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: «Система підтримки прийняття рішення авіадиспетчера на видачу дозволу на зліт та посадку»

Виконав: **Левко В.О.**

Керівник: **Аргунов Г. Ф.**

Керівники спеціального розділу

д.т.н. проф. Остроумов Іван Вікторович

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Нормоконтролер: **Аргунов Г. Ф.**

Київ 2023

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONICS AND TELECOMMUNICATIONS
AIR NAVIGATION SYSTEMS DEPARTMENT

PERMISSION FOR DEFENCE
Head of the Department
Doctor of Sciences (Engineering), prof.
__________________V.Y. Larin
"_____" __________ 2023

MASTER'S THESIS
ON THE EDUCATIONAL PROFESSIONAL PROGRAM "AIR TRAFFIC SERVICE"
(EXPLANATORY NOTE)

Theme: "Air Traffic Controller Decision Support System for Issuing Takeoff and Landing Permits"

Performed by: **Levko V.O.**

Supervisor: **Argunov G. F.**

Special chapter supervisors:

Doctor of Sciences (Engineering), prof. Ostroumov I.V.

Doctor of Sciences (Engineering), prof. Shmelova T.F.

Standard inspector: **Argunov G. F.**

Kyiv 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.т.н., професор
____________В.Ю. Ларін
« ___ »________2023 р.

ЗАВДАННЯ
на виконання дипломної роботи

________________Левка Володимира Олексійовича_______________
(прізвище, ім'я, по батькові випускника в родовому відмінку)

1. Тема дипломної роботи: «Система підтримки прийняття рішення авіадиспетчера на видачу дозволу на зліт та посадку» затверджена наказом ректора від "22" жовтня 2023 р. № 1443/ст.
2. Термін виконання роботи: 23.10.2023 – 31.12.2023.
3. Вихідні дані до роботи: теоретичні дані керівних документів ІСАО та національних документів України у сфері забезпечення та виконання польотів цивільних повітряних суден.
4. Зміст пояснювальної записки:
   - Аналіз дій операторів УПР під час зльоту та посадки.
   - Сучасні методи ешелонування літаків під час зльоту та посадки.
   - Розробка прототипу системи підтримки прийняття рішень диспетчера під час зльоту та посадки.
   - Спеціальний розділ.
   - Охорона праці та охорона навколишнього середовища при забезпеченні польотів пілотованих та безпілотних повітряних суден.
5. Перелік обов'язкового графічного (ілюстративного) матеріалу: 28 рисунків, 18 таблиць.

6. Календарний план-графік:

№	Завдання	Терміни виконання	Відмітка про виконання
1	Підготовка та написання 1 розділу «Аналіз дій операторів УПР під час зльоту та посадки»	22.10.23 – 30.10.23	Виконано
2	Підготовка та написання 2 розділу «Сучасні методи ешелонування літаків під час зльоту та посадки»	31.10.23 – 10.11.23	Виконано
3	Підготовка та написання 3 розділу «Розробка прототипу системи підтримки прийняття рішень диспетчера під час зльоту та посадки»	11.11.23 – 22.11.23	Виконано
4	Підготовка та написання 4 розділу «Спеціальний розділ»	23.11.23 – 30.11.23	Виконано
5	Підготовка та написання 5 розділу «Охорона праці та охорона навколишнього середовища при забезпеченні польотів пілотованих та безпілотних повітряних суден»	01.12.23 – 05.12.23	Виконано
6	Оформлення пояснювальної записки та ілюстрованого матеріалу	06.12.20 – 12.12.20	Виконано
7	Попередній захист дипломної роботи	13.12.20 – 15.12.20	

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 Іван Вікторович	23.10.2022	
4.2. Ефективність авіаційних перевезень України	д.т.н, проф. Шмельова Тетяна Федорівна	23.10.2022	

8. Дата видачі завдання: 23.10.2023.

Керівник дипломної роботи __________________ Аргунов Г.Ф.
(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання ______________ Левко В.О.
(підпис випускника) (П.І.Б.)

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Система підтримки прийняття рішення авіадиспетчера на видачу дозволу на зліт та посадку».

Мета дипломної роботи – розроблення прототипу програми для забезпечення підтримки прийняття рішення диспетчера на видачу дозволу на зліт та посадку.

Об'єкт дослідження – технологія дій диспетчера при видачі дозволу на зліт та посадку с дотриманням необхідних безпечних інтервалів.

Предмет дослідження – комп'ютерне моделювання процесу видачі дозволу на зліт та посадку.

Метод дослідження – теоретичні методи, комп'ютерне та математичне моделювання, математичні розрахунки.

Сучасна тенденція розвитку систем управління повітряного руху (ATM) й рекомендації ICAO передбачають розробку й інтеграцію систем підтримки прийняття рішень диспетчерами-операторами (ATCO). Головним обмеженням пропускної здатності при збереженні прийнятного рівня ризику є людський фактор пілотів й диспетчерів, їх професійні навички, досвід праці й фізичний стан.

За головною концепцією управління повітряним рухом (ATM) усі операції й маневрування в контрольованому повітряному просторі базуються на взаємодії пілота й диспетчера управління повітряним рухом. Ця взаємодія передбачає радіокомунікацію, своєчасні оцінка й надання інформації, прийняття рішень й виконання вказівок. Усі ці взаємодії займають певний час, що напряму залежить від навичок операторів, багатьох внутрішніх і зовнішніх факторів. Один з рекомендованих методів забезпечування максимально високого рівня працездатності оператора, це введення допоміжних систем, що будуть зменшувати навантаження на диспетчера при рутинній праці й зменшувати ризики при великій кількості бортів або при виникненні інших нестандартних ситуацій.

PAGE OF REMARKS

Faculty of Air Navigation, Electronics and Telecommunications
Air Navigation Systems Department
Specialty: 272 “Aviation Transport”
Educational Professional Program: “Air Traffic Service”

APPROVED BY
Head of the Department
_____________ V.Y. Larin
«__»_________________2023

Graduate Student’s Degree Thesis Assignment

________________Levko Volodymyr Oleksiiovych_______________

1. The work subject: **Air Traffic Controller Decision Support System for Issuing Takeoff and Landing Permits** approved by the Rector’s order of № 1443/st from 22.10.2023
2. The work (Thesis) to be completed between 22.10.2023 and 31.12.2023.
3. Initial data to the work: theoretical data of ICAO guiding documents and national documents of Ukraine in the field of ensuring and performing flights of civil aircraft.
4. The contents of the explanatory note:
   - Analysis of ANS Operator’s Actions During Take-off and Landing.
   - Current Methods of Aircrafts Separation During Take-off and Landing.
   - Prototype of ATC Decision Support System for Issuing Take-off and Landing Permits.
   - Special Chapter.
   - Occupational Health and Safety and Environmental Protection in Ensuring the Flights of Manned and Unmanned Aerial Vehicles
5. The list of mandatory graphics (illustrated) materials: 28 figures, 18 tables.

6. Calendar schedule:

№	Completion Stages of Degree Thesis	Stage Completion Dates	Completion Mark
1	Preparation of Charter 1: “Analysis of ANS Operator’s Actions During Take-off and Landing”	22.10.23 – 30.10.23	Completed
2	Preparation of Chapter 2: “Current Methods of Aircrafts Separation During Take-off and Landing”	31.10.23 – 10.11.23	Completed
3	Preparation of Chapter 3: “Prototype of ATC Decision Support System for Issuing Take-off and Landing Permits”	11.11.23 – 22.11.23	Completed
4	Preparation of Chapter 4: “Special Chapter”	23.11.23 – 30.11.23	Completed
5	Preparation of Chapter 4: “Occupational Health and Safety and Environmental Protection in Ensuring the Flights of Manned and Unmanned Aerial Vehicles”	01.12.23 – 05.12.23	Completed
6	Preparation of report and graphic materials	06.12.20 – 12.12.20	Completed
7	Preliminary presentation of the graduate work	13.12.20 – 15.12.20	

7. Assignment accepted for completion: “22” October 2022

8. Special chapter supervisors

<table>
<tr><th rowspan="2">Chapter</th><th rowspan="2">Supervisor
(position, Surname.)</th><th colspan="2">Date, Signature</th></tr>
<tr><th>Task Given</th><th>Task Checked</th></tr>
<tr><td>4.1. Автоматизована обробка Аеронавігаційних даних великої розмірності</td><td>Doctor of Sciences (Engineering), prof. Ostroumov I.V.</td><td>23.10.2022</td><td></td></tr>
<tr><td>4.2. Ефективність авіаційних перевезень України</td><td>Doctor of Sciences (Engineering), prof. Shmelova T.F.</td><td>23.10.2023</td><td></td></tr>
</table>

Supervisor ________________________ Argunov G.F..
(signature) (Full Name)

Assignment Accepted for Completion ___________________ Levko V.O.
(signature) (Full Name)

ABSTRACT

Explanatory note to the graduation work: Air Traffic Controller Decision Support System for Issuing Takeoff and Landing Permits.

The purpose of the research – development of a prototype of an air traffic controller support system for issuing take-off and landing permits.

The object of the research – the technology of the controller's actions when issuing permission for take-off and landing in compliance with the necessary safe intervals.

The subject of the research – modeling the decision support system for issuing take-off and landing permits.

The method of the research – theoretical methods, computer and mathematical modeling, mathematical calculations.

The current trend in the development of air traffic management (ATM) systems and ICAO recommendations are proposing the development and integration of decision support systems for air traffic controllers (ATCOs). The main limitation of airspace capacity while maintaining an acceptable level of risk is the human factor of pilots and controllers, their professional skills, work experience and physical condition.

According to the main concept of air traffic management systems (ATM), all operations and maneuvering in controlled airspace are based on the interaction between the pilot and the air traffic controller. This interaction involves radio communication, in-time assessment and provision of information, decision-making and execution of instructions.

All these interactions take a certain amount of time, which directly depends on the skill of operators, many internal and external factors. We cannot significantly influence external factors without introducing new restrictions on the use of airspace, but we can ensure the highest possible level of operator efficiency by introducing supporting systems that will reduce the workload on the ATCO during routine work and reduce risks from high-capacity situations or other non-standard situations.

CONTENTS

LIST OF ABBREVIATIONS

A/P – Auto-pilot.

AMAN – Arrival Manager.

ANS – Air Navigation System.

A-SMGCS – Advanced Surface Movement Guidance and Control Systems

ATC – Air Traffic Control.

ATCO – Air Traffic Control Operator.

ATM – Air Traffic Management.

CAMI – Civil Aeromedical Institute.

CRA – Correlation-Regression Analysis.

DMAN – Departure Manager.

EATA – European Association for Transactional Analysis.

FAA – Federal Aviation Administration.

FO – Flying Officer.

GAT – General Air Traffic.

IATA – International Air Transport Association.

ICAO – International Civil Aviation Organization.

IDE – Integrated Development Environment.

IFR – Instrumental Flight Rules.

ILS – Instrument Landing System.

JAA – Joint Aviation Authorities.

JST – Japan Standard Time.

LSA – Lateral Safety Areas.

MTOW – Maximum Take-off Weight.

NTSB – National Transportation Safety Board.

PANS – Procedures for Air Navigation Services.

PF – Pilot Flying.

PIC – Pilot in Command.

RSA – Runway Safety Areas.

SMAN – Surface Management.

TMA – Traffic Management Area.

VFR – Visual Flight Rules.

WTC – Wake Turbulence Category.

УПР – Управління Повітряним Рухом.

INTRODUCTION

From the early days of aviation development, the more flights conducted the more accidents and incidents occurred. Firstly, all flights were applying visual flight rules which meant that all safety and navigation was lying on the shoulders of the pilots. This led to common situations of accidents and incidents with human factors included such as midair and ground collisions due to lack of situational awareness, piloting errors on-route and in aerodrome vicinity. The early airplanes were difficult to operate and had high mechanical complicity that required a lot of pilot attention, this created additional stress and workload on pilots leading to the increased probability and room for errors. Due to all of that it seems safe to say that the human factor was probably the major factor leading to accidents and incidents. But we must not forget that early aviation was an unreliable, unlearned new transportation method. Airplanes made in the XIX century were a new thing, always growing and evolving, materials used in these airplanes were never used for such stresses and fatigue that can be experienced in-flight. So, with the sudden growth of aviation transportation a major problem for aviation was not the human factor but mechanical failure.

According to the Boeing report about the maintenance human factor errors [1] based on the International Air Transport Association (IATA) statistics, from all accidents and incidents about 80% of that consisted of machine and equipment failures. But a hundred years after that, in the year of 2003 the statistics drastically changed, and now about 80% of accidents and incidents have occurred due to human error (pilots, air traffic controllers, mechanics, etc.). And to this day the human factor remains one of the most common causes of accidents in aviation.

Human error is defined as "an inappropriate or undesirable human decision or behavior that reduces, or has the potential for reducing, effectiveness, safety, or system performance". Human error can occur at any level of the aviation system, from pilots and air traffic controllers to maintenance technicians and ground personnel. Human error can be classified into two main types: active and latent.

Active errors are those that have an immediate and direct impact on the system, such as a pilot entering a wrong heading or a controller issuing a wrong clearance. Active errors are usually easy to detect and correct, but they can also have serious consequences if they are not noticed or corrected in time.

Latent errors are those that have a delayed and indirect impact on the system, such as a faulty design or a poor procedure. Latent errors are usually hard to detect and correct, but they can also create conditions that increase the likelihood of active errors or make them more difficult to manage.

Human error can be caused by a variety of factors, such as physical, psychological, environmental, organizational, and social. Some of the common causes of human error in aviation are:

- Fatigue: a state of reduced alertness and performance due to lack of sleep, long working hours, or circadian rhythm disruption. Fatigue can impair memory, attention, decision making, and coordination, as well as increase the risk of errors and accidents.
- Stress: a state of physical or mental tension due to high workload, time pressure, conflict, or uncertainty. Stress can affect mood, motivation, judgment, and communication, as well as increase the risk of errors and accidents.
- Complacency: a state of reduced vigilance and awareness due to overconfidence, boredom, or routine. Complacency can lead to missed cues, assumptions, and shortcuts, as well as increase the risk of errors and accidents.
- Distraction: a state of diverted attention due to external or internal stimuli, such as noise, conversation, or personal problems. Distraction can cause loss of focus, concentration, and situational awareness, as well as increase the risk of errors and accidents.
- Communication: a process of exchanging information and understanding between individuals or groups, such as verbal, written, or nonverbal. Communication can be affected by language, culture, personality, and emotion, as well as by noise, interference, and ambiguity. Communication can

cause misunderstanding, confusion, and conflict, as well as increase the risk of errors and accidents.

- Teamwork: a process of collaborating and coordinating with others to achieve a common goal, such as crew resource management, threat and error management, or safety management. Teamwork can be influenced by leadership, roles, norms, and feedback, as well as by trust, respect, and cooperation. Teamwork can enhance performance, safety, and system resilience, but it can also create challenges, such as groupthink, conformity, or diffusion of responsibility.

We can see that having a human operator in the air traffic management system and in aviation in general is a major vulnerability for aviation safety, but we cannot fully replace human operators from the system because of the unique abilities of humans.

Human operators have the ability to adapt to changing and unexpected situations, which may not be anticipated or programmed by automation. For example, human pilots can use their judgment and experience to deal with emergencies, weather conditions, or conflicting traffic.

Human operators have the ability to communicate with other humans, such as passengers, crew members, air traffic controllers, or maintenance personnel. This communication is vital for ensuring safety, coordination, and customer satisfaction.

Human operators have the ability to monitor and supervise the automation, and intervene when necessary. Automation can sometimes fail, malfunction, or provide misleading information, which can lead to hazardous situations. Human operators can detect and correct these errors, and override the automation when needed.

Human operators have the ability to learn from their own and others' experiences, and improve their performance and skills over time. Automation can only perform what it is designed and programmed to do, and cannot acquire new knowledge or capabilities.

Human error cannot be completely eliminated, but it can be reduced and managed by applying a human factors approach, which aims to optimize the interaction between humans and the aviation system. Some of the possible ways to prevent and mitigate human error are:

- Design: improving the design and usability of the equipment, interfaces, and environments, such as by applying ergonomic principles, human-centered design, and user feedback.
- Training: enhancing the knowledge, skills, and attitudes of the human operators, such as by providing initial and recurrent training, simulation, and assessment.
- Procedures: establishing and following the rules, standards, and guidelines for the human tasks, such as by developing and implementing standard operating procedures, checklists, and manuals.
- Supervision: monitoring and controlling the human performance and behavior, such as by providing leadership, oversight, and feedback.
- Culture: creating and maintaining a positive and supportive organizational and social climate, such as by promoting safety culture, just culture, and reporting culture.
- Technology: using and integrating the appropriate tools and systems to assist and augment human capabilities, such as by implementing automation, decision support, and error detection and correction.

So, in this work will focus on the actions, procedures that are available to ATCO. After that I will develop a system prototype that can support ATC decision, reducing the risk and helping to implement new methods without big changes to the current airport ATM systems.

CHAPTER 1. ANALYSIS OF ANS OPERATORS` ACTIONS DURING TAKE-OFF AND LANDING

1.1 Actions recommendations for ATCOs when issuing permission for take-off and landing

Air traffic control (ATC) operators are responsible for ensuring the safe and orderly flow of aircraft in the airspace and on the ground. They communicate with pilots and other ATC facilities to provide instructions, information, and clearance for take-off and landing. ATC operators need to have a high level of situational awareness, communication skills, and decision-making abilities to perform their duties. Here are some recommendations for ATC operators to improve their performance and efficiency.

ATC operators should use the standard phraseology and procedures as prescribed by the International Civil Aviation Organization (ICAO) and the local authorities. This ensures clear and consistent communication with pilots and other ATC facilities, and reduces the risk of misunderstanding or confusion. Standard phraseology and procedures also help ATC operators to convey information in a concise and precise manner, which is essential for maintaining a high workload and avoiding frequency congestion. ATC operators should avoid using jargon, slang, or non-standard terms that may not be understood by pilots or other ATC facilities.

ATC operators are encouraged to engage in proactive planning, anticipating both the traffic scenario and pilots' requirements. This involves monitoring radar, weather, and other pertinent information sources to identify potential conflicts, hazards, or delays. Coordination with other ATC facilities is essential for facilitating a smooth and seamless transition of aircraft across various sectors or regions. Anticipating pilots' requests or actions, ATC operators should offer timely and proactive instructions, information, or clearance. For instance, issuing take-off or landing clearance promptly and minimizing unnecessary changes or cancellations is a key aspect of this anticipatory approach.

ATC operators need to demonstrate flexibility and adaptability to navigate the dynamic and unpredictable characteristics of air traffic. They should have the capability to modify their plans and strategies based on evolving traffic scenarios and operational conditions. Additionally, they must effectively manage unforeseen events or emergencies, including equipment failures, weather fluctuations, or aircraft incidents. Preparedness to employ alternative procedures or methods, such as voice communication, text chat, or visual signals, becomes crucial in instances where the standard means of communication are either unavailable or unreliable.

ATC operators must exhibit patience and politeness in their communications with pilots and other ATC facilities. It is imperative for them to acknowledge and respect the professionalism and competence of the pilots, refraining from any rudeness, sarcasm, or condescension. Recognizing that pilots may possess varying levels of experience, knowledge, or language proficiency, ATC operators should be ready to offer additional assistance or clarification when needed. Courtesy and helpfulness should be prioritized, with the use of positive and encouraging language, including expressions like "please," "thank you," or "well done." Furthermore, ATC operators should avoid interrupting or speaking over pilots or other ATC facilities, patiently waiting for acknowledgment or a response before proceeding.

ATC operators play a vital role in ensuring the safety and efficiency of air traffic. They need to have a high level of skills and knowledge to perform their duties. By following these recommendations, ATC operators can improve their performance and efficiency, and provide a better service to the pilots and the aviation industry.

1.2 Basic radiotelephony and interaction sequence between ATC and pilot during take-off and landing

The main mean of the interactions between pilot and ATCO are a radio transmitted communication sending reports and commands and receiving them. So for better context I will include basic radiotelecommunication between pilot and ATCO with the usage of standard phraseology.

Takeoff:

Pilot: "Tower, this is Alpha Bravo Charlie, holding short runway 27, ready for takeoff."

ATCO: "Alpha Bravo Charlie, Tower. Hold short, landing traffic on final."

ATCO: "Alpha Bravo Charlie, runway 27, cleared for takeoff. Wind is 240 degrees at 10 knots."

Pilot: "Cleared for takeoff, Alpha Bravo Charlie."

Landing:

Pilot: "Tower, this is Alpha Bravo Charlie, inbound for landing."

ATCO: "Alpha Bravo Charlie, Tower. Make straight-in approach, runway 27, report final."

Pilot: "Wilco, straight-in approach for runway 27, Alpha Bravo Charlie."

(Pilot approaches runway)

ATCO: "Alpha Bravo Charlie, you are cleared to land, runway 27. Wind is 230 degrees at 8 knots."

Pilot: "Cleared to land, runway 27, Alpha Bravo Charlie."

So, as we can see the communication time between the “tower” ATCO, responsible for issuing take-off and landing commands are relatively short, and contains all the necessary information for the landing of take-off and initial climb.

1.3 Wake turbulence as one of the dangerous aviation phenomena during take-off and landing

Aircraft are capable of flight by generating a force known as lift, which counteracts their weight and gravity. The process of creating wing lift for an aircraft to navigate the air is rooted in the principles of physics and fluid dynamics. It involves the wing's shape, motion, and the air's properties.

Aircraft wings are intentionally designed with a curved shape on the top and a flatter shape on the bottom. This design induces faster airflow over the wing's top compared to the bottom. According to Bernoulli's principle, faster-moving air results in lower pressure. Consequently, there is lower air pressure over the top of the wing than under the bottom, leading to a net upward force termed lift.

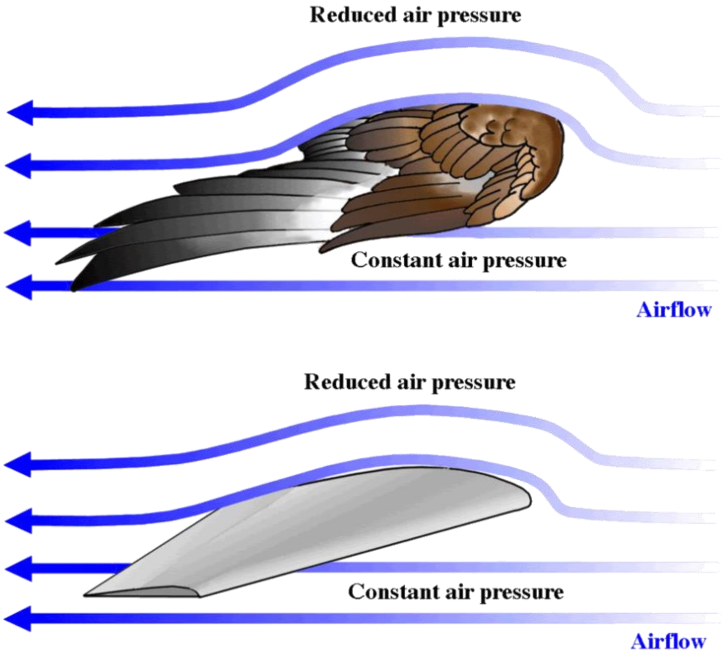

Figure 1.1 Comparison of the bird wing to the aircraft wing airflow

Several factors influence the amount of lift generated, including wing size and shape, wing angle of attack, airflow speed and direction, and air density and viscosity. These factors are encapsulated in a mathematical equation known as the lift coefficient, a dimensionless number relating lift to air dynamic pressure and wing area. The lift coefficient's calculation can utilize experimental data or computational methods, and its value may vary based on flight conditions.

Lift constitutes one of the four primary forces acting on an aircraft, alongside weight, thrust, and drag. Lift is always perpendicular to the airflow, allowing for tilting or rotation based on aircraft maneuvers. To alter the flight's direction or altitude, the aircraft employs control surfaces like ailerons, elevators, and rudders to modify the lift's magnitude and direction.

In addition to lift, aircraft require thrust to move forward, overcoming air resistance known as drag. Thrust is typically generated by engines that propel the aircraft by burning fuel and air. The magnitude of thrust depends on the engine type and size, as well as the aircraft's speed and altitude.

Wake turbulence is the disturbed airflow trailing an aircraft during its movement through the air, primarily caused by vortices originating from the wingtips. These vortices emerge due to the pressure difference between the upper and lower wing surfaces.

The intensity and duration of wake turbulence hinge on various factors, encompassing the size and weight of the aircraft generating the wake and prevailing atmospheric conditions. Larger and heavier aircraft produce more robust vortices that can endure for extended periods. Typically, concerns about wake turbulence arise during takeoff and landing phases, given the lower speeds and closer proximity to the ground.

Every aircraft generates wake turbulence during flight, a consequence of the lift creation process that gives rise to two counter-rotating vortices trailing behind the aircraft. The encountering aircraft can be affected by the strength, duration, and direction of these vortices. The resultant rolling moments may surpass the encountering aircraft's roll-control capabilities, potentially causing harm to occupants and damage to the aircraft. Pilots must remain vigilant regarding the potential for encountering wake turbulence when traversing the wake of another aircraft, adjusting their flight path accordingly.

The generation of lift, stemming from a pressure disparity over the wing surface, is responsible for creating wake turbulence. This pressure difference leads to the development of swirling air masses at the wingtips, forming two counter-rotating cylindrical vortices after the completion of the airflow roll-up process. The energy concentration within a few feet of the vortex core characterizes the wake vortex. (Refer to Fig. 1.2)

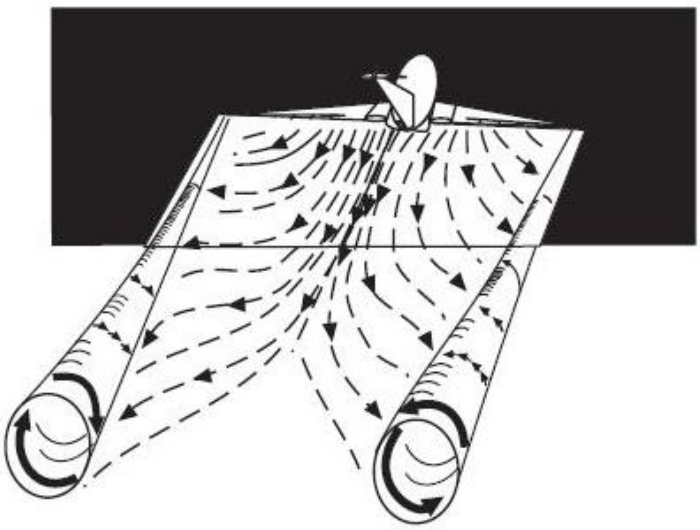

Figure 1.2 Basic vortex generation depiction after an aircraft take-off

An increasing number of aircraft are being produced or modified with winglets, which come in various types, primarily aiming to enhance fuel efficiency by improving the lift-to-drag ratio. Research indicates that winglets have minimal impact on wake turbulence generation, particularly during departures and arrivals with slower speeds.

Factors such as weight, speed, wingspan, and the shape of the generating aircraft's wing govern the strength of the vortex. The characteristics of an aircraft's vortex can also be altered by deploying flaps or other wing configuring devices. However, the strength of the vortex increases proportionally with higher operating weight or reduced aircraft speed. The most potent vortex strength occurs when the generating aircraft is HEAVY, CLEAN, and SLOW, with "dirty" aircraft configurations hastening wake decay

While rare, a wake encounter could potentially lead to catastrophic in-flight structural damage to an aircraft. However, the more common risk involves induced rolling moments that may surpass the roll-control capabilities of the encountering aircraft. Inflight tests intentionally involved aircraft flying directly into trailing vortex cores of larger counterparts, revealing that the ability to counteract the induced roll depends primarily on the wingspan and counter-control responsiveness of the encountering aircraft. These tests also highlighted the challenge for aircraft to remain within a wake vortex, as the natural tendency is for the circulation to eject the aircraft from the vortex.

Counter control is generally effective and induced roll minimal when the wingspan and ailerons of the encountering aircraft extend beyond the rotational flow field of the vortex. Aircraft with shorter wingspans relative to the generating aircraft find it more challenging to counter the induced roll caused by vortex flow. Pilots of short-span aircraft, even high-performance ones, must remain particularly vigilant for potential vortex encounters. (Refer to Fig. 1.3)

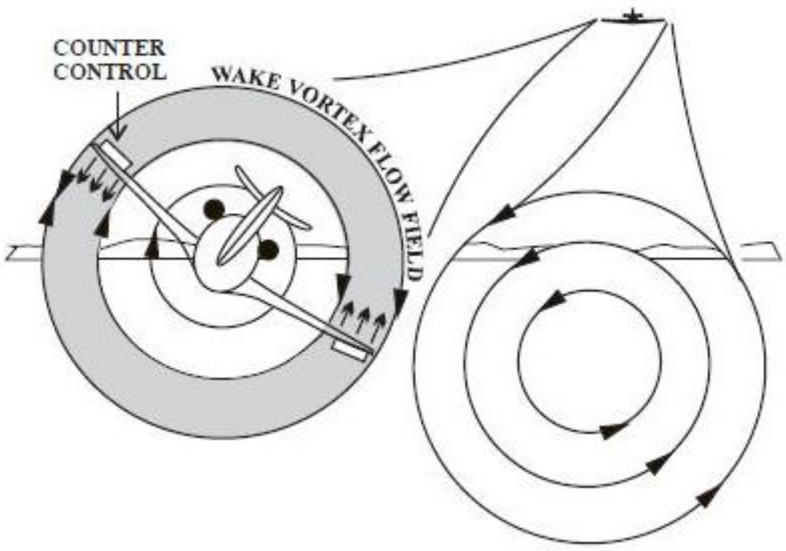

Figure 1.3 Wake vortex encounter proposed actions for pilot

Trailing vortices exhibit specific behavioral traits that enable pilots to visualize their location and, consequently, take precautionary measures for avoidance. Vortices are produced by an aircraft from the moment it rotates during takeoff to the point of touchdown, as they are an inherent result of wing lift. Pilots should pay attention to the rotation or touchdown point of the preceding aircraft before takeoff or landing. (Refer to Fig. 1.4).

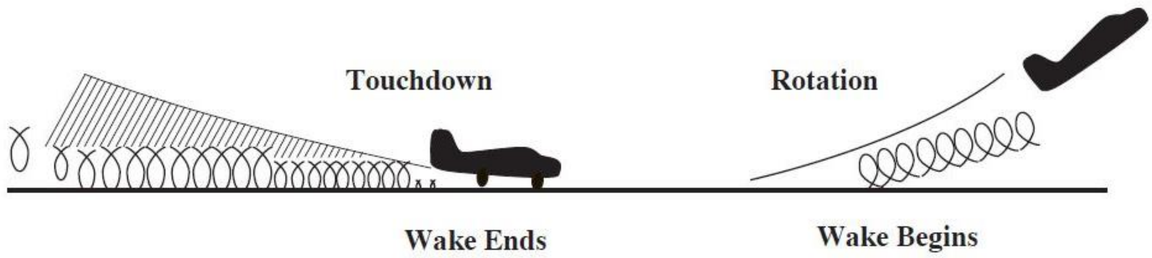

Figure 1.4 Wake vortex horizontal profile on the airfield

The vortex circulation around the wingtips is outward, upward, and observable from both the front and rear of the aircraft. Extensive tests with larger aircraft have demonstrated that these vortices maintain a spacing slightly less than a wingspan apart, drifting with the wind at altitudes exceeding a wingspan from the ground. In the presence of persistent vortex turbulence, adjusting the flight path by a slight change in altitude (upward) and lateral position (upwind) can provide a trajectory free from turbulence.

In-flight assessments have revealed that vortices from larger aircraft descend at a rate of several hundred feet per minute, slowing their descent and diminishing in strength over time and distance behind the generating aircraft. Pilots should fly at or above the flight path of the preceding aircraft, making course adjustments as needed to steer clear of the region directly behind and below the generating aircraft. Throughout all flight phases, pilots must remain vigilant for potential wake effects from other aircraft. Research indicates that atmospheric turbulence accelerates wake breakup, while various atmospheric conditions can transport wake both horizontally and vertically.

As vortices from larger aircraft approach the ground (within 100 to 200 feet), they tend to move laterally over the ground at a speed of 2 or 3 knots.

1.4 Statistics of aviation incidents and accidents caused by wake turbulence

While wake turbulence is a dangerous phenomenon that severely affects aircraft performance and controllability it’s one of the quite rare factors of aviation incidents and accidents. According to the National Transportation Safety Board (NTSB) database from the year 2002 there were only 28 events with aircraft wake turbulence encounter in United States of America [4]. And according to the Aviation Safety Network database there were 18 events of which 11 were fatal [5].

Number of events may seem very low but all of them marked as accident meaning that there were loss of life, loss of aircraft, or significant financial damage, so there also a large portion of incidents that didn’t make it to the statistics reports. Even if with all unaccounted incidents the number will be about 100 events the wake turbulence is still one of the dangerous phenomena, an approach to which can be reviewed and approved. From the statistics we can also see that while simple turbulence is the cause to accidents majorly on-route, the wake turbulence has a lot of its incidents near the ground, during take-off and landing

In this section I want to review three events reports involving wake turbulence and review their causes.

1.4.1 Beech Liner, Boeing 757 & Israel Westwind

Based on the National Transportation Safety Board Aviation Accident Final Report LAX94FA073 [6], Beech Liner, Boeing 757, and Israel Westwind were directed for landings on Runway 19R. The 757 and Westwind were sequenced for visual approaches behind the Beech Liner. Prior to being authorized for a visual approach, the Westwind was closing in at a distance of 3.5 miles from the 757 on a converging course. Both the 757 and Westwind crews received instructions to reduce speed to 150 knots. The 757 decelerated below 150 knots and approached on final with a descent angle of 5.6 degrees. Meanwhile, the Westwind continued to converge and reached a distance of approximately 2.1 miles behind the 757 on a 3-degree approach. Air Traffic Control (ATC) did not explicitly inform, nor was it mandated by the ATC handbook to inform, the Westwind pilots that they were trailing a Boeing 757. The captain discussed potential wake turbulence, maintained an Instrument Landing System (ILS) trajectory 1 dot high, acknowledged proximity to the 757, and expressed confidence in the situation. While descending at approximately 1100 feet above sea level, the Westwind encountered wake turbulence from the 757, entered into a steep descent, and subsequently crashed. The crew lacked specific training on wake turbulence. Chlorpheniramine, a common over-the-counter antihistamine not approved for flying, was detected in the pilot's lung tissue at a concentration of 0.094 μg/mL.

Management Activities, Inc., the officially registered owner, was responsible for the airplane's maintenance and supplied the Safety Board with the aircraft's maintenance records. The company's maintenance personnel adhered to the manufacturer's inspection program, as approved by the FAA Long Beach Flight Standards District Office.

On June 10, 1993, the maintenance personnel completed the most recent 150-hour inspection. At the moment of the accident, the airplane had accumulated a total of 3,027 hours, which included the flights conducted on the day of the incident. This represented 95 hours since the completion of the last inspection.

Data from multiple radar facilities were acquired and graphed. The radar track depicting the flight profile reveals that, at a location 7 nautical miles from the airport, the trajectory of N309CK consistently remained beneath that of UAL 103. As N309CK approached the airport and reached approximately 3.5 nautical miles from it, its flight path dipped to around 400 feet below the flight path of UAL 103, while maintaining a separation of approximately 2.1 miles behind. Both N309CK and UAL 103 followed glide paths of 3 degrees and 5.6 degrees, respectively.

The aircraft crashed in an empty area adjacent to several nearby buildings, positioning it approximately 100 feet to the right of the extended centerline of John Wayne Airport's runway 19R. Analysis of ground scars and wreckage examination indicated that the airplane impacted the ground at a roughly 45-degree nose-down angle with level wings. The airplane's nose was oriented toward approximately 165 degrees, while its flight path exhibited a descent angle of about 80 degrees. Debris from the wreckage scattered outward from the primary impact site, reaching up to 100 feet in a 30-degree arc tangential to the airplane's centerline.

The Santa Ana Fire Department reached the accident site at 1743 hours. The battalion chief stated that the firefighting team faced no challenges in extinguishing the fire. The fire was successfully suppressed by 1758 hours.

Postmortem examinations on both pilots were conducted by the Orange County Medical Examiner/Coroner's Office. The pathologist's findings revealed that neither pilot exhibited any medical condition or disease that could have impacted their ability to perform their duties. The FAA's Civil Aeromedical Institute (CAMI) in Oklahoma City, Oklahoma, performed toxicological examinations on both pilots. The toxicologist's report confirmed the absence of alcohol or drugs in the first officer's examinations.

In the case of the pilot-in-command (PIC), toxicological analysis of lung tissue indicated the presence of 0.01 percent (11 mg/dl) ethanol and 0.094 ug/g (0.094 mg/kg) of chlorpheniramine. It was noted in the toxicological report that the specimen was in a state of decomposition. However, analysis of kidney, gastric content, and other body tissues was not conducted, and a blood specimen for analysis was unavailable.

The Guide for Aviation Medical Examiners [7], issued by the Office of Aviation Medicine of the Federal Aviation Administration, stipulates that "Any airman who is undergoing continuous treatment with antihistaminic, antiviral, ataraxic, barbiturate, experimental, hypoglycemic, investigational, mood-ameliorating, motion sickness, narcotic, sedative, tranquilizer, or steroid drugs must be deferred certification unless the treatment has previously been cleared by FAA medical authority." The duration of the pilot's use of the antihistaminic drug, chlorpheniramine, and the timing of its last usage are unknown. Nevertheless, in accordance with the provided guidance and discussions with Aviation Medicine staff, the utilization of this drug while flying is prohibited.

The FAA classifies airplanes based on their maximum gross takeoff weight. Aircraft weighing less than 12,500 pounds fall into the category of light airplanes, those between 12,500 pounds and 300,000 pounds are classified as large airplanes, and those exceeding 300,000 pounds are designated as heavy airplanes. Both the Westwind and Boeing 757 are considered large aircraft.

These categories form the foundation for the FAA's IFR separation standards. As of the accident date, the separation standard between a large and heavy airplane is 5 nautical miles, while the standard between large airplanes is 3 nautical miles.

According to the FAA Air Traffic Handbook 7110.65H, change 1[8], Visual Separation, it is stated that, "...The tower shall not provide visual separation between aircraft when wake turbulence separation is required or when the lead aircraft is a B-757...." Change 1 was scheduled to take effect on January 6, 1994.

The National Business Aircraft Association (NBAA) furnished the Safety Board with information detailing fly-by and other engineering tests carried out by the FAA through independent investigators and by the British Civil Aviation Authority (CAA) in 1992. This data, originating in 1991, revealed multiple cases wherein large turbine jets such as the Boeing 737, McDonnell-Douglas DC-8, and various corporate jet aircraft experienced loss of control while trailing Boeing 757 aircraft.

The National Transportation Safety Board has determined that the probable cause(s) of this accident is the failure of the pilot-in-command to maintain sufficient separation behind the Boeing 757 and/or remain above its flight path during the approach, leading to an encounter with wake vortices from the 757. Contributing factors to the accident include deficiencies in the air traffic control procedure concerning visual approaches and VFR operations behind heavier airplanes. This, in turn, resulted in a lack of information available to the Westwind pilots to assess the relative flight path of their airplane in relation to the Boeing 757's flight path.

1.4.2 Cessna 185F ZK-PRM wake turbulence encounter Wellington International Aerodrome

According to Transport accident investigation commission Aircraft Accident Report 97-004 [9], on Monday, March 3, 1997, at 10:14 hours, Cessna 185F ZK-PRM took off from runway 16 at Wellington International Aerodrome, following a Boeing 727 that had departed just ahead. The Cessna encountered wake turbulence, leading to a loss of control at an altitude from which recovery was not possible. Fortunately, neither of the two occupants sustained injuries, but the aircraft suffered substantial damage. The pilot-initiated takeoff from a midpoint runway position and had specifically requested and received a waiver for the wake turbulence separation standards. However, the pilot miscalculated the anticipated area of wake turbulence in the takeoff path. This error resulted from a momentary lapse in concentration, attributed in part to the routine nature of the flight and the pilot's preoccupation with personal concerns. Safety issues discussed include the appropriateness of granting waivers for wake turbulence separation standards. Safety recommendations were proposed in response to these identified safety issues.

ZK-PRM encountered wake turbulence shortly after taking off, leading to an involuntary loss of control at an altitude from which recovery was not possible. The wake turbulence was generated by a preceding Boeing 727 that had departed directly ahead of the Cessna. Subsequently, ZK-PRM experienced a sharp roll to the right, indicating a likely encounter with the left wing-tip vortex from the Boeing. The pilot attempted recovery by applying full opposite aileron and rudder; however, the roll exceeded the aircraft's capability to overcome it. The relatively short wing span of the Cessna 185 likely contributed to its inability to recover. At the time of the encounter, the crosswind component was less than five knots from the left, and there was a headwind component of approximately 13 knots. Consequently, the left wing-tip vortex would have remained within the Boeing's flight path over the runway and drifted back toward ZK-PRM.

The pilot's initial plan was to climb above the Boeing's departure path to avoid encountering its vortices. However, the pilot either miscalculated or did not fully consider the vortices' location in relation to the aircraft's flight path or the impact of the wind on the vortices' movement and dissipation time. The aerodrome controller on duty at Wellington Tower provided the pilot with ample warning regarding the potential wake turbulence behind the Boeing, informing the pilot of a standard three-minute delay for take-off clearance. Despite this, the pilot chose to exercise his right to take responsibility for his own wake turbulence separation and requested a waiver of the standard separation requirements. The controller granted the request, instructing the pilot to line up on the runway and be prepared for an immediate departure. It's crucial to note that the pilot had the discretion to reject this instruction if he deemed it inappropriate or unsafe, yet he accepted it and took off shortly afterward. The pilot, an experienced international airline captain, had accrued significant flight hours in light aircraft and was well-versed in operating the Cessna 185. He possessed knowledge about wake turbulence and its avoidance.

Wing-tip vortices exhibit an unpredictable nature, making it challenging to accurately predict their path. Adequate time should be allowed for the vortices to dissipate before initiating take-off behind a departing aircraft, especially when the subsequent aircraft is scheduled to become airborne near the rotation point of a heavier aircraft.

Opting for a departure from an intermediate runway position increases the likelihood of placing a following lighter aircraft in the wake of a preceding heavier aircraft. Had the pilot adhered to the standard three-minute wait before taking off, the accident could likely have been averted. However, the controller had the authority to grant the pilot's request. The pilot's decision to take off shortly after the Boeing, in close proximity to its departure point, and to disregard clear warnings of wake turbulence appears inconsistent with the behavior expected from a pilot of his experience and background. The pilot's actions thus necessitate an explanation.

In the week preceding the accident, the pilot had experienced a heightened level of emotional stress due to the suspension of his airline's operating license. This situation was novel for him, and the uncertainty regarding the future of his airline and the employment of its staff added to his frustration in resolving the issues leading to the suspension. ZK-PRM was the pilot's personal aircraft used for commuting between his home and Wellington. The purpose of the accident flight was to return home with his wife, refresh, and then return to Wellington later in the day. As he taxied and initiated take-off, he was performing a routine task that he had executed many times before.

The elevated emotional stress and events of the preceding week likely combined to divert the pilot's conscious attention away from the imperative task of safely operating his aircraft. While performing routine tasks during taxiing and pre-takeoff preparations that required minimal cognitive effort, the pilot, accustomed to hearing warnings about wake turbulence, made an error in assessing or overlooked the probable area of wake turbulence in his take-off path. This lapse in judgment resulted from a momentary lapse in concentration, partly due to the routine nature of the flight and partly due to his preoccupation with personal concerns.

This incident underscores the potential challenges faced by an aircraft taking off from an intermediate runway position behind a larger aircraft when the wake turbulence separation standard is waived.

Globally implemented standard separation criteria exist for valid reasons, given the severity and somewhat unpredictable nature of wing-tip vortices. Aerodrome controllers bear the responsibility of providing advice and warnings about potential wake turbulence and applying standard separations when they anticipate its presence. Pilots must assume the responsibility of avoiding wake turbulence and exercise sound judgment when alerted to its possible existence.

Aerodrome controllers, however, should have clear guidelines for granting waivers of separation standards. In certain circumstances, some countries prohibit the issuance of waivers.

Certain commercial operators permit their pilots to request waivers, creating the potential for a similar incident at a busy aerodrome with potentially catastrophic consequences, such as a collision with a terminal building or a collision with a taxiing aircraft.

1.4.3 Embraer ERJ170-100STD Cabin Attendant injury by the shaking of the aircraft.

On Tuesday, April 29, 2014, at 09:16 Japan Standard Time (JST, UTC+9h), a J-AIR Co., LTD. operated Embraer ERJ170-100STD with registration JA211J commenced its departure from Yamagata Airport as scheduled flight 1252, part of a codeshare arrangement with Japan Airlines Co., Ltd. At approximately 09:45 JST, during the descent for Tokyo International Airport, the aircraft experienced turbulence at an altitude of around 10,600 ft over Ishioka City, Ibaraki Prefecture. During this event, one cabin attendant sustained serious injuries, and another cabin attendant suffered minor injuries, both of whom were situated in the aft galley. The total number of occupants on board was 39, comprising the pilot in command (PIC), three additional crew members, and 35 passengers. It's worth noting that the aircraft itself sustained no damage.

At the moment of this accident, the Pilot-in-Command (PIC) was seated in the left seat, primarily responsible for duties other than flying, while the First Officer (FO) occupied the right seat, serving as the Pilot Flying (PF). The flight's chronological account leading up to the accident is outlined below, derived from the flight recorder data, Air Traffic Control (ATC) communications records, and statements provided by the crew members. During the pre-flight weather briefing, the Pilot-in-Command (PIC) verified the presence of a front echo in western Japan. However, there was no anticipated adverse weather forecast for the journey from Yamagata Airport to Tokyo International Airport. Approximately five minutes after departure from Yamagata Airport, the PIC deactivated the seat belt sign.

The aircraft received instructions to change heading and reduce speed to maintain separation with the preceding aircraft before reaching STONE (waypoint), the initial point for the standard terminal arrival route. It successfully passed STONE at the instructed speed of 250 knots and an altitude of 11,000 feet. Subsequently, around 10 nautical miles before reaching DREAD (waypoint), the aircraft commenced descent upon receiving an instruction to descend to 8,000 feet.

Shortly after the Pilot-in-Command (PIC) finished providing information, the aircraft experienced turbulence, leading to a significant left bank. Observing this unexpected movement, the PIC promptly activated the seat belt sign as the aircraft banked more rapidly than usual during circling. Although the roll was unintended, it was a relatively fast but not extreme bank. The Auto Pilot (A/P) was disengaged at this point. As the PIC monitored the First Officer's (FO) actions, the aircraft's attitude began to recover. Assessing that the FO could manage the aircraft, the PIC relinquished control, allowing the FO to remain the Pilot Flying (PF). Once the aircraft stabilized, the FO instructed to set the A/P, and with mutual agreement, the PIC engaged the Auto Pilot.

While the PIC couldn't recall the specific details of the aircraft's shaking during the bank, he remembered it was not within clouds. Despite having adequate separation from the preceding aircraft, the PIC attributed the shaking to wake turbulence, drawing on past experiences with similar encounters. To reassure the passengers, the pilot made a public address announcement, assuring them that there would be no more shaking. Additionally, he verified the cabin situation with the cabin attendants, and since no issues were reported, he instructed them once again to conduct cabin safety checks. The aircraft landed on runway 23 of Tokyo International Airport without any further incidents.

One cabin attendant was seriously injured and one other cabin attendant was slightly injured.

After the day’s flight, the Aircraft underwent a special inspection which is required after encountering severe turbulence, the auto flight operational test and the flight control system test; however, no damage or anomalies were found.

Based on the radar track records from the Tokyo radar approach control facility, an Airbus A340-600, hereafter referred to as the "Preceding Aircraft," was flying approximately 10 nautical miles in front of the subject aircraft (about two minutes ahead) on route to Tokyo International Airport. The Preceding Aircraft executed a left turn to a heading of 190° for the final approach course to runway 22 of Tokyo International Airport, following radar vectors provided by the Tokyo radar approach control facility. This turn occurred around 12 nautical miles before reaching the point known as DREAD, and the altitude had been maintained at 11,000 feet since before passing STONE.

While the Tokyo radar approach control facility instructed the subject aircraft, which was trailing the Preceding Aircraft, to descend earlier than the Preceding Aircraft, the radar track records indicate that the separation between the two aircraft was approximately 10 nautical miles. This confirms that there was ample separation exceeding the prescribed 5 nautical miles, which represents the Minimum Separation mandated by the wake turbulence control procedure between HEAVY and MEDIUM aircraft.

The likelihood is that this incident occurred due to the Aircraft encountering significant wake turbulence from the Preceding Aircraft while in descent, resulting in the shaking of the Aircraft. Consequently, two cabin attendants in the aft galley fell, with one sustaining serious injury. The extended duration of the encountered strong wake turbulence is likely attributable to the stable weather conditions characterized by calm winds.

Conclusions to chapter 1

Concluding this chapter almost all interactions between pilot and air traffic controller are achieved trough the means of the radiotelephony. And the big part of the information about aircraft position and possible maneuvers in the near future are passed from pilot to the air traffic controller also through the verbal communication channel. So, such simple channel can be used for low-cost systems, and user-friendly systems.

Wake turbulence is one of the dangerous conditions during take-off and landing and not easily detectable as for example bad visibility or icing. Wake vortex turbulence encounter is hard to detect and very dangerous especially in the low altitude conditions as such as during landing and take-off.

There were a decent number of incidents main cause of which was an occurrence of the wake turbulence in the flight path of the aircraft. And after looking through them there were piloting errors and errors in evaluation of the wake turbulence effect by pilot, but there were also an incidents when all current separations where met and they were not sufficient to prevent wake turbulence effect on the succeeding aircraft.

CHAPTER 2. CURRENT METHODS OF AIRCRAFTS SEPARATION DURING TAKE-OFF AND LANDING

2.1 ICAO wake turbulence categorization

The ICAO wake turbulence category (WTC) is denoted by the appropriate single-character wake turbulence category indicator in Item 9 of the ICAO model flight plan form. This categorization is determined based on the maximum certificated take-off mass.

Maximum Take-Off Weight. The maximum takeoff mass (MTOM), often referred to as maximum takeoff weight (MTOW), of an aircraft is a value defined by the aircraft manufacturer. It is the maximum mass at which the aircraft is certified for take off due to structural or other limits. MTOW is usually specified in units of kilograms or pounds. The mass is a fixed value and does not vary with changes in temperature, altitude or runway available.

As of 2020, there are four distinct categories defined as follows:

- Light (L) — Encompassing aircraft types with a maximum certificated take-off mass of 7,000 kg or less.
- Medium (M) — Covering aircraft types exceeding 7,000 kg but falling below 136,000 kg.
- Heavy (H) — Including all aircraft types with a maximum certificated take-off mass of 136,000 kg or more, excluding those in the Super (J) category.
- Super (J) — Comprising aircraft types explicitly designated as such in ICAO Doc 8643, Aircraft Type Designators.

As of 2023, the lone aircraft in Category J is the Airbus A380, boasting a maximum take-off weight (MTOW) of 575 t (1,268,000 lb). Before its unfortunate demise, the singular Antonov An-225 (MTOW of 640 t or 1,410,000 lb) held the FAA classification of Super, although ICAO classified it as Heavy. It's noteworthy that the Antonov An-225 and the Antonov An-124 Ruslan bear the Super classification by the UK Civil Aviation Authority, whereas ICAO designates them as Heavy.

It's important to recognize that not all aircraft variants of the same model share identical wake turbulence categories. For instance, the narrow-bodied Boeing 707-100 falls under the Medium category, while the 707-300 is categorized as Heavy. Upon initial radio contact with ATS units, aircraft classified as "super" or "heavy" are required to incorporate the term "super" or "heavy" immediately after the aircraft call-sign. This serves as a cautionary measure, alerting ATS and other aircraft to exercise additional separation precautions to mitigate the risk of encountering wake turbulence from these specific aircraft types.

Using this wake turbulence categories, we can separate aircraft by distance or use time-based separation. For the distance-based separation the following minimal values used:

Table 2.1 Distance-based wake separation minima

Preceding aircraft	Succeeding aircraft	Distance-based wake turbulence separation minima
Super	Heavy	9.3 kilometers (5.0 nm.)
	Medium	13 kilometers (7.0 nm.)
	Light	14.9 kilometers (8.0 nm.)
Heavy	Heavy	7.4 kilometers (4.0 nm.)
	Medium	9.3 kilometers (5.0 nm.)
	Light	11.1 kilometers (6.0 nm.)
Medium	Light	9.3 kilometers (5.0 nm.)

As for the time-based separation the departing aircrafts separation minima are differ taking into consideration the runway scheme of the airport, while the approaching aircraft intervals are as follows:

Table 2.2 Time-based wake turbulence separation minima for departure

Preceding aircraft	Succeeding aircraft	Time-based wake turbulence separation minima
Super	Heavy	2 minutes
	Medium	3 minutes
	Light	4 minutes
Heavy	Medium	2 minutes
	Light	3 minutes
Medium	Light	3 minutes

For departing aircraft on the:

- Same runway ;
- Parallel runways separated by less than 760 m (2 500 ft) ;
- Crossing runways if the projected flight path of the second aircraft will cross the projected flight path of the first aircraft at the same altitude or less than 300 m (1 000 ft) below ;
- Parallel runways separated by 760 m (2 500 ft) or more, if the projected flight path of the second aircraft will cross the projected flight path of the first aircraft at the same altitude or less than 300 m (1 000 ft) below.

Separation minimal used:

Table 2.3 Time-based wake turbulence separation minima for departure on parallel runways

Preceding aircraft	Succeeding aircraft	Time-based wake turbulence separation minima
Super	Heavy	2 minutes
	Medium	3 minutes
	Light	3 minutes
Heavy	Medium	2 minutes
	Light	2 minutes
Medium	Light	2 minutes

For departing aircraft taking off from an intermediate part of the same runway or an intermediate part of a parallel runway separated by less than 760 m (2 500 ft), the following minimum separations shall be applied:

Table 2.4 Time-based wake turbulence separation minima for departure from intermediate part

Preceding aircraft	Succeeding aircraft	Time-based wake turbulence separation minima
Super	Heavy	3 minutes
	Medium	4 minutes
	Light	4 minutes
Heavy	Medium	3 minutes
	Light	3 minutes
Medium	Light	3 minutes

When using wake turbulence categories contained in and when operating a displaced landing threshold, the following minimum separations shall be applied if the projected flight paths are expected to cross:

Table 2.5 Time-based wake turbulence separation minima for displaced threshold runways on arrival.

Preceding arriving aircraft	Succeeding arriving aircraft	Time-based wake turbulence separation minima
Super	Heavy	2 minutes
	Medium	3 minutes
	Light	3 minutes
Heavy	Medium	2 minutes
	Light	2 minutes
Medium	Light	2 minutes

Table 2.6 Time-based wake turbulence separation minima for displaced threshold runways on departure.

Preceding arriving aircraft	Succeeding departing aircraft	Time-based wake turbulence separation minima
Super	Heavy	2 minutes
	Medium	3 minutes
	Light	3 minutes
Heavy	Medium	2 minutes
	Light	2 minutes
Medium	Light	2 minutes

When applying the wake turbulence categories and a heavier aircraft is making a low or missed approach and the lighter aircraft is:

- Utilizing an opposite-direction runway for take-off; or
- Landing on the same runway in the opposite direction, or on a parallel opposite-direction runway separated by less than 760 m (2 500 ft),

The following minimum separations shall be used:

Table 2.7 Time-based wake turbulence separation minima for opposite directions.

Preceding arriving aircraft	Succeeding departing aircraft	Time-based wake turbulence separation minima
Super	Heavy	3 minutes
	Medium	4 minutes
	Light	4 minutes
Heavy	Medium	3 minutes
	Light	3 minutes
Medium	Light	3 minutes

2.2 ICAO RECAT wake turbulence categorization

The current wake vortex separation regulations established by the rely solely on aircraft weight, categorized as Heavy, Medium, or Light. While generally safe, these rules are now considered outdated and often result in excessive separation, reducing airport capacity and causing unnecessary traffic delays, leading to increased costs, fuel consumption, and emissions.

For instance, both the Boeing 747 and the Boeing 767 fall under ICAO's "Heavy" aircraft category. While the traditional 4nm separation distance is suitable when the 767 is trailing the 747, it becomes excessive in the opposite scenario. To safely reduce separation distances between specific aircraft pairs, whether during departure or final approach, it's essential to consider both the wake vortex generated by the leading aircraft and the ability of the following aircraft to resist it.

Difference with legacy	A380	A124	A330 / B777	MD11 / B767	B757	A320 / B737NG	E190 / DH8D	E170 / ATR72 / CRJ1	CL30	LIGHT
A380	0	-2	-2	-1	-2	-2	-1	-1	1	0
A124	0	-1	-1	0	-1	-1	0	0	2	1
A330 / B777	0	-1	-1	0	-1	-1	0	0	2	1
MD11 / B767	0	-1.5	-1.5	-1.5	-2	-2	-1.5	-1.5	1	0
B757	0	0	0	0	0	0	0	0	1.5	-1
A320 / B737NG	0	0	0	0	0	0	0	0	1.5	-1
E190 / DH8D	0	0	0	0	0	0	0	0	1.5	-1
E170 / ATR72 / CRJ1	0	0	0	0	0	0	0	0	0	-2.5
CL30	0	0	0	0	0	0	0	0	0	-2.5
LIGHT	0	0	0	0	0	0	0	0	0	0

Figure 2.1 Difference between RECAT and legacy in nm.

The ICAO's classification of aircraft into three weight-dependent groups has long been deemed insufficient by numerous National Aviation Authorities, resulting in regional variations in categories and separation standards. The introduction of the Airbus A380 and concerns about its wake vortex turbulence prompted an ICAO-supervised joint study involving experts from Airbus, the FAA, EUROCONTROL, and JAA/EASA. While the primary focus was the A380, the study also led to the introduction of the RECAT program, following over 180 hours of innovative flight testing, including back-to-back comparative tests, cruise wake encounter evaluations, and ground and airborne LIDAR wake measurements.

Difference ICAO	A380	A124	A330 / B777	MD11 / B767	B757	A320 / B737NG	E190 / DH8D	E170 / ATR72 / CRJ1	CL30	LIGHT
A380	0	-20	-20	0	-40	-40	-20	-20	0	0
A124	0	0	0	0	-20	-20	0	0	20	20
A330 / B777	0	0	0	0	-20	-20	0	0	20	20
MD11 / B767	0	0	0	0	-40	-40	-20	-20	0	0
B757	0	0	0	0	0	0	0	0	60	0
A320 / B737NG	0	0	0	0	0	0	0	0	60	0
E190 / DH8D	0	0	0	0	0	0	0	0	40	-20
E170 / ATR72 / CRJ1	0	0	0	0	0	0	0	0	0	-60
CL30	0	0	0	0	0	0	0	0	0	-60
LIGHT	0	0	0	0	0	0	0	0	0	0

Figure 2.2 Difference in time-based separation between legacy and RECAT

When approved by the appropriate ATS authority, wake turbulence separation minima may be applied utilizing wake turbulence groups and shall be based on wake generation and resistance characteristics of the aircraft. These depend primarily on maximum certificated take-off mass, wing characteristics and speeds; the group designators are described as follows:

- GROUP A — aircraft types of 136 000 kg or more, and a wing span less than or equal to 80 m but greater than 74.68 m;
- GROUP B — aircraft types of 136 000 kg or more, and a wing span less than or equal to 74.68 m but greater than 53.34 m;
- GROUP C — aircraft types of 136 000 kg or more, and a wing span less than or equal to 53.34 m but greater than 38.1 m;

- GROUP D — aircraft types less than 136 000 kg but more than 18 600 kg, and a wing span greater than 32 m;
- GROUP E — aircraft types less than 136 000 kg but more than 18 600 kg, and a wing span less than or equal to 32 m but greater than 27.43 m;
- GROUP F — aircraft types less than 136 000 kg but more than 18 600 kg, and a wing span less than or equal to 27.43 m;
- GROUP G — aircraft types of 18 600 kg or less (without wing span criterion).

Using this wake turbulence groups we can separate aircrafts by distance or use time-based separation. For the distance-based separation the following minimal values used:

Table 2.8 RECAT Distance-based wake turbulence separation minima.

Preceding aircraft	**Succeeding aircraft**	**Distance-based wake turbulence separation minima**
A	B C D E F G	7.4 kilometers (4.0 nm.) 9.3 kilometers (5.0 nm.) 9.3 kilometers (5.0 nm.) 11.1 kilometers (6.0 nm.) 11.1 kilometers (6.0 nm.) 14.9 kilometers (8.0 nm.)
B	B C D E F G	5.6 kilometers (3.0 nm.) 7.4 kilometers (4.0 nm.) 7.4 kilometers (4.0 nm.) 9.3 kilometers (5.0 nm.) 9.3 kilometers (5.0 nm.) 13 kilometers (7.0 nm.)
C	D E F G	5.6 kilometers (3.0 nm.) 6.5 kilometers (3.5 nm.) 6.5 kilometers (3.5 nm.) 11.1 kilometers (6.0 nm.)
D	G	7.4 kilometers (4.0 nm.)
E	G	7.4 kilometers (4.0 nm.)

When using wake turbulence groups and when the aircraft are using:

- the same runway;
- parallel runways separated by less than 760 m (2 500 ft);
- crossing runways if the projected flight path of the second aircraft will cross the projected flight path of the first aircraft at the same altitude or less than 300 m (1 000 ft) below;
- parallel runways separated by 760 m (2 500 ft) or more, if the projected flight path of the second aircraft will cross the projected flight path of the first aircraft at the same altitude or less than 300 m (1 000 ft) below;

The following separations shall be applied:

Table 2.9 RECAT Time-based wake turbulence separation minima.

Preceding aircraft	**Succeeding aircraft**	**Time-based wake turbulence separation minima**
A	B C D E F G	100 seconds 120 seconds 140 seconds 160 seconds 160 seconds 180 seconds
B	D E F G	100 seconds 120 seconds 120 seconds 140 seconds
C	D E F G	80 seconds 100 seconds 100 seconds 120 seconds
D	G	120 seconds
E	G	100 seconds

When applying the wake turbulence groups for aircraft taking off from an intermediate part of the same runway or an intermediate part of a parallel runway separated by less than 760 m (2 500 ft), the following minimum separations shall be applied:

Table 2.10 RECAT Time-based wake turbulence separation minima for departure from intermediate part of runway.

Preceding aircraft	Succeeding aircraft	Time-based wake turbulence separation minima
A	B C D E F G	100 seconds 120 seconds 140 seconds 160 seconds 160 seconds 180 seconds
B	D E F G	100 seconds 120 seconds 120 seconds 140 seconds
C	D E F G	80 seconds 100 seconds 100 seconds 120 seconds
D	G	120 seconds
E	G	100 seconds

When using wake turbulence groups and when operating a displaced landing threshold, the following minimum separations shall be applied when a departing aircraft follows an arriving aircraft, if the projected flight paths are expected to cross:

Table 2.11 RECAT Time-based wake turbulence separation minima for displaced landing threshold Departing/Arriving.

Preceding arriving aircraft	Succeeding departing aircraft	Time-based wake turbulence separation minima
A	B C D E F G	100 seconds 120 seconds 140 seconds 160 seconds 160 seconds 180 seconds

B	D E F G	100 seconds 120 seconds 120 seconds 140 seconds
C	D E F G	80 seconds 100 seconds 100 seconds 120 seconds
D	G	120 seconds
E	G	100 seconds

When using wake turbulence groups and when operating a displaced landing threshold, the following minimum separations shall be applied when an arriving aircraft follows a departing aircraft, if their projected flight paths are expected to cross:

Table 2.12 RECAT Time-based wake turbulence separation minima for displaced landing threshold Arriving/Departing.

Preceding departing aircraft	Succeeding arriving aircraft	Time-based wake turbulence separation minima
A	B C D E F G	100 seconds 120 seconds 140 seconds 160 seconds 160 seconds 180 seconds
B	D E F G	100 seconds 120 seconds 120 seconds 140 seconds
C	D E F G	80 seconds 100 seconds 100 seconds 120 seconds
D	G	120 seconds
E	G	100 seconds

When applying the wake turbulence groups and a heavier aircraft is making a low or missed approach and the lighter aircraft is:

- Utilizing an opposite-direction runway for take-off; or
- Landing on the same runway in the opposite direction, or on a parallel opposite-direction runway separated by less than 760 m (2 500 ft),

The following minimum separations shall be used:

Table 2.13 RECAT Time-based wake turbulence separation minima for opposite directions.

Preceding aircraft	Succeeding aircraft	Time-based wake turbulence separation minima
A	B C D E F G	160 seconds 180 seconds 200 seconds 220 seconds 220 seconds 240 seconds
B	D E F G	160 seconds 180 seconds 180 seconds 200 seconds
C	D E F G	140 seconds 160 seconds 160 seconds 180 seconds
D	G	180 seconds
E	G	160 seconds

2.3 AMAN/DMAN

The Arrival Manager (AMAN) assists air traffic controllers in the effective coordination of incoming flights, optimizing the use of available runway and airspace capacities. It offers decision support to controllers handling arrival traffic, accommodating multi-runway configurations and multi-airport scenarios when necessary. Equipped with advanced functionalities such as route recommendations, holding and speed advice, as well as the computation of take-off times for short-route flights and what-if analyses, the system minimizes aircraft holding, leading to more streamlined and predictable flight operations.

The Departure Manager (DMAN) ensures consistent and optimized planning for outbound traffic at airports, resulting in refined target times for both runways and stands. DMAN maximizes the utilization of runway capacity, reduces fuel consumption, and brings about substantial enhancements in the predictability of outbound traffic. Among its advanced features are minimum departure intervals to facilitate efficient Traffic Management Area (TMA) control, resolution of stand contentions to prevent conflicts during push-backs from neighboring stands, and integration with Advanced Surface Movement Guidance and Control Systems (A-SMGCS) or Surface Management (SMAN) systems.

The Integrated Arrival Manager/Departure Manager (IAD) efficiently manages the balance between incoming and outgoing traffic demands. It plans the respective traffic streams in an optimized mixed-mode runway sequence to make the best use of the constrained runway capacity. Additionally, it enhances predictability by providing more realistic and precise accuracy on landing and departure times, thereby increasing runway throughput. The system not only facilitates coordination between the tower and approach but also improves the situational awareness of the controllers involved.

Conclusions to chapter 2

The usage of legacy separation is a simple and easy to use and memorize method to minimize risk of wake vortex turbulence induced incidents and accidents. But the four categories-based system of separation is in some times are providing to much separation and sometimes gives not enough separation resulting in incidents. The transfer to the new ICAO RECAT wake turbulence group based system is an effective measure, but involving a more detailed seven groups of wake turbulence that not only based on the aircraft maximum take-off weight but also on the wingspan of the aircraft is putting additional work on the ATCO needing from him a more detailed knowledge about aircrafts that are operating in his area of responsibility. Also, the possible separations minima number are increased because of seven groups of preceding aircrafts and seven group of succeeding aircraft in the change of just three and one category where only one type of aircraft is placed.

There are modern complex solutions for automatic air traffic managing such as AMAN/DMAN but it’s a complex system introduced in one of the busiest airports of the world and with costly requirements to the equipment installed on the aerodrome.

CHAPTER 3. PROTOTYPE OF ATC DECISION SUPPORT SYSTEM FOR ISSUING TAKE-OFF AND LANDING PERMITS

3.1 ATC Decision support system for issuing take-off and landing permits concept.

As seen from previous chapters we can conclude that major part of ATC-pilot interaction is verbal, trough the radiotelephony. ATC can receive additional information about aircraft: its speed, altitude, heading, identification code etc., but this adds requirements for the ground facilities available on the field. All of additional systems are help greatly to improve safety, efficiency and speed of flights processing. Also, the implementation of new or improved methods or guidelines with the evolution of air manufacturing industry helps to achieve preciously unobtainable levels of capacity, with no damage to safety of flights.

In case of Ukraine the RECAT system has been implemented in Ukraine since 2018. The Ukrainian Air Navigation Service Provider (UkSATSE) is responsible for implementing and enforcing the RECAT system in Ukraine.

The RECAT system has several benefits for aviation in Ukraine, including:

- Improved safety: The RECAT system helps to mitigate the risk of wake turbulence encounters, which can lead to serious accidents.
- Increased capacity: By allowing for closer separation between aircraft, the RECAT system can increase air traffic capacity at airports in Ukraine.
- Reduced fuel consumption: By flying closer together, aircraft can reduce their fuel consumption.

There are a few challenges to the implementation of the RECAT system in Ukraine, including:

- Lack of awareness: Some pilots and air traffic controllers may not be fully aware of the RECAT system or its requirements.
- Inconsistent implementation: The RECAT system may not be implemented consistently across all airports in Ukraine.

- Limited data: There is limited data on wake turbulence production from aircraft operating in Ukraine.

To ease the pilots and ATCO familiarization with the RECAT system and to have the ability to implement RECAT system almost on any possible airport I propose the semi-automatic decision support system. This system prototype will be based on the ICAO RECAT-EU categories of wake turbulence groups and provide the ATCO with the time-based separation minima intervals. For this the ATCO will enter the next landing or take-off info such as the aircraft type or the wake turbulence group and keep in mind time to land\time to take-off based on the pilot report. The program will return optimal separation intervals for wake separation based on RECAT wake turbulence groups. After that the ATCO will make the decision whether or not to give clearance for take-off/landing with the support of the information given by decision support system.

3.2 Case study – take-off queue at airport Kharkiv/Student

For the basic case of this system usage, I will model the landing que at the Kharkiv/Student airport.

The "Kharkiv/Student" aerodrome belongs to class 4F, has two runways with artificial covering, operates around the clock, and is intended for conducting scheduled, training, and experimental flights. The aerodrome operates at a minimum of ICAO category II. Depending on the aircraft equipment, the aerodrome is approved for landing with a minimum of 30x400, and the takeoff visibility minimum is set at 200m. The aerodrome is suitable as an alternate aerodrome around the clock for all types of aircraft.

The aerodrome has two concrete runways (IFR and VFR). Both runways and approach strips have day and night markings. The maximum allowable single-wheel load on a notional single wheel gear is 400 tons (PCN 57/R/B/X/T).

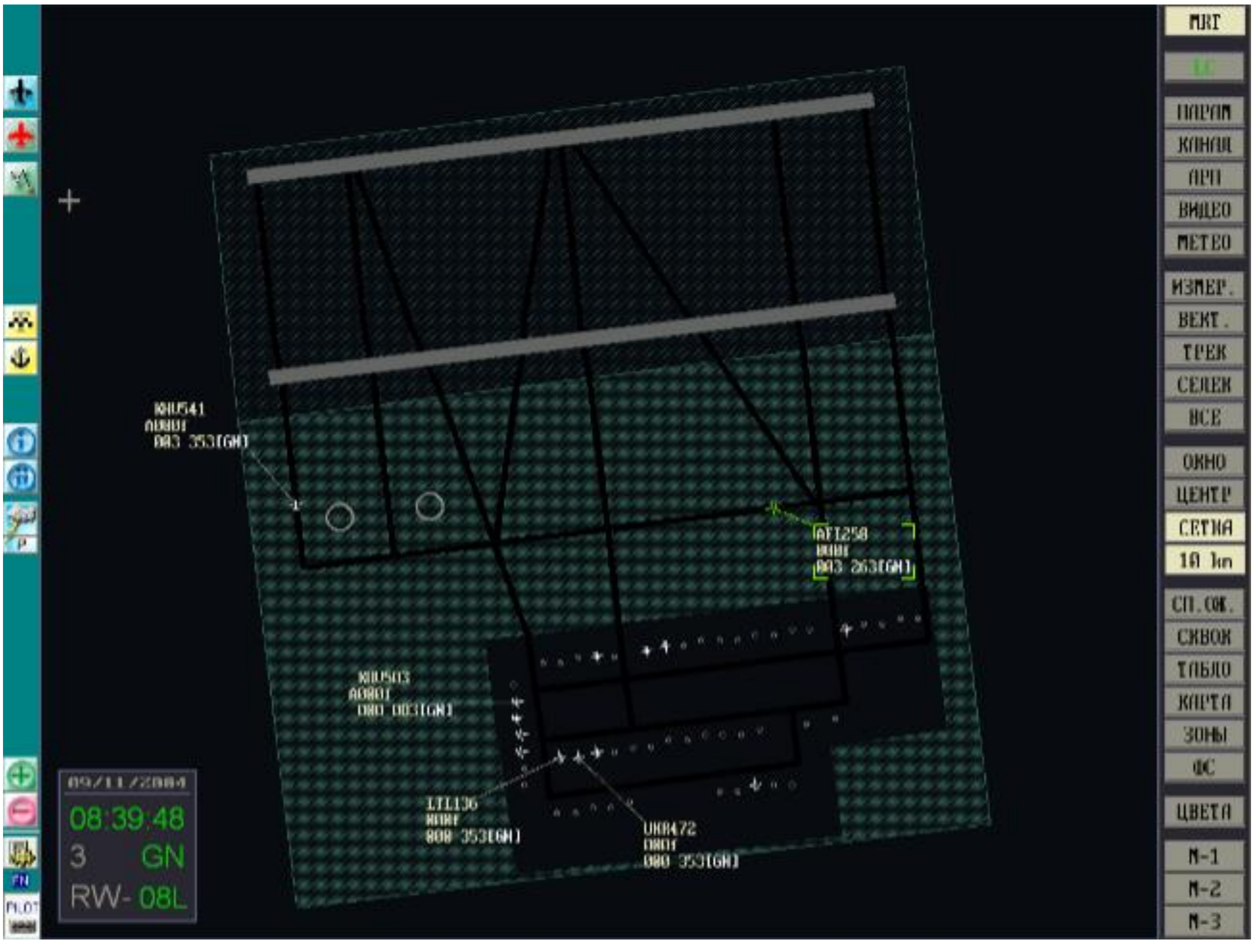

Figure 3.1 Kharkiv/Student airport scheme in the ATCO simulator

For our case we will simulate the 3-plane take-off queue on the same runway, we will use the 08L as an active runway for take-off.

For the 08L/26R we have next characteristics:

Magnetic landing course = 083°, absolute threshold elevation = +157m, true track angle of the runway = 088°.

Magnetic landing course = 263°, absolute threshold elevation = +154m, true track angle of the runway = 268°.

Runway dimensions are 3500x80m. The artificial covering thickness is 38cm. The average slope from west to east is 0.1% (1/875). The runway safety areas (RSA) at thresholds 08/26 are 200m, and the lateral safety areas (LSA) are 100m wide. The maximum allowable load on a hypothetical single-wheel landing gear is 400 tons.

As for the aircraft we will use the Airbus 330-200, AN-24B and Cessna 208 keeping the order.

3.3 Usage of current ICAO categorization and RECAT

Firstly, we need to find out which category or group our given aircraft from the take-off que are belongs to. ICAO legacy wake categorization depends only on the maximum certificated take-off mass of the airplane.

For Airbus 330-200 its maximum certificated take-off mass is 202 tons or 445,000 lb. So, it belongs to Heavy (H) category that includes all aircraft types with a maximum certificated take-off mass of 136,000 kg or more, excluding those in the Super (J) category.

An-24B with the maximum certificated take-off mass 21,000 kg or 46,297 lb which places it in the Medium (M) category, that covers aircraft types exceeding 7,000 kg but falling below 136,000 kg.

Cessna 208 maximum certificated take-off mass is 3,629 kg or 8,000 lb placing it into Light (L) category where aircraft types with a maximum certificated take-off mass of 7,000 kg or less are placed.

For the ICAO RECAT wake turbulence groups are depend primarily on maximum certificated take-off mass, wing characteristics and speeds.

Airbus 330-200 with maximum certificated take-off mass of 202 tons or 445,000 lb and the wingspan of 60.3 meters belongs to the B Group.

An-24B with maximum certificated take-off mass of 21,000 kg (46,297 lb) and the wingspan of 29.2 meters belongs to the E Group.

Cessna 208 with maximum certificated take-off mass of 3,629 kg (8,000 lb) and the wingspan of 15.87 meters belongs to the G Group.

Secondly, we need to find out what type of situation and runway scheme do we have. In our case we have the aircraft take-off from the same runway so we will have next time-based separation minima:

For the ICAO legacy wake turbulence categorization:

Table 3.1Time-based wake turbulence separation minima for departure

Preceding aircraft	Succeeding aircraft	Time-based wake turbulence separation minima
Super	Heavy	2 minutes
	Medium	3 minutes
	Light	3 minutes
Heavy	Medium	2 minutes
	Light	2 minutes
Medium	Light	2 minutes

For the ICAO RECAT wake turbulence groups:

Table 3.2 ICAO RECAT Time-based wake turbulence separation minima for departure

Preceding aircraft	Succeeding aircraft	Time-based wake turbulence separation minima
A	B C D E F G	100 seconds 120 seconds 140 seconds 160 seconds 160 seconds 180 seconds
B	D E F G	100 seconds 120 seconds 120 seconds 140 seconds
C	D E F G	80 seconds 100 seconds 100 seconds 120 seconds
D	G	120 seconds
E	G	100 seconds

Thirdly we need to find what time intervals we will have in our take-off queue Airbus 330-200/ An-24B / Cessna 208:

For the legacy ICAO wake turbulence categorization system such time intervals are applied:

- 2 minutes between Airbus 330-200 and An-24B;
- 2 minutes between An-24B and Cessna 208.

For the RECAT ICAO wake turbulence groups system such time intervals are applied:

- 120 seconds or 2 minutes between Airbus 330-200 and An-24B;
- 100 seconds between An-24B and Cessna 208.

So even in this situation small scale situation we managed to save 20 seconds or 14.5% of runway occupancy time without compromising safety.

3.4 Choosing a programming language to write a program

Choosing a programming language is an important decision that can affect the success and efficiency of a project. There are many factors to consider, such as the purpose of the project, the target platform, the availability of libraries and frameworks, the performance and readability of the code, and the personal preference of the programmer. In this essay, I will compare three popular programming languages that I have some level of knowledge: C++, Python, and C#, and explain why I would choose C# for my next project.

C++ is a low-level, compiled language that offers high performance and control over memory management. It is widely used for system programming, game development, and embedded systems. C++ has a rich set of features, such as classes, templates, inheritance, polymorphism, and operator overloading, that enable object-oriented and generic programming. However, C++ also has some drawbacks, such as the complexity and verbosity of the syntax, the lack of memory safety and garbage collection, and the difficulty of debugging and testing. C++ requires a lot of experience and discipline to write reliable and maintainable code.

Python is a high-level, interpreted language that emphasizes readability and simplicity. It is widely used for data science, web development, and scripting.

Python has a large and diverse standard library, as well as many third-party modules and frameworks, that provide a lot of functionality and convenience. Python supports multiple programming paradigms, such as procedural, object-oriented, functional, and imperative. However, Python also has some drawbacks, such as the slow execution speed, the dynamic typing system, and the indentation-based syntax. Python may not be suitable for performance-critical or low-level applications.

C# is a multi-paradigm, compiled language that runs on the .NET Framework, a cross-platform and open-source software platform that provides a common runtime environment and a large class library. C# combines the best features of C++ and Python, such as the high performance and control of C++, and the readability and simplicity of Python. C# has a clear and concise syntax, a strong and static typing system, and a built-in garbage collector. C# supports object-oriented, generic, functional, and asynchronous programming, as well as lambda expressions, delegates, events, and LINQ. C# also has a powerful integrated development environment (IDE), Visual Studio, that offers code completion, debugging, testing, and refactoring tools.

Based on these comparisons, I would choose C# for my next project, because it offers a balance between performance and productivity, flexibility and reliability, and simplicity and expressiveness. C# is a modern and versatile language that can handle a wide range of applications, from desktop to web to mobile. C# also has a large and active community that provides support and resources. C# is a language that I enjoy using and learning, and I believe it can help me achieve my goals.

4.2 Program development

Firstly, I opened a Visual Studio C# development environment, and created a new Windows Forms project. In the form constructor I created the basic output of the Kharkiv/Student Airport and added a button, that will be later used for the creation of new aircrafts in the queue.

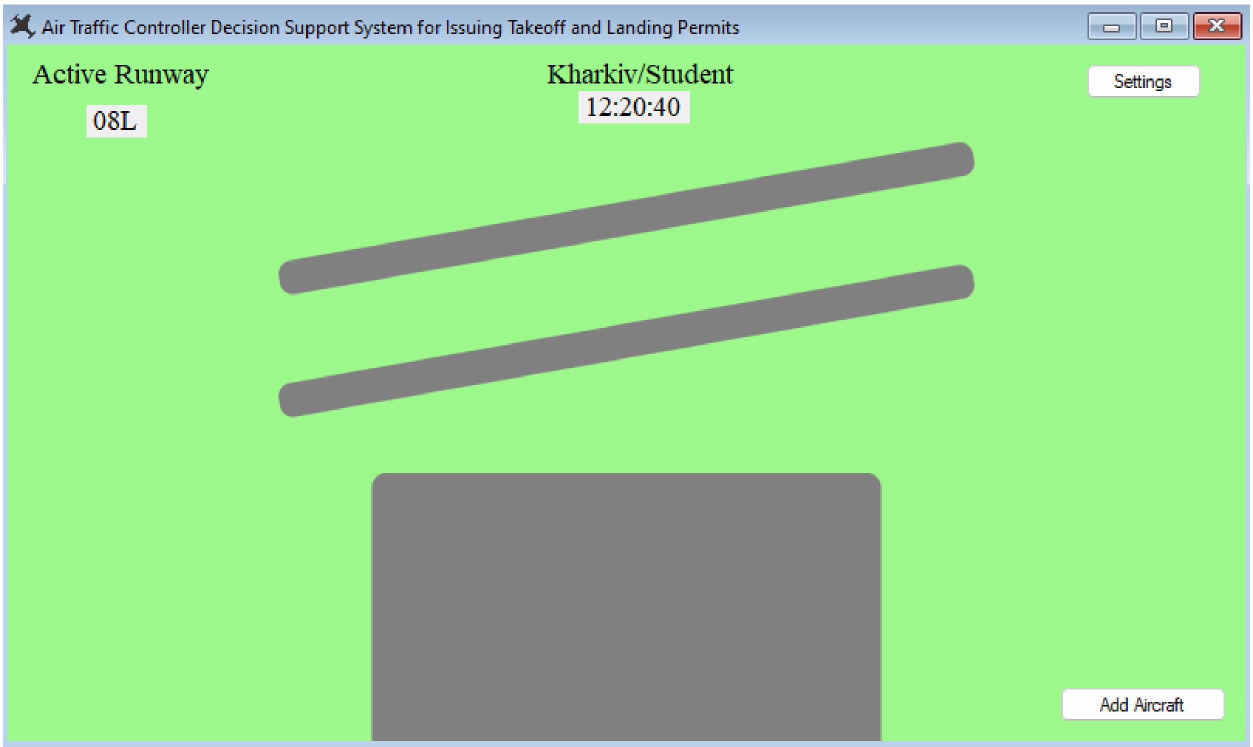

Figure. 3.2 Early program window.

After that I created special "Aircraft" class that contains information about aircrafts such as: Name, Aircraft Type, Wake Turbulence Group, Type of flight (Arrival/ Departure), Priority and Wait time. With the press of the button new window will be summoned, so the user can add the aircraft entering the Aircraft Type / or the Wake Turbulence Group and Type of Flight.

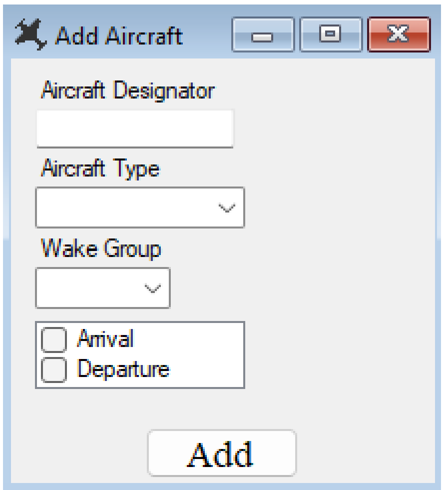

Figure 3.3 Aircraft addition window.

Also, we need settings window where we can change the time if needed and the active runway change. And Created runway class will store the data about last aircraft that interacted with runway (took-off / landed).

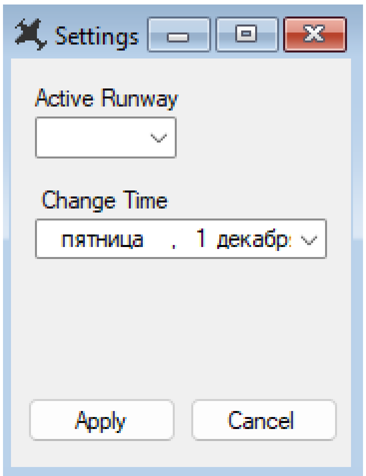

Figure 3.4 Settings window.

The added aircrafts will appear on the “parking lot” section of the airport depiction if they are about to depart or in the vicinity of the airport depiction if they are going to land on the aerodrome.

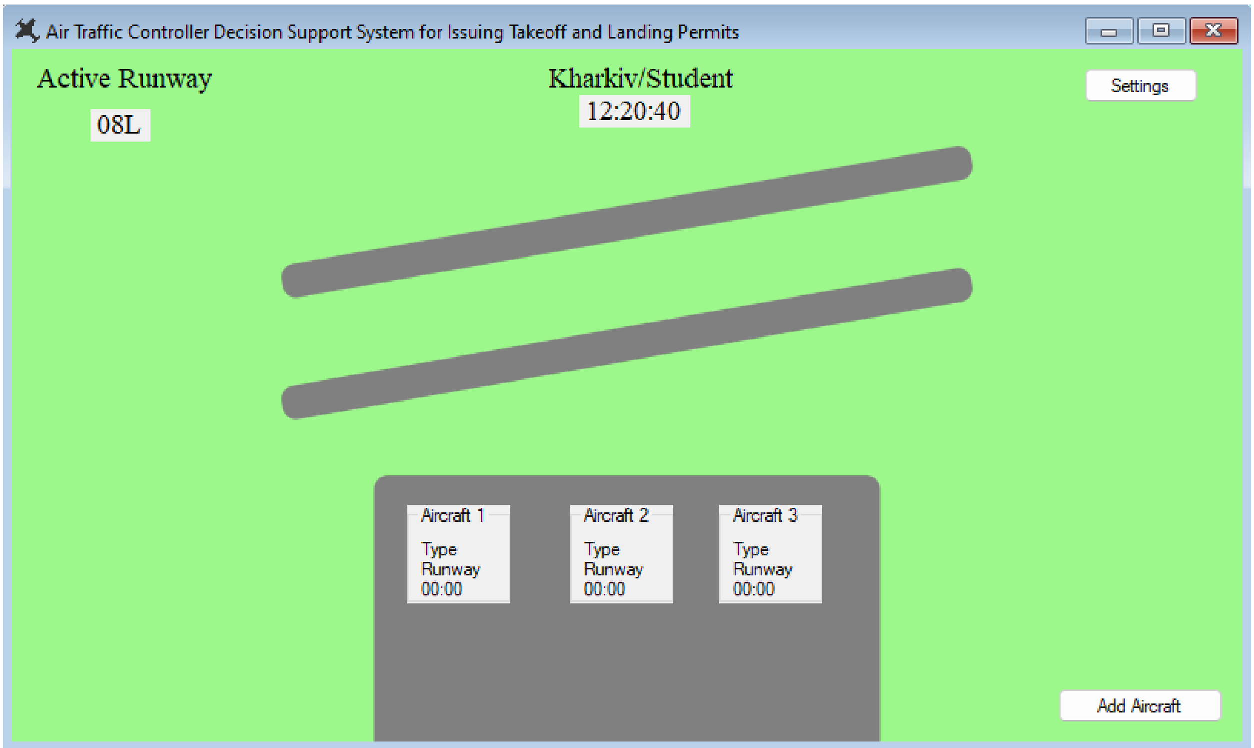

Figure 3.5 Added aircrafts on the airport depiction.

With the aircraft selected we can tell program that aircraft is landed/took-off or delete the aircraft if it was added by mistake, or diverted, by the press of the appearing buttons.

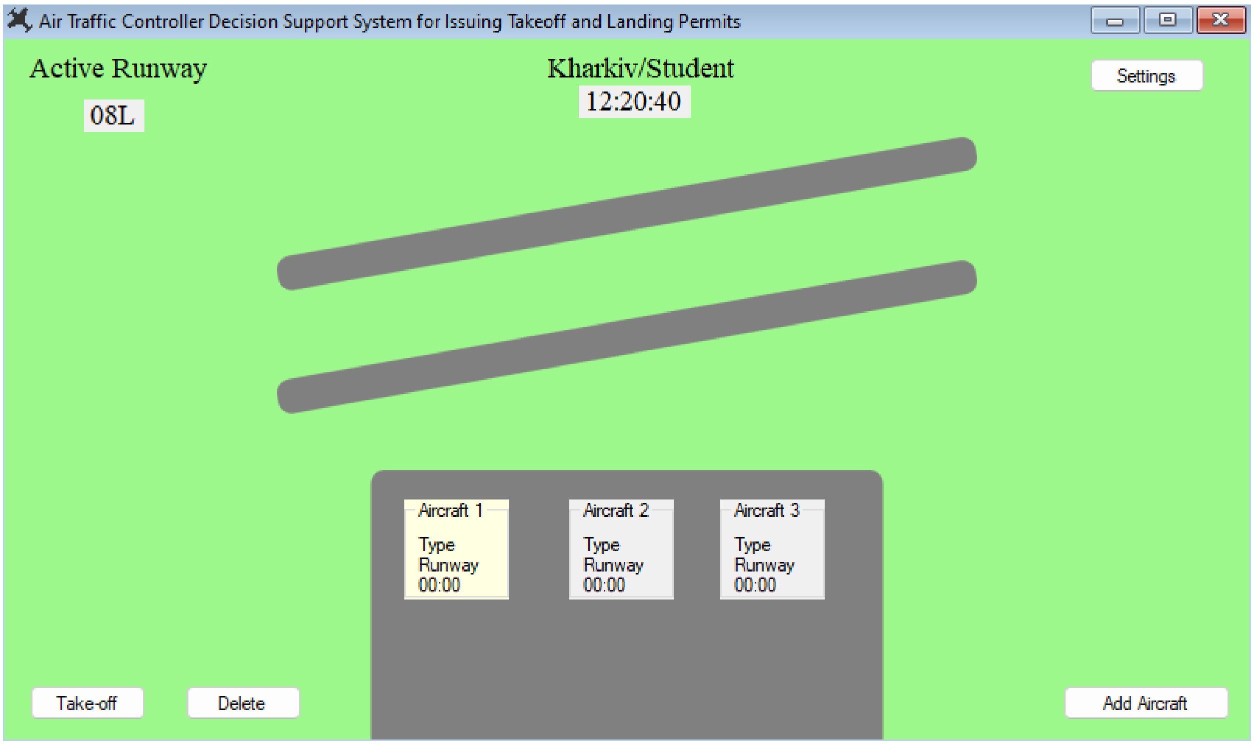

Figure 3.6 Aircraft selected and command buttons appeared

When the aircraft is commanded to take-off/land in the program all other aircrafts timers start corresponding to the time needed for the wake turbulence vortexes to disperse for safe aircraft operations in the area according to the ICAO RECAT wake turbulence groups.

Also, to ensure fast usage of a program I created a list of aircraft types and their corresponding wake turbulence group according to the ICAO RECAT. For the simplicity of the prototype of the program list consists of only 10 most popular aircrafts [15] with addition of small and medium air traffic of Ukraine and consists of: Airbus A320, Boeing 737-800, Embraer E175, Airbus A330-300, Bombardier CRJ700, An-24B, An-2, ATR 72, Cessna 172, L-410.

4.3 Usage of program and calculation check

To test the program workability and how time it takes corresponding to the traditional methods of calculation we will input three aircrafts queue in the program and calculate the time intervals manually.

So, we will take such aircraft take-off queue: Airbus A330-300, Boeing 737-800, Embraer E175. And add the aircrafts to the program:

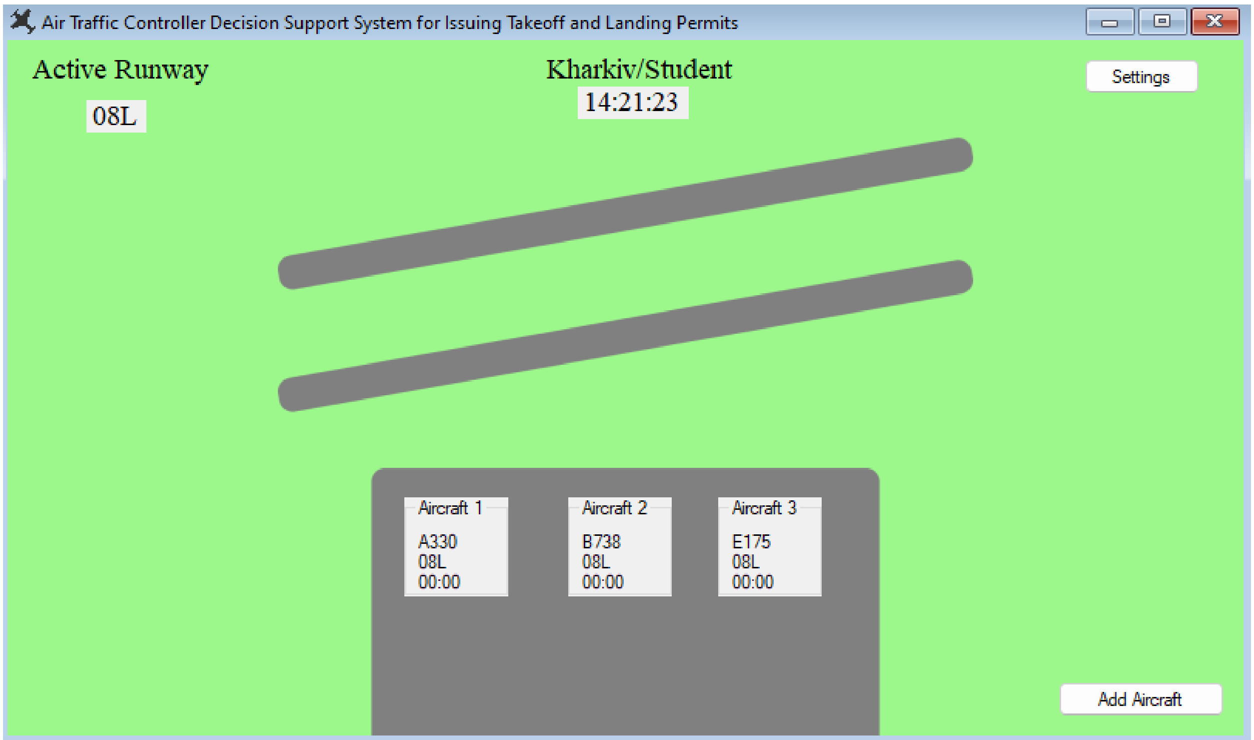

Figure 3.7 Active Runway selected and aircraft queue added

Next user will press the take-off button starting the timer for the aircrafts with the active runway and deleting the aircraft that taken-off from the queue.

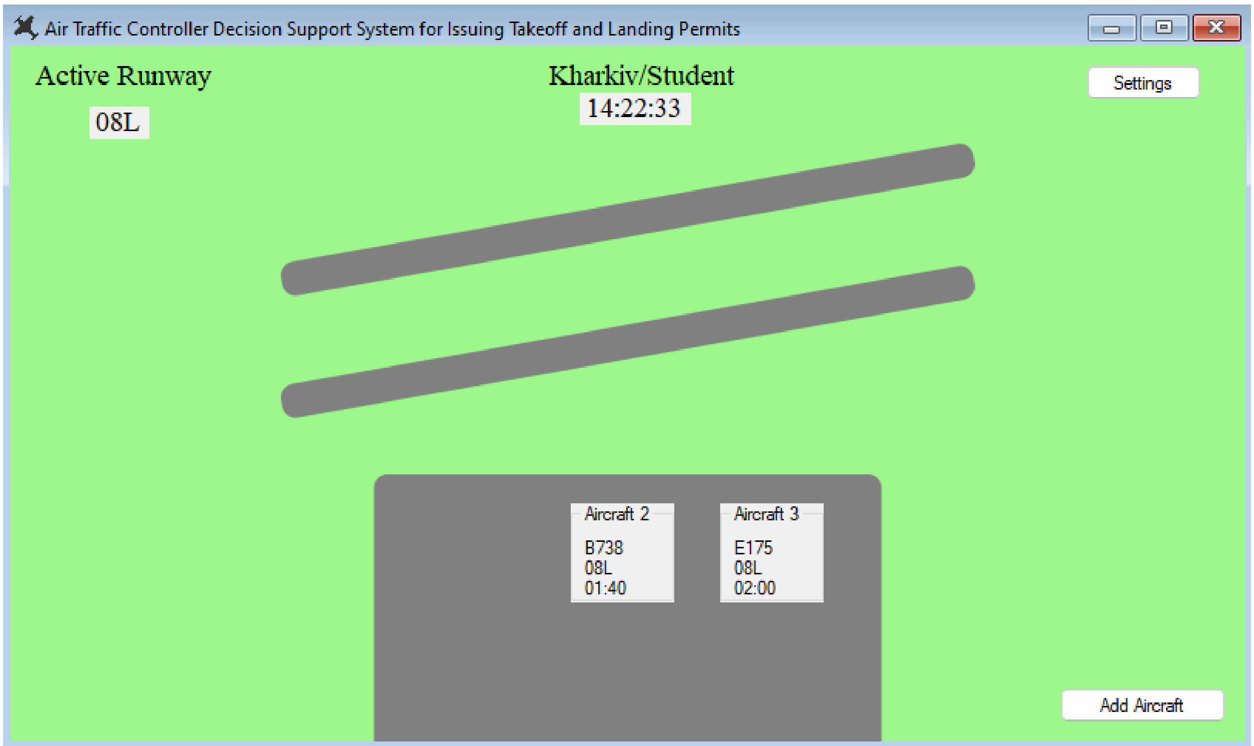

Figure 3.8 Timer of wake turbulence presence started, and first aircraft deleted

And to calculate manually we need to obtain the wake turbulence groups for the aircraft from the queue, and recognize the situation of wake turbulence generation. For this queue we have the aircrafts that take-off from the same runway. The wake turbulence groups for this aircraft are next: Airbus A330 – Group B, Boeing 737-800 – Group D, Embraer E175 – Group F. And we have such time separation intervals: A330 / 100 seconds / B748 / 0 seconds / E175.

So the program calculate with the accordance to the ICAO minima correctly, but it has an advantage of calculating for the all aircrafts in the available query, so if needed we can easily let another aircraft from the queue priority.

Conclusion to chapter 3

In the study of the possible implementation of RECAT wake turbulence groups separation in Ukraine there were such plans from 2018 but its introduction was postponed by the UkSatse for later. There are many of challenges in this system introduction because of the need of additional personnel training and airport compliance with system check so the system cannot be implemented homogeneously across all territory of Ukraine.

Usage of ICAO RECAT used to be practical even on the small scale in theoretical test on Kharkiv/Student airport saving 15% of time. This can increase the airport and airspace capacity near the airport, increase safety and reduce the emissions of the aircraft transportation.

In this chapter I chosen the programing language that will be ideal from my perspective for the creation of this program. Choosing from C++, python and C# I chosen a C# because this is a modern programing language that have a decent performance, a lot of useful libraries and used to work with databases a lot.

The prototype of a program is focused on the Kharkiv/Student airport and have the layout of the airport for better visual proof of concept. With the addition of airport basic layout, time settings, and buttons for the aircraft's addition to the queue the program have its basic functionality. Addition of the basic aircrafts database in the current program form have 10 aircrafts with their wake groups which later with the further program development the aircraft database can be widened with additional aircrafts. When the ATCO initiates the take-off or landing the runway wake turbulence countdown time starts for all aircrafts in the queue regarding of the group of the aircraft and current airport layout. The program proved itself working in the small scale queue tests.

CHAPTER 4. SPECIAL CHAPTER

4.1 Automated processing of large-scale aeronavigation data

Automated data processing is a typical task, which is solved by modern air navigation systems. Processing of air navigation data is provided both on board airplanes in particular avionics units and in ground data processing equipment. Navigation parameters in modern systems are measured using a significant number of different sensors, which ensure creation of a data archive, the processing of which requires the use of specialized statistical data 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 by taking into account each sensor error. In this case, confidence bands are used, which guarantee getting a particular frame in the interval with a certain probability [16]. The most commonly used confidence band is the double root mean square deviation, which provides 95% localization of the measured values, based on the assumption of a normal distribution of errors.

The structure of each unit of avionics is more similar to the architecture of a personal computer with the corresponding elements: processor, memory, and analog-to-digital / digital-to-analog converters, which allows processing of measured data at the software level [17]. The sensor’s data is converted to digital form by sampling analog values. Results of different value measurements are stored in appropriate registers, variables, matrices, or data archives.

Detection of an airplane's exact location is one of the most important tasks in civil aviation [18]. Continuously growing volumes of air transportation require a constant review of separation minimums to meet needs of modern air transport. Separation minimums between airplanes set up maximum permissible limits of airplane separation in space on vertical plane, lateral and longitudinal sides. One of the possible ways to solve the issue of airspace congestion is to increase the bandwidth of a particular part of the airspace by reducing the safe distances between airplanes. In practice, this is implemented by introducing more precise requirements for determining the location of airplanes in the air space. The introduction of more precise requirements for airplane positioning is possible only if there are appropriate systems capable of satisfying them. Operation of on-board positioning sensors of a civil airplane is provided by the field of aeronautical signals created in space by various systems.

As an example of big-data processing, we will use the trajectory of particular aircraft and perform its calculation using MATLAB software.

4.1. Input data

The safety of air transportation mostly depends on the accuracy of preplanned trajectory maintained by each airspace user. Flight technique and performance of on-board positioning sensor specify the level of airplane deviation from cleared trajectory. The receiver of Global Navigation Satellite System (GNSS) is the main positioning sensor on board a modern airplane of civil aviation. Performance of on-board positioning system specifies an area of airplane location with a certain level of probability. Airplane operation within a particular airspace volume is regulated by navigation specification which specifies requirements for the performance of on-board positioning system. To guarantee a safe flight through a particular airspace volume each user should perform navigation with the required levels of performance.

Measured position of an airplane is classified as critical data due to its role in the safety of the whole air transport system. According to Automatic Dependent Surveillance-Broadcast (ADS-B), the position is shared with other airspace users to guarantee surveillance and improve the safety of aviation. Today the majority of airplanes are equipped with transponders of mode 1090 ES (extended squitter). The airplane transponder transmits periodically digital message which includes a position report [21, 22]. This data can be easily received and used on-board of other airplanes for improving situation awareness or can be received by ground receivers. An air navigation service provider uses a national network of ground ADS-B receivers to support surveillance and airspace user identification [23, 24]. Also, there are multiple commercial networks of ADS-B receivers, that process and collect all data transmitted via the 1090 MHz channel.

In particular, computation clusters of Flightradar24 and FlightAware companies provide simultaneous processing of data from more than 30,000 software-defined radios of ADS-B signals located all over the globe (Fig. 4.1).

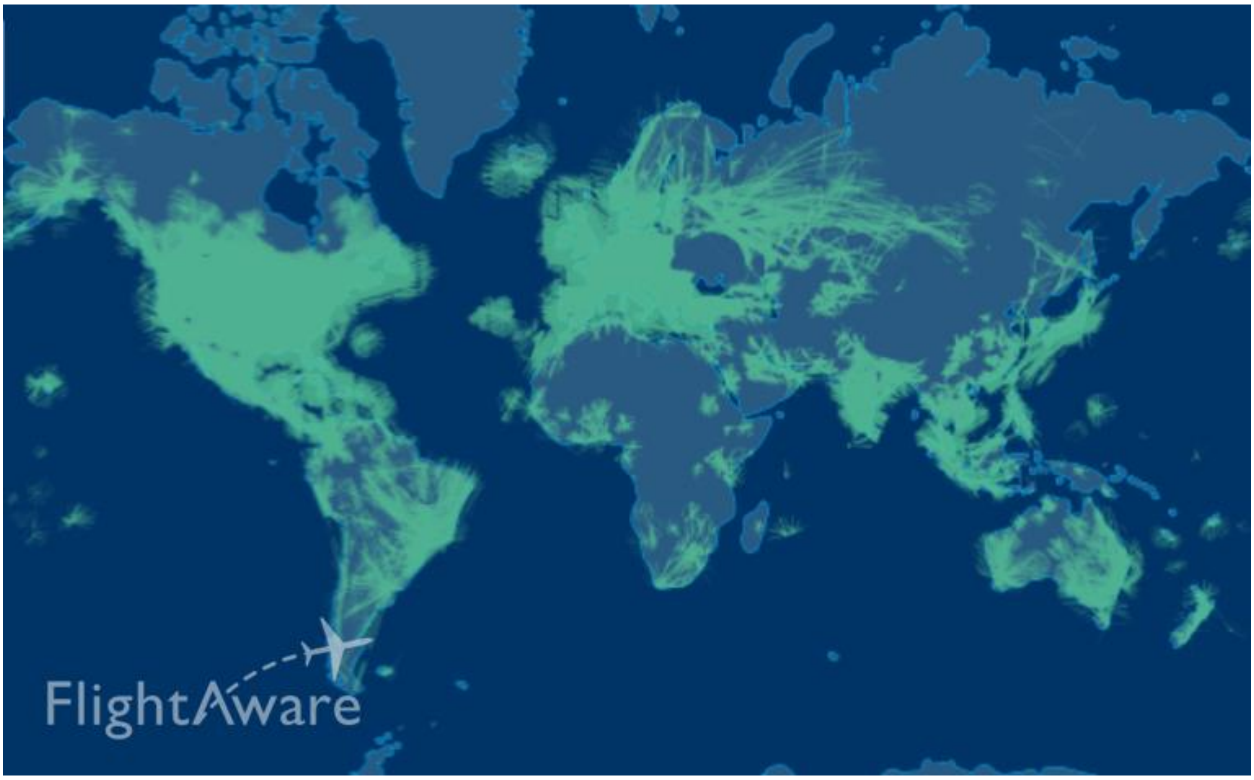

Figure 4.1 – Maps of global traffic [10]

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 AFR9406 / AF9406 (Air France 9406) operated by Air France for connection between Paris, France (CDG) and Marrakech, Morocco (RAK). Departure date is November 8, 2022 at 07:46PM (+1). Landing date is 8 November at 11:12 PM (CET). The flight ended on time of the scheduled landing time. This flight was performed by Airbus A321 (A321). Input data obtained from the archive at https://flightaware.com/live/flight/AFR9406/history/20221108/1855Z/LFPG/GMMX. Table 4.1.1 shows the first and final 15 rows of flight raw data.

Table 4.1 Trajectory data of AFR9406 from 8 November 2022

Time (EEST)	**Latitude**	**Longitude**	**Heading angle**	**Ground speed (kts)**	**Ground speed (mph)**	**Barometric altitude (feet)**
Tue 01:58:22 PM	48.9957	2.5479	← 266°	159	183	1,575
Tue 01:58:38 PM	48.9947	2.5302	← 265°	153	176	2,325
Tue 01:58:54 PM	48.9938	2.5136	← 265°	149	171	2,825
Tue 01:59:10 PM	48.9927	2.4975	← 263°	149	171	3,225
Tue 01:59:26 PM	48.9914	2.4802	← 264°	151	174	3,650
Tue 01:59:31 PM	48.9911	2.4743	← 264°	152	175	3,449
Tue 02:00:46 PM	48.9856	2.3813	← 265°	210	242	4,925
Tue 02:00:55 PM	48.9836	2.3683	← 253°	209	241	4,899
Tue 02:02:12 PM	48.9224	2.292	↙ 216°	222	255	8,325
Tue 02:02:42 PM	48.8982	2.265	↙ 217°	219	252	9,650
Tue 02:03:12 PM	48.874	2.2376	↙ 217°	229	264	10,575
Tue 02:03:42 PM	48.8458	2.2059	↙ 217°	249	287	11,325
Tue 02:04:12 PM	48.8172	2.174	↙ 216°	273	314	11,850
Tue 02:04:42 PM	48.7867	2.1402	↙ 216°	295	339	12,350
Tue 02:05:12 PM	48.7515	2.1012	↙ 216°	311	358	13,025
…						
Tue 04:46:08 PM	33.0925	-7.4116	↓ 185°	443	510	31,000
Tue 04:46:45 PM	33.0149	-7.4186	↓ 184°	443	510	30,975
Tue 04:47:15 PM	32.9540	-7.4241	↓ 184°	443	510	30,975
Tue 04:47:46 PM	32.8921	-7.4295	↓ 184°	444	511	30,975
Tue 04:48:35 PM	32.7888	-7.4385	↓ 184°	444	511	30,975
Tue 04:49:14 PM	32.7109	-7.4453	↓ 184°	437	503	30,975
Tue 04:49:44 PM	32.6520	-7.4502	↓ 184°	430	495	30,175
Tue 04:50:19 PM	32.5818	-7.4563	↓ 184°	444	511	28,000
Tue 04:50:49 PM	32.5179	-7.4619	↓ 184°	453	521	26,225
Tue 04:51:19 PM	32.4545	-7.4676	↓ 184°	462	532	24,200
Tue 04:51:50 PM	32.3906	-7.4731	↓ 184°	461	531	22,500
Tue 04:52:28 PM	32.3082	-7.4803	↓ 184°	455	524	20,425
Tue 04:53:07 PM	32.2278	-7.4871	↓ 184°	444	511	18,500
Tue 04:53:28 PM	32.1839	-7.4925	↓ 191°	438	504	17,425
Tue 04:53:46 PM	32.1525	-7.5039	↙ 203°	420	483	16,400

4.4.2. Visualization of trajectory data at specific software

Let`s import trajectory data of AFR9406 from 8 November 2022 into specialized software of MATLAB [25]. Results of trajectory data visualization for flight is represented in fig. 4.2. and vertical profile of flight is in fig. 4.3.

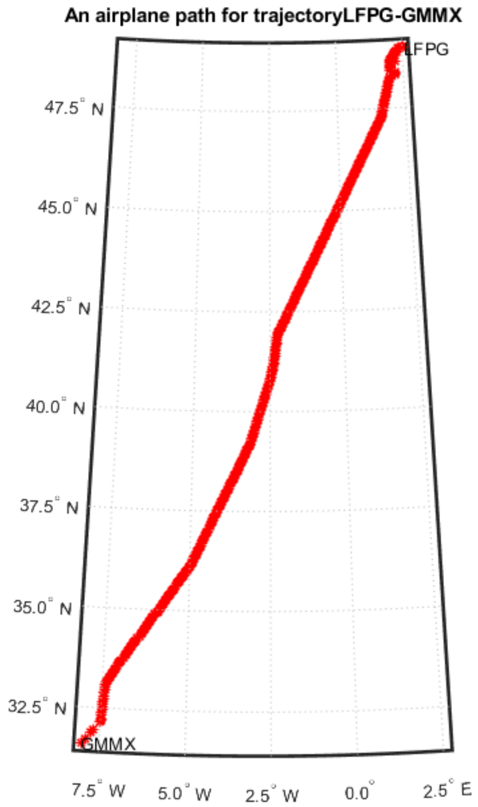

Figure 4.2 – Flight path of AFR9406 (8 November 2022)

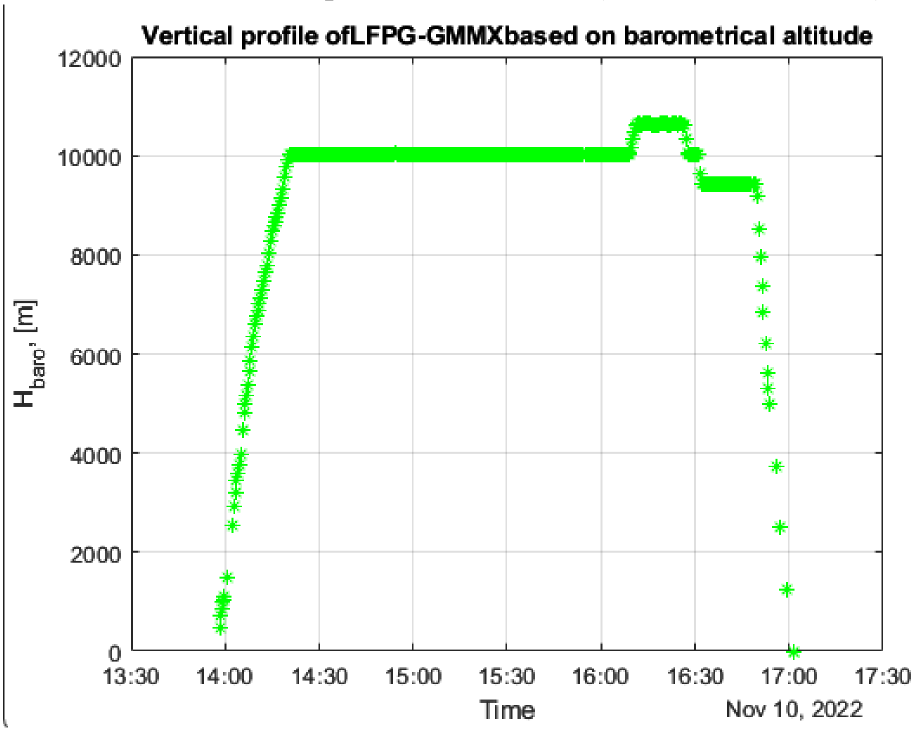

Figure 4.3 – Vertical profile AFR9406 (8 November 2022)

4.4.3. *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 Fig. 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 fig. 4.7 and fig. 4.8.

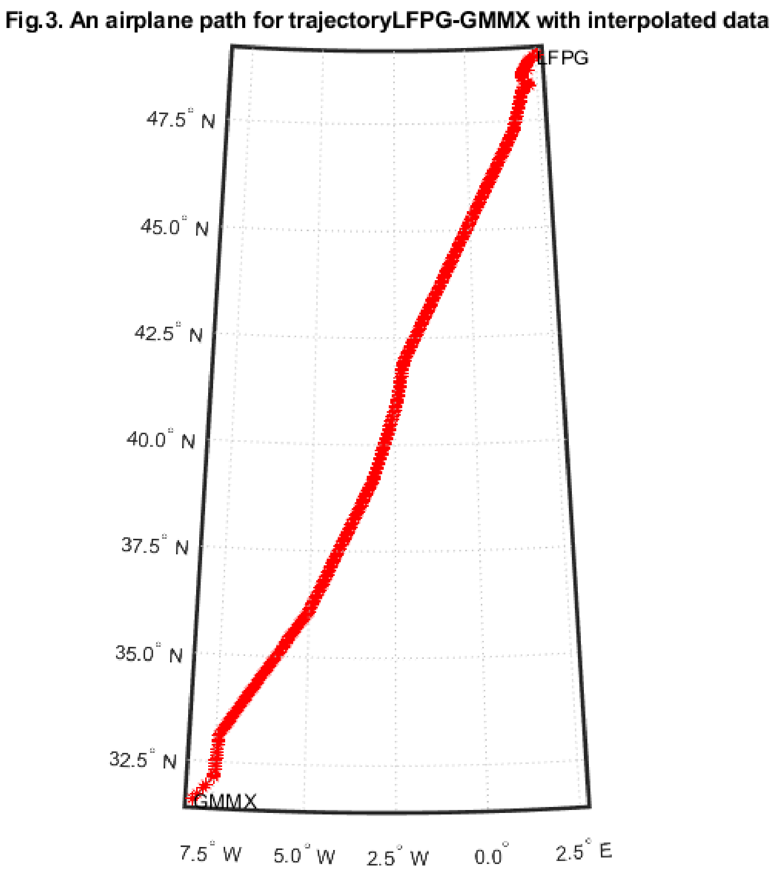

Figure 4.4 – Interpolated airplane trajectory of AFR9406 (8 November 2022)

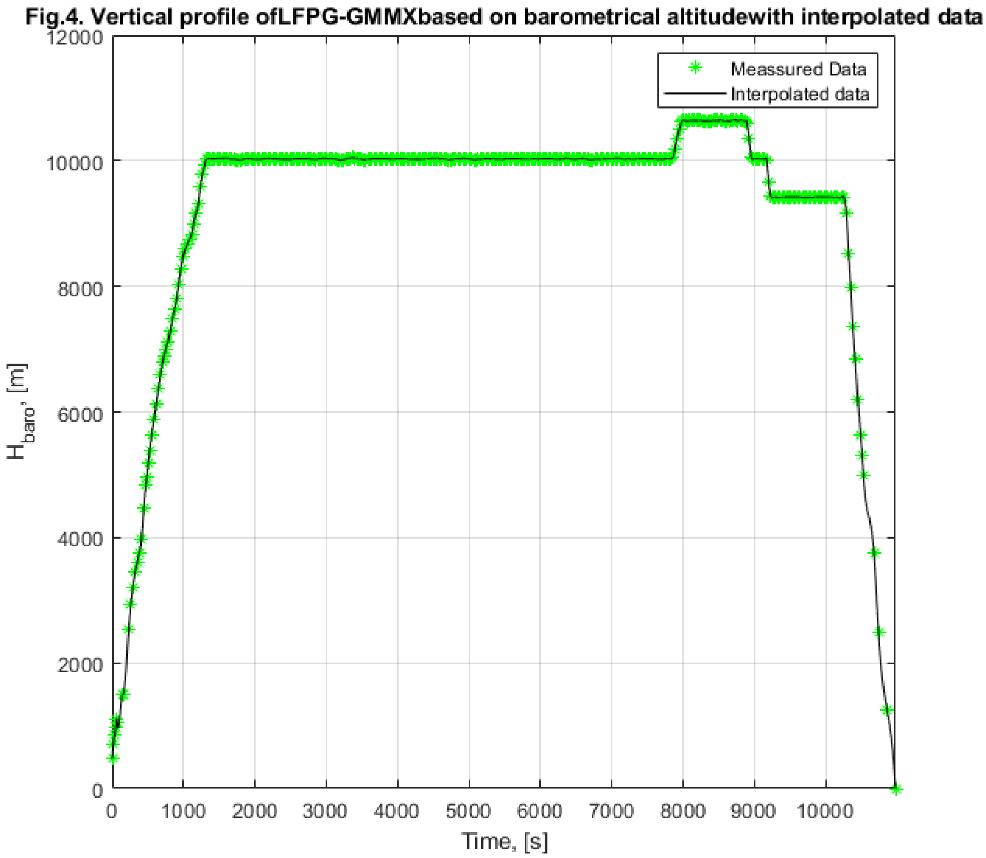

Figure 4.5 – Interpolated vertical profile of AFR9406 (8 November 2022)

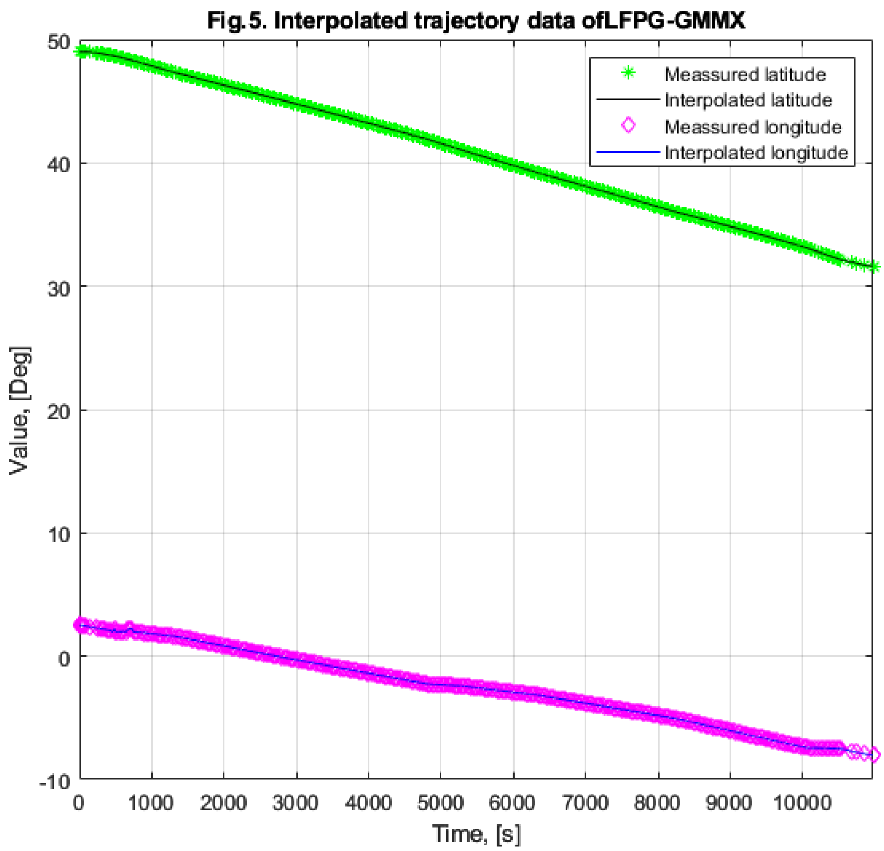

Figure 4.6 – Interpolated data for 1 Hz of AFR9406 (8 November 2022)

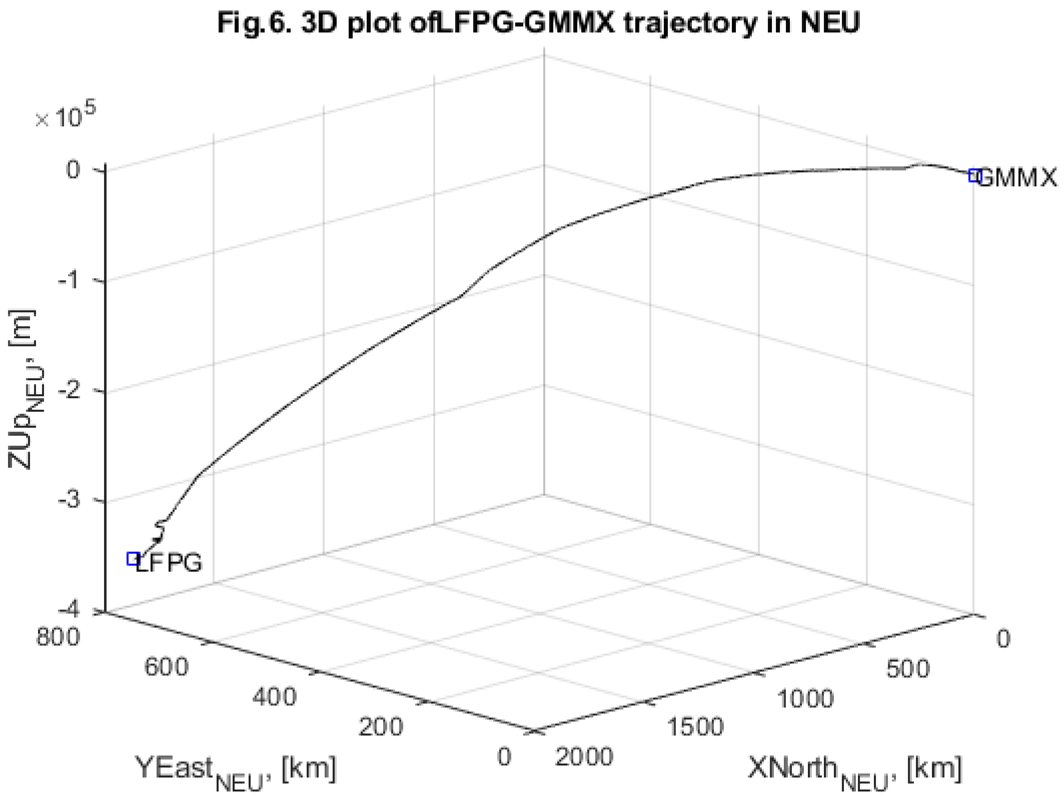

Figure 4.7 – 3D trajectory of AFR9406 in NED reference frame

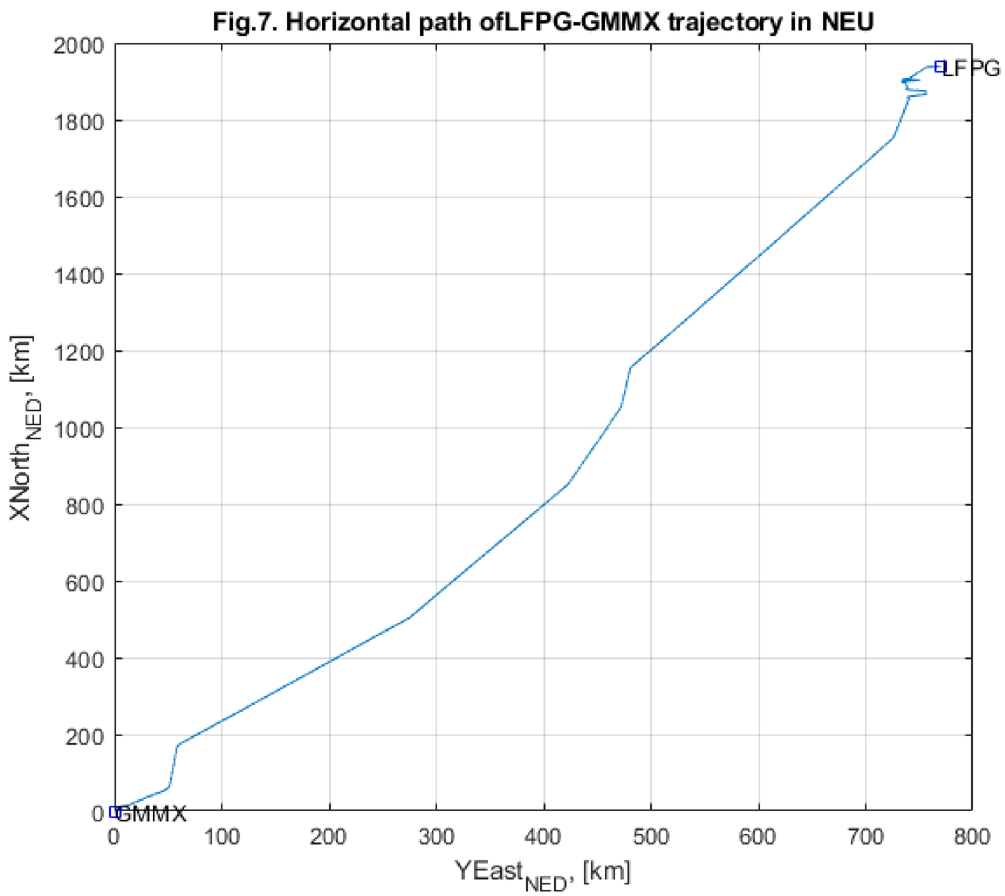

Figure 4.8 – Flight path of AFR9406 in local NED

4.4.4. Trajectory data calculation

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

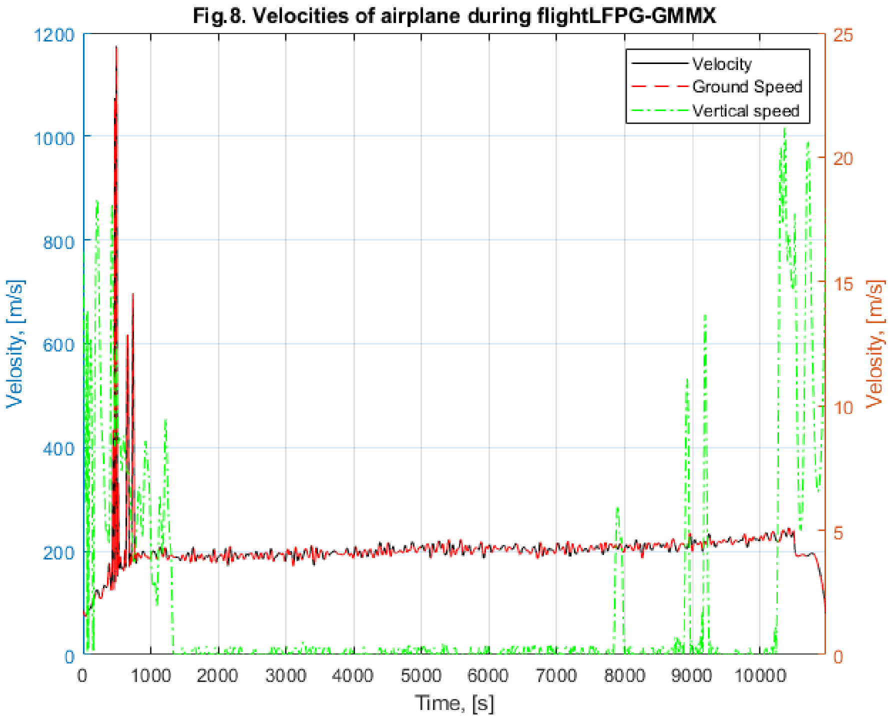

Figure 4.9 – Results of velocity estimation of AFR9406 (8 November 2022)

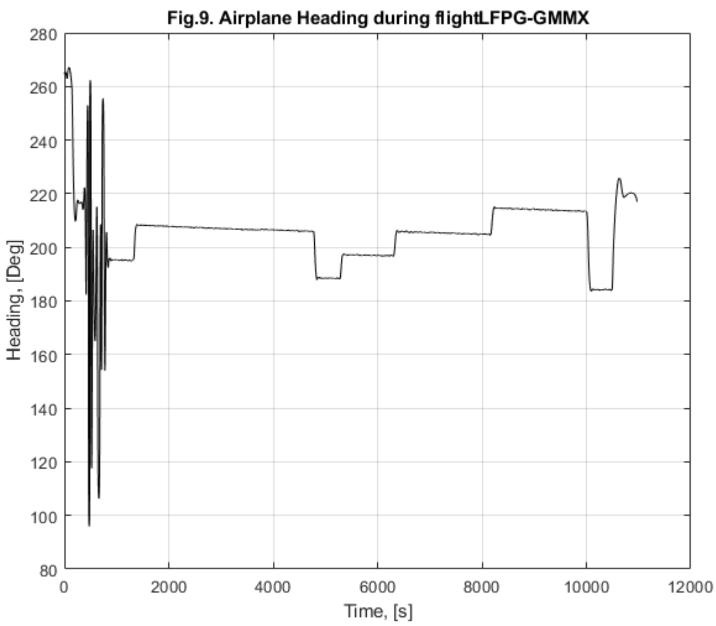

Figure 4.10 – Results of heading angle calculation of AFR9406 (8 November 2022)

The total flight time of AFR9406 on November 8, 2022, was 3 hours 2 minutes 55s. The length of the trajectory is 2226.6 km, and the length of the flight path (horizontal component) is 2225.9 km.

4.5 Efficiency of the airspace usage of Ukraine

4.5.1 Forecasting the efficiency of the airspace usage of Ukraine

The current situation in the world, related to the impact of global economic and political processes (the outbreak of COVID-19 and the restrictions imposed by states to counter its spread, military situations, etc.), has directly affected the aviation industry of countries worldwide, including Ukraine. As a result of the 2020 outcomes, there was a significant reduction in the performance indicators of aviation enterprises compared to the previous year.

The complication of the epidemic situation in Ukraine and globally led to a decline in demand for air transportation and a decrease in the commercial load factor of flights by the end of the first quarter of 2020. Consequently, airlines were forced to reduce the frequency or cancel the operation of the majority of flights.

In Figure 4.11, you can see the dynamics of a volumes of aircraft traffic (IFR/GAT) in Ukraine.

Figure 4.11 Air traffic volumes in Ukraine

In 2021, the overall volume of flights in Ukraine's airspace (IFR, GAT) reached 230,513, marking a significant increase of 62.3% compared to the previous year [39]. Despite the ongoing implementation of quarantine measures aimed at preventing and controlling the spread of COVID-19, there was a noticeable trend toward the resurgence of flight numbers in Ukraine's airspace.

In addition, the volumes of air traffic serviced in Ukraine have returned to approximately the levels of 2016-2017 when the mentioned indicator was respectively 214,3 thousand and 253,9 thousand of serviced aircrafts.

Specifically, statistical data on aviation transport in Ukraine from 2016 to 2021 is presented in Table 4.5.1 [35, 36, 37, 38, 39].

Table 4.5.1 Statistical data on aviation transport in Ukraine

Year	X - Year Coefficient	Y - Number of flights
2016	16	214262
2017	17	253969
2018	18	300853
2019	19	335407
2020	20	142047
2021	21	230513

Through the correlation-regression analysis method, we will analyze aviation transportation and forecast transportation for the next few years. The correlation-regression analysis (CRA) involves selecting the type of regression equation, calculating its parameters, and establishing interdependencies between the measured data.

The main characteristics of CRA are the correlation coefficient (r) and the regression line. The correlation coefficient (r) takes values in the range [-1;1]. The value of the coefficient indicates the relationship between variables. The closer r is to 1, the stronger the correlation:

- When $r = 0$, there is no correlation, and the regression line is parallel to the x-axis.
- When $r = 1$, the relationship is functional (all values lie on a single line).
- When $r = 0.7...0.8$, the correlation is direct.
- When $r = -1$, the correlation is called inverse.

The regression line determines the form of dependence and relates the average value of the response function f(x) to the values of the factor x.

Stages of CRA:

1. Collect statistical data.

2. Correlation analysis - using the correlation coefficient (r) to determine the strength and nature of the relationship.
3. Regression analysis - determining the form of dependence using the correlation field.
4. Determining the values of regression coefficients: y = b0 + b1x.
5. Determining the significance of obtained correlation and regression coefficient values using Student's and Fisher's criteria.
6. Constructing the regression line.
7. Forecasting (extrapolation and interpolation).

Using Microsoft Excel, we will conduct a statistical analysis of aircraft transportation airspace usage and use CRA to forecast transportation until 2030. The results obtained are reflected in Table 4.5.2.

As a result, we obtain a model for forecasting transportation demand:

y = -6284,5x + 268171;

Table 4.5.2 Forecast transportation in Ukraine until 2030

Year	Year Coefficient	Prognosed number of flights	Real number of flights
2016	16	261886	214262
2017	17	255602	253969
2018	18	249317	300853
2019	19	243033	335407
2020	20	236748	142047
2021	21	230464	230513
2022	22	224179	
2023	23	217895	
2024	24	211610	
2025	25	205326	
2026	26	199041	
2027	27	192757	
2028	28	186472	
2029	29	180188	
2030	30	173903	

Based on statistical and forecasted data, we construct a graph forecasting volume of traffic in Ukraine until 2030 (Figure 4.12).

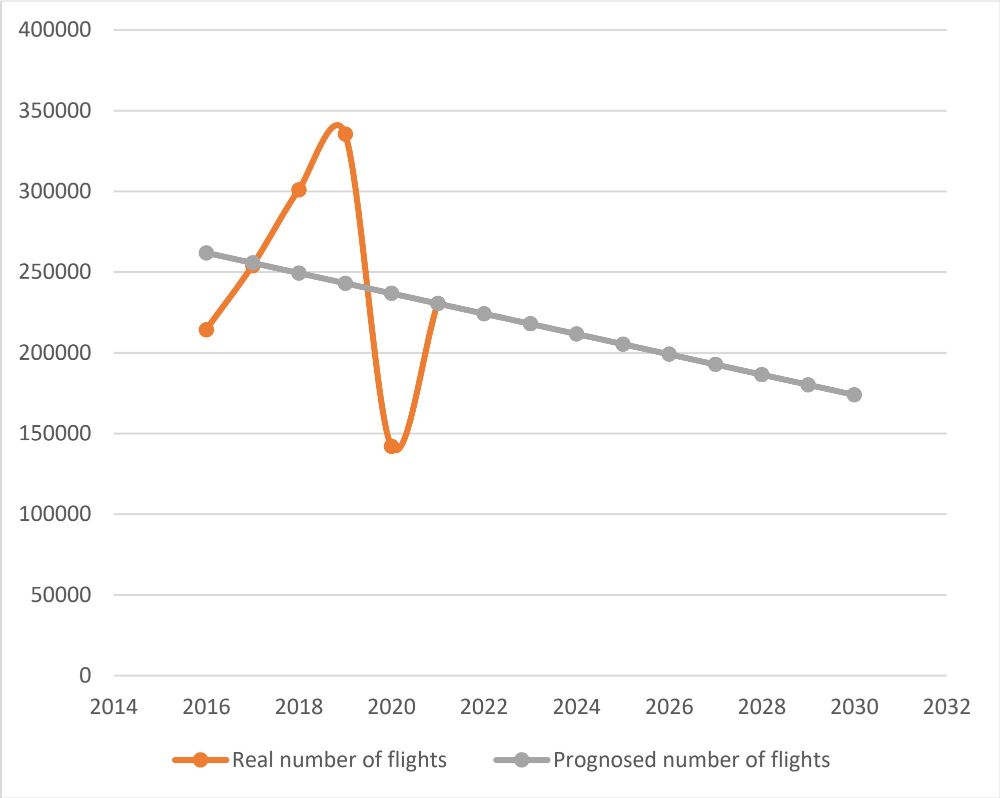

Figure 4.12 Forecast of Volume of air traffic in Ukraine until 2030

4.5.2 Comparing the efficiency of Ukraine airspace usage to the Europe statistics

Since March 2023, the trajectory of European flights has broadly followed EUROCONTROL monthly base scenario [34], with a slight decline noted since June. The projections for the number of European flights in 2023 and 2024 have been marginally adjusted downward, reflecting a modest reduction in traffic compared to our previous Summer 2023 base scenario. This adjustment also considers lower expected economic growth for 2024 and 2025.

EUROCONTROL outlook maintains the anticipation of reaching 2019 flight levels (11.1 million) by 2025. Beyond 2025, projected an average annual flight growth of 1.6% in base forecast. However, heightened uncertainties within the 7-year horizon—such as increased inflation, pressure on oil prices, economic risks, and environmental concerns—contribute to this projection.

In low forecast, several downside risks lead to a stagnation of the number of flights from 2025 onward. Users of forecasts are strongly encouraged to consider the forecast range, as uncertainties persist. Furthermore, potential unforeseen events such as a further deterioration of the economy, escalation of geopolitical tensions, or other unpredictable occurrences may adversely affect traffic.

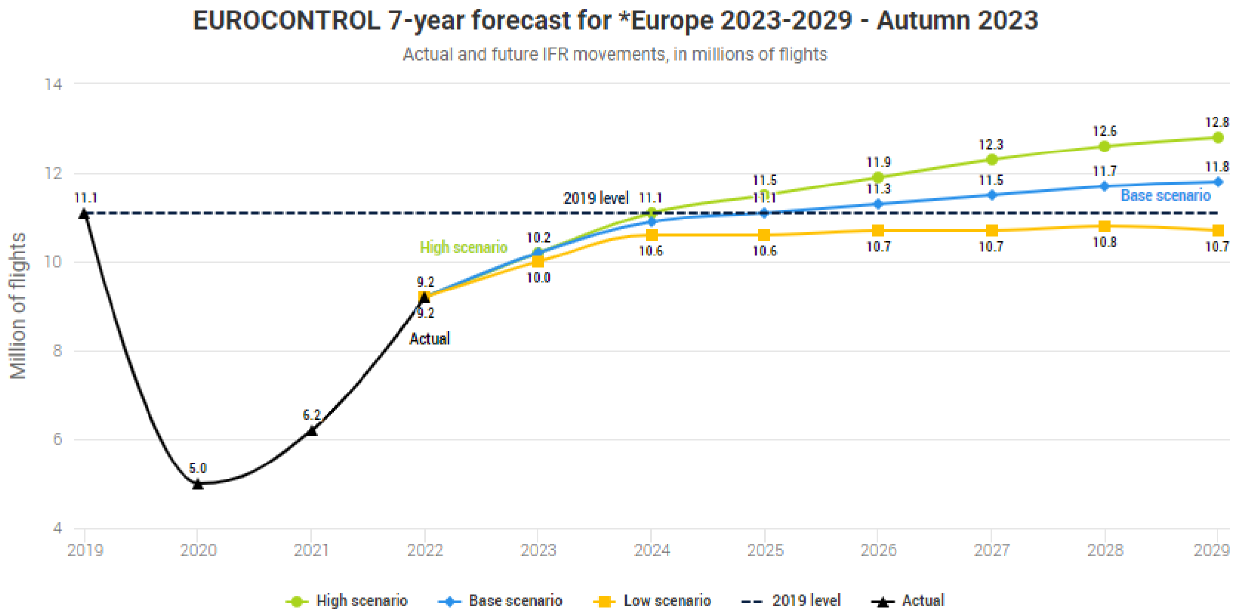

Figure 4.13 EUROCONTROL 7-year forecast [34]

According to the EUROCONTROL forecast and statistics the European airspace volumes decreased by more that 50% during the implementation of strict regulations of border crossings and international transportation in 2019. By the year of 2021 there was only a small increase of transportation volume jumping from 45% to 56% comparing to the levels of 2019. But eventually with the decisions to cancel the regulations completely or soften them up in some countries the 2022 level of transportation volumes increased to the 9.2 million of flights or the 83% of the flights in the year 2019.

In Ukraine we had similar statistics during the COVID regulations:

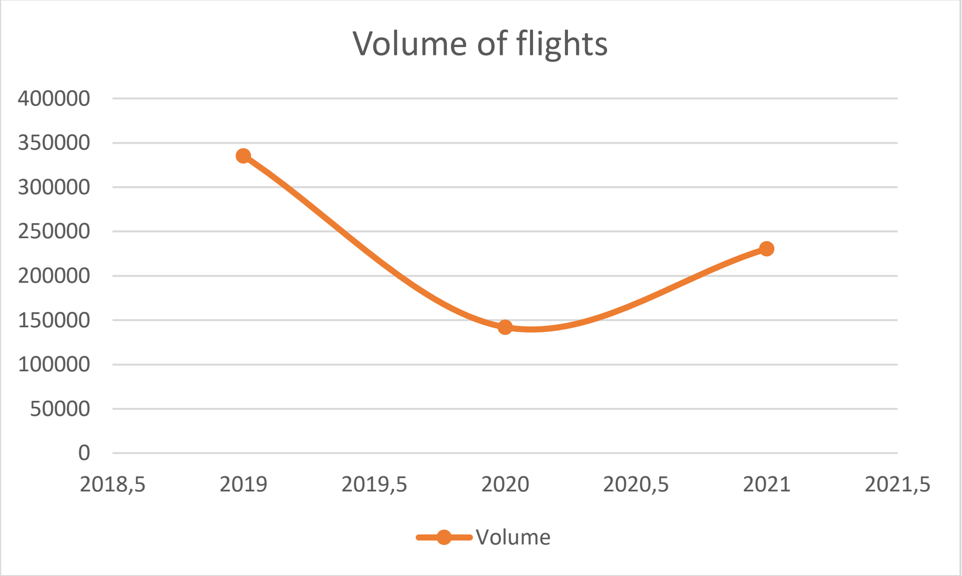

Figure 4.14 Volumes of flights in Ukraine 2019-2021

During the first year of border regulations and transportation restricts the traffic volume dropped to the 42% of the year 2019. To the next year the Ukrainian airspace usage improved even more than Europe group statistics increasing over a year from 42% to 68% entering the 2022 with 230513 of conducted flights in 2021. In first two months of 2022 there was conducted 31 thousand flights.

Conclusion to chapter 5

The first section of the specialized segment involved the automated processing of the flight trajectory data for AFR9406 / AF9406 (Air France 9406). These data were supplied by Air France for the route connecting Paris, France (CDG), and Marrakech, Morocco (RAK). The flight departed on November 8, 2022 at 07:46PM (+1) and landed on the same day at 11:12 PM (CET), arriving on the scheduled arrival time. The Airbus A321 (A321) was used for this flight, and the processed data led to the creation of graphs in Figures 5.1.4 - 5.1.10. Additionally, the comprehensive flight analysis revealed that the total flight time for AFR9406 on November 8, 2022, was 3 hours 2 minutes 55 seconds. The trajectory covered a distance of 2226.6 km, while the route's horizontal projection spanned 2225.9 km.

The last segment of the focused on projecting the efficiency of aviation transport in Ukraine, taking into account global economic and political factors. A statistical analysis of air traffic volumes, employing CTA, was conducted, forecasting air traffic volumes up to the year 2030. The outcomes are presented in Table 4.3. Moreover, a comparison to the EUROCONTROL forecast was conducted with the observance of the rapid development to up to the 80% of the original air traffic volumes.

CHAPTER 5. OCCUPATIONAL HEALTH AND SAFETY AND ENVIROMENTAL PROTECTION IN ENSURING THE FLIGHTS OF MANNED AND UNMANNED AERIAL VEHICLES

5.1 Workload affection on the work of an ATCO

Air Traffic Control (ATC) operators play a crucial role in ensuring the safe and efficient movement of aircraft within the airspace. However, the demands on these professionals have increased significantly over the years, leading to a surge in workload. This article explores the effects of workload on ATC operators and how it influences their ability to manage the intricate web of flights in the sky.

The workload of ATC operators encompasses a multitude of tasks, including aircraft separation, vectoring, communication with pilots, weather monitoring, and handling emergency situations. As air traffic continues to grow globally, so does the complexity of their responsibilities. Modern ATC systems involve advanced technologies, but they also introduce new challenges and information to process.

Workload have various effects on the work of the ATCO including increased stress levels. The relentless demands on ATC operators can lead to heightened stress levels. Managing multiple aircraft, especially during peak hours, requires constant attention and rapid decision-making. High-stress levels may affect cognitive functions and decision-making abilities, potentially compromising safety.

Long hours and continuous mental alertness contribute to operator fatigue. The risk of burnout is significant, as ATC operators often work irregular hours, handle intense situations, and are subject to shift work. Fatigued controllers may experience decreased vigilance and slower response times.

Excessive workload can diminish a controller's situational awareness, making it challenging to keep track of all aircraft under their jurisdiction. This can increase the likelihood of errors and decrease the overall efficiency of the air traffic management system.

Effective communication is paramount in air traffic control. However, excessive workload may lead to communication breakdowns, misunderstandings, and delays in conveying critical information between controllers and pilots.

We can address Workload Challenges by next techniques:

- Technology Integration

Investing in advanced technologies, such as automation and artificial intelligence, can assist ATC operators in managing their workload more efficiently. These tools can handle routine tasks, allowing controllers to focus on critical decision-making.

- Training and Support

Providing comprehensive training programs and ongoing support for ATC operators is essential. This includes stress management techniques, fatigue prevention strategies, and resources to cope with the challenges of the job.

- Staffing and Shift Planning:

Adequate staffing levels and thoughtful shift planning are crucial in preventing burnout and fatigue. Implementing effective scheduling practices can help distribute workload more evenly among controllers.

As the aviation industry continues to evolve, the workload on air traffic control operators remains a critical concern. Recognizing the challenges posed by increased workload and implementing proactive measures to address them is essential for ensuring the safety and efficiency of air travel. By prioritizing the well-being of ATC operators and embracing technological advancements, the industry can navigate the skies with confidence in the face of growing demands.

5.2 Sound pollution in areas near airports

Airports are essential for the development of trade, tourism, and transportation, but they also generate a lot of noise that can have negative impacts on the health and well-being of nearby residents. Airport noise is one of the most important sources of environmental noise pollution, affecting millions of people around the world. In this article, we will explore the causes, effects, and possible solutions of airport noise pollution.

Airport noise pollution is mainly caused by the following factors:

- **Aircraft take-off and landing:** This is the most obvious and loud source of airport noise, as the engines of the aircraft produce a lot of thrust and noise during these phases. The noise level depends on the type, size, and number of aircraft, as well as the distance and direction from the airport.
- **Aircraft overflight:** This is the noise generated by the aircraft flying over the nearby areas, either on their way to or from the airport. The noise level depends on the altitude, speed, and flight path of the aircraft, as well as the weather conditions and the background noise of the area.
- **Ground operations:** This is the noise generated by the activities on the ground, such as taxiing, maintenance, testing, loading, and unloading of the aircraft, as well as the vehicles and equipment used for these purposes. The noise level depends on the frequency, duration, and location of these activities, as well as the design and layout of the airport.

Airport noise pollution can have serious and diverse effects on the health of the people living in the vicinity of the airport, such as:

- **Hearing loss:** Exposure to high levels of noise can damage the inner ear and cause temporary or permanent hearing loss, as well as tinnitus, which is a ringing or buzzing sensation in the ears. According to a study by ACKO[26], airport noise can cause cochlear damage, especially in children and elderly people, if the decibel levels are high enough.
- **Sleep disturbance:** Exposure to noise can interfere with the quality and quantity of sleep, as it can make it harder to fall asleep, cause frequent awakenings, and reduce the amount of deep and restorative sleep. According to the same study by ACKO[1], people living near airports can take up to three times longer to fall asleep, and have more difficulty relaxing. This can lead to fatigue, irritability, and impaired cognitive and physical performance during the day.
- **Cardiovascular and hypertension problems:** Exposure to noise can increase the blood pressure, heart rate, and stress hormones, as well as the

irisk of blood clots, which can lead to various cardiovascular and hypertension problems, such as coronary artery disease, stroke, and heart failure. According to a white paper by ICAO[27], airport noise has been linked to a higher risk of these diseases, especially in people with pre-existing conditions or genetic predisposition.

- **Aggressive behavior and anxiety:** Exposure to noise can affect the mood and mental health of the people, as it can induce feelings of annoyance, anger, frustration, and helplessness, as well as increase the levels of anxiety and depression. According to the study by ACKO [26], airport noise can lead to aggressive behavior and anxiety, especially in people who are sensitive to noise or have low coping skills.
- **Quality of life:** Exposure to noise can reduce the quality of life of the people, as it can affect their social, recreational, and educational activities, as well as their personal and professional relationships. According to the study by ACKO [26], airport noise can reduce the satisfaction and well-being of the people, as well as their property values and economic opportunities.

Airport noise pollution is a complex and challenging problem that requires the cooperation and coordination of various stakeholders, such as the aviation industry, the government, the local authorities, the environmental groups, and the affected communities. Some of the possible solutions for airport noise pollution are:

- **Noise reduction at the source:** This involves the development and implementation of new technologies and practices that can reduce the noise generated by the aircraft and the ground operations, such as quieter engines, propellers, and landing gears, as well as optimized flight paths and procedures.
- **Noise mitigation at the receiver:** This involves the installation and maintenance of noise barriers, insulation, and soundproofing materials that can reduce the noise transmission and impact on the nearby buildings and areas, such as walls, fences, berms, windows, and doors.

- **Noise management and regulation:** This involves the establishment and enforcement of noise standards, limits, and rules that can control and monitor the noise levels and exposure at the airport and the surrounding areas, such as noise contours, noise zones, noise charges, and noise curfews.
- **Noise awareness and education:** This involves the provision and dissemination of information and guidance that can increase the awareness and understanding of the causes, effects, and solutions of airport noise pollution among the public and the stakeholders, as well as the promotion and support of noise reduction and prevention initiatives and programs.

Airport noise pollution is a serious threat to the public health that can cause hearing loss, sleep disturbance, cardiovascular and hypertension problems, aggressive behavior and anxiety, and reduced quality of life. It is a complex and challenging problem that requires the cooperation and coordination of various stakeholders, and the implementation of noise reduction, mitigation, management, and education measures. By doing so, we can ensure the sustainable development of aviation and the protection of the environment and the people.

5.3 Fuel Dumping and its effects on the environment and health

Aviation fuel dumping, also known as fuel jettison, is a procedure used by some aircraft in certain emergency situations to reduce their weight before landing. This is done to avoid damage to the aircraft or to increase its performance in case of engine failure, fire, or other problems. However, this practice also has negative impacts on the environment and human health, as the dumped fuel can contaminate the air, water, and soil.

Fuel dumping is usually performed at high altitudes, above 6,000 feet, where the fuel is expected to evaporate and disperse before reaching the ground. However, some studies have shown that not all of the fuel evaporates, and some of it can form droplets that fall to the earth or remain suspended in the atmosphere. The amount of fuel that is dumped depends on the type of aircraft, the fuel type, the engine condition, and the operation mode.

Fuel dumping is coordinated with air traffic control, and the aircraft is directed to fly over unpopulated areas or large bodies of water as much as possible. However, this is not always feasible, and sometimes the aircraft has to dump fuel over urban or agricultural areas, where it can affect people, animals, and plants.

Fuel dumping can cause several environmental problems, such as:

- Air pollution: Fuel dumping can increase the emissions of greenhouse gases, such as carbon dioxide and methane, which contribute to global warming and climate change. It can also release volatile organic compounds (VOCs), such as benzene, which can react with sunlight and other pollutants to form ozone and smog. These can harm the respiratory system and aggravate asthma and other lung diseases. Moreover, fuel dumping can emit particulate matter (PM), which are tiny particles that can penetrate deep into the lungs and cause inflammation, infection, and cancer [28].
- Water pollution: Fuel dumping can contaminate water resources, such as rivers, lakes, and oceans, where it can harm aquatic life and ecosystems. Jet fuel contains various hydrocarbons, metals, and additives, which can be toxic to fish, algae, and coral reefs. Some of these substances can also accumulate in the food chain and affect human health through the consumption of seafood. Furthermore, fuel dumping can affect the water quality and availability, as it can reduce the oxygen levels, increase the acidity, and alter the temperature of the water [29].
- Soil pollution: Fuel dumping can also affect the soil quality and fertility, as it can introduce harmful chemicals and nutrients that can alter the soil pH, texture, and composition. This can affect the growth and development of plants, crops, and microorganisms, and reduce the agricultural productivity and biodiversity. Additionally, fuel dumping can cause soil erosion and runoff, which can carry the pollutants to other areas and increase the risk of flooding and landslides [30].

Fuel dumping can also pose a threat to human health, especially for airport workers and residents living near airports, who are exposed to higher levels of jet engine emissions. Some of the health effects of fuel dumping are:

Cancer: Fuel dumping can increase the risk of cancer, as jet fuel contains carcinogenic substances, such as benzene, polycyclic aromatic hydrocarbons (PAHs), and metals, which can damage the DNA and cause mutations and tumors. Studies have shown that airport workers and residents have higher levels of biomarkers of exposure and effect, such as DNA adducts and oxidative stress, which indicate a higher risk of cancer [31].

Respiratory diseases: Fuel dumping can also cause or worsen respiratory diseases, such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD), as jet fuel can irritate the airways and lungs and cause inflammation, infection, and scarring. Studies have shown that airport workers and residents have higher rates of hospital admissions and self-reported symptoms, such as cough, wheeze, and shortness of breath, related to respiratory diseases [32].

Cardiovascular diseases: Fuel dumping can also affect the cardiovascular system and increase the risk of heart attacks, strokes, and hypertension, as jet fuel can affect the blood vessels and the heart and cause blood clots, plaque formation, and arrhythmias. Studies have shown that airport workers and residents have higher levels of biomarkers of cardiovascular risk, such as blood pressure, heart rate, and inflammation, which indicate a higher risk of cardiovascular diseases [33].

Fuel dumping is a rare and costly procedure that airlines try to avoid as much as possible. However, there are some measures that can be taken to reduce or prevent the need for fuel dumping, such as:

- Improving the aircraft design and performance, so that they can land safely with more fuel on board, or use less fuel during the flight.
- Improving the flight planning and management, so that the aircraft can avoid unnecessary delays, diversions, or emergencies that require fuel dumping.
- Improving the airport infrastructure and operations, so that the aircraft can have shorter taxiing times, faster take-offs and landings, and more efficient routes and schedules.

- Improving the fuel dumping procedures and regulations, so that the aircraft can dump fuel only when absolutely necessary, and only in designated areas and altitudes, where the environmental and health impacts are minimized.

Fuel dumping is a practice used by some aircraft in certain emergency situations to reduce their weight before landing. However, this practice also has negative impacts on the environment and human health, as the dumped fuel can contaminate the air, water, and soil, and cause various diseases, such as cancer, respiratory diseases, and cardiovascular diseases. Therefore, fuel dumping should be reduced or prevented as much as possible, by improving the aircraft design and performance, the flight planning and management, the airport infrastructure and operations, and the fuel dumping procedures and regulations.

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