Framework with Core Principles for Global Harmonization,3d ed. Canada, Montreal: ICAO Publ., 2017.
6. Unmanned Aircraft Systems (UAS), Cir. 328/AN 190. Canada, Montreal: ICAO, 2011.
7. V. Gollnick, M.Niklass, M.Swaid, J.Berling, N.Dzikus. A methodology and first results to assess the potential of urban air mobility concepts. Proceeding of Conference: Aerospace Europe Conference, Hamburg, February 2020.
8. Unmanned Airspace (2021). The information portal for unmanned air system traffic management (UTM), urban air mobility (UAM), counter-UAS (C-UAS), and space traffic management systems. [Electronic resource]. URL: https://www.unmannedairspace.info/
9. World Civil Unmanned Aerial Systems market profile and forecast. USA, Fairfax, Virginia: Teal Group Corporation, 2019.
10. Aviation Administration Federal. Bird migration and areas with sensitive Fauna: migratory bird activity,2022.[Electronic resource].

URL: https://www.faa.gov/air_traffic/publications/atpubs/aip_html/part2_enr_section_5.6.html

11. Aviation Administration Federal. Wildlife strikes to civil aircraft in the United States, 1990–2021: national wildlife strike database serial report number 28. 2022. [Electronic resource]. URL: https://www.faa.gov/sites/faa.gov/files/2022-07/Wildlife-Strike-Report-1990-2021.pdf

12. Шмельова Т.Ф., Яшан О.В.. Оцінювання впливу психофізіологічних факторів на операторів БПЛА під час нападу птахів. Сталий розвиток глобальної системи зв'язку, навігації, спостереження та організації повітряного руху CNS/ATM: матеріали Всеукр. наук.-техн. конференції, Київ, 29-30 травня, 2023 р. К.: Національний авіаційний університет, 2023.

13. Guidelines for Controller Training in the Handling of Unusual/Emergency Situations. – EUROCONTROL, 2003.

14. Skybrary. Bird Strike in UAS Operations. [Electronic resource]. URL: https://skybrary.aero/articles/bird-strikes-uas-operations

15. T. Shmelova, Y. Sikirda. 2021. Collaborative Decision-Making Models for UAV Operator's Intelligent Decision Support System in Emergencies. Proceedings of Conference: the 2nd International Conference of Artificial Intelligence and Information Systems. 2021, Ukraine. DOI: 10.1145/346913.469222

16. Tetiana Shmelova, Maxim Yatsko, Iurii Sierostanov. Collaborative Decision Making in Emergency Caused by Captain Incapacitation: Deterministic and Stochastic Modelling. 2023. № 15(1). P. 9-10 DOI: 10.4018/IJDSST.320477

17. T. Shmelova, Y. Sikirda, M. Yatsko, M. Kasatkin. Synthesis of the Collaborative Decision-Making models for remote pilot in flight emergency. Proceedings of Conference: IEEE 6th International Conference on Actual Problems of Unmanned Aerial Vehicles Development (APUAVD). 2021, Ukraine. DOI: 10.1109/APUAVD53804.2021.9615175

18. Ostroumov I.V., Kuzmenko N.S. Outliers detection in Unmanned Aerial System data. 2021 11th International Conference on Advanced Computer Information Technologies (ACIT). 2021. P. 591-594.

19. Kharchenko V.P., Ostroumov I.V. Avionics. Kyiv: NAU, 2013. 281c. ISBN: 978-966-598-573-0.

20. Ostroumov I.V., Kuzmenko N.S. Performance Modeling of Aircraft Positioning System. Conference on Integrated Computer Technologies in Mechanical Engineering–Synergetic Engineering – ICTM 2021. ICTM 2021. Lecture Notes in Networks and Systems. 2022. No 367. P. 297-310 DOI: 10.1007/978-3-030- 94259-5_26.

21. Ostroumov I.V., Marais K., Kuzmenko N.S. Aircraft positioning using multiple distance measurements and spline prediction. Aviation. 2022. No 26(1). P. 1-10 DOI: 10.3846/aviation.2022.16589.

22. Ostroumov I.V., Kharchenko V.P., Kuzmenko N.S. An airspace analysis according to area navigation requirements. Aviation. 2019. No 23(2). P. 36-42 DOI: 10.3846/aviation.2019.10302.

23. Ostroumov I.V., Kuzmenko N.S. Statistical Analysis and Flight Route Extraction from Automatic Dependent Surveillance-Broadcast Data. 2022 Integrated Communications Navigation and Surveillance Conference (ICNS). 2022. P. 1-9. DOI: 10.1109/ICNS54818.2022.9771515.

24. Ostroumov I.V., Ivashchuk O. Risk of mid-air collision estimation using minimum spanning tree of air traffic graph. Paper presented at the CEUR Workshop Proceedings of the 2st International Workshop on Computational & Information Technologies for Risk-Informed Systems CITRisk-2021. 2022. No 3101. P. 322-334.

25. Ostroumov I.V., Kuzmenko N.S. A Probability Estimation of Aircraft Departures and Arrivals Delays. Gervasi O. et al. (eds) Computational Science and Its Applications – ICCSA 2021. ICCSA 2021. Lecture Notes in Computer Science. 2021. No 12950. P. 363-377 DOI: 10.1007/978-3-030-86960-1_26.

26. Ostroumov I.V., Kuzmenko N.S. Incident detection systems, airplanes. In Vickerman, Roger. International Encyclopedia of Transportation. vol. 2. 4569 p. UK: Elsevier Ltd., 2021. 351-357p. DOI: 10.1016/B978-0-08-102671-7.10150-2. ISBN: 9780081026717.

27. Flightaware. Official website of the company. [Electronic resource]. URL: https://www.flightaware.com

28. Software for Air Navigation analysis. Visualization of airplane trajectory based on ADS-B data messages. [Electronic resource]. URL: https://www.ostroumov.sciary.com/codes_airplane-trajectory-visualization

29. Law of Ukraine on Environmental Protection. №41, ст.546. 1991. [Electronic resource]. URL: https://zakon.rada.gov.ua/laws/show/1264-12 - Text

30. Wikipedia. Noise pollution. [Electronic resource]. URL: https://uk.wikipedia.org/wiki/Шумове_забруднення -Шумове_забруднення_середовища_і_вплив_шуму_на_людину

31. Law of Ukraine on Labor Protection. №49, ст.668. 1992. . [Electronic resource]. URL: https://zakon.rada.gov.ua/laws/show/2694-12#Text

32. Occupational health and safety instructions for the operator of the ground means of controlling an unmanned aerial vehicle . [Electronic resource]. URL: https://ohoronapraci.com.ua/instructions/656370-instruktsiya-z-okhorony-pratsi-operatora-nazemnykh-zasobiv-keruvannya

33. Харченко В.П., Ларін В.Ю. Методичні рекомендації до виконання магістерських робіт. – Київ: НАУ, 2012. - 52 с.