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: «Сучасні методи збільшення пропускної здатності в зоні підходу»

Виконав:____ Еркінов О. Д.

Керівник:____ Луппо О. Є.

Керівник спеціального розділу:

________________________________д.т.н. проф. Остроумов Іван Вікторович

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"
(EXPLANOTARY NOTE)

Theme: "Modern Methods of Increasing Capacity in the Approach Zone"

Performed by: ____ Erkinov O.D.

Supervisor: ____ Luppo O. E.

Supervisors of special chapter: ___________________________ Ostrumov I.V.

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. Ларін
« ___ »____________2023 р.

ЗАВДАННЯ
на виконання дипломної роботи
Еркінова Отабека Ділшод угли

1. Тема дипломної роботи: **«Сучасні методи збільшення пропускної спроможності в зоні підходу»** затверджена наказом ректора від 28 серпня 2023 № 1443/ст.

2. Термін виконання роботи: з 23.10.2023 по 31.12.2023.

3. Вихідні дані до роботи: теоретичні дані керівних документів ICAO, EUROCONTROL та національних документів України у сфері організації повітряного руху, забезпечення та виконання польотів цивільних повітряних суден.

4. Зміст пояснювальної записки: опис та аналіз пропускної спроможності аеронавігаційної системи України. Аналіз процедурних методів збільшення пропускної спроможності в зоні підходу. Розрахунок ефективності впровадження цих методів в аеронавігаційну систему України.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: графіки результатів даних, таблиці, формули, алгоритми.

6. Календарний план-графік:

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1.	Підготовка та написання 1 розділу «Аналіз факторів, що впливають на пропускну здатність в зоні підходу»	23.10.2023 – 04.11.2023	Виконано
2.	Підготовка та написання 2 розділу «Сучасні методи збільшення пропускної спроможності в зоні підходу»	05.11.2023 – 11.11.2023	Виконано
3.	Підготовка та написання 3 розділу «Розробка рекомендацій з впровадження сучасних методів збільшення пропускної спроможності в зоні підходу на прикладі аеропорту Київ та розрахунок ефективності застосування»	12.11.2023 – 24.11.2023	Виконано
4.	Підготовка та написання 5 розділу “Спеціальний розділ”	25.11.2023 – 01.12.2023	Виконано
5.	Підготовка та написання 6 розділу “Охорона праці та захист навколишнього середовища”	02.12.2023 – 05.12.2023	Виконано
6.	Оформлення та друк пояснювальної записки	06.12.2023 – 08.12.2023	Виконано
7.	Підготовка презентації та доповіді	09.12.2023 – 12.12.2023	Виконано
8.	Попередній захист дипломної роботи	13.12.2023	Виконано

7. Консультанти з окремих розділів:

Розділ	Консультант (посада, П.І.Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Автоматизована обробка великих даних в аеронавігації	д.т.н. проф. Остроумов Іван Вікторович	25.11.2023	05.12.2023

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

Керівник дипломної роботи ______________________ Луппо О.Є.

(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання ____________________ Еркінов О.Д.

(підпис випускника) (П.І.Б.)

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Сучасні методи збільшення пропускної спроможності в зоні підходу»: 92 сторінок, 39 рисунків, 5 таблиць, 34 використаних джерел.

ПРОЦЕДУРНІ МЕТОДИ ЗБІЛЬШЕННЯ ПРОПУСКНОЇ СПРОМОЖНОСТІ В ЗОНІ ПІДХОДУ, ОРГАНІЗАЦІЯ ПОВІТРЯНОГО РУХУ, ПІДВИЩЕННЯ КВАЛІФІКАЦІЯ ДИСПЕТЧЕРА УПР, АЕРОНАВІГАЦІЙНА СИСТЕМА УКРАЇНИ.

Об'єкт дослідження – процес організації повітряного руху в зоні підходу.

Предмет дослідження – процедурні методі збільшення пропускної спроможності у зоні підходу.

Мета дипломної роботи – розробити комплексне рішення (підхід) для підвищення ефективності організації повітряного руху та збільшення пропускної спроможності у зоні підходу.

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

Збільшення польотів цивільної авіації створює проблему організації повітряних потоків у зоні підходу, так як велика кількість рейсів сходяться в одній точці, а саме біля аеропортів. Тому впровадження сучасних методів збільшення пропускної спроможності є одним з головних пріорітетів розвитку аеронавігаційної системи будь-якої країни. Це дозволить обслуговувати більшу кількість рейсів у такий самий проміжок часу зі збереженням прийнятного рівня безпеки польотів.

У цій роботі розглянуті сучасні методи збільшення пропускної спроможності. Виявлено, що процедурні методи є найбільш економічно ефективними. Обрані найбільш ефективні ці методи та шляхи їх впровадження. Аналітично було обчислено ефективність застосування цих методів. Також були підготовлені рекомендації підготовки диспетчерів УПР з урахуванням особливостей цих методів.

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

_______________Erkinov Otabek Dilshod ugli______________

1. The work subject: **Modern Methods of Increasing Capacity in the Approach Zone** approved by the Rector’s order of № 1443/st from 28.09.2023.
2. The work (Thesis) to be completed between from 23.10.2023 to 31.12.2023.
3. Initial data to the work: theoretical data of ICAO, EUROCONTROL guiding documents and national documents of Ukraine in the field of air traffic management, ensuring and performing flights of civil aircraft.
4. The contents of the explanatory note: description and analysis of the capacity of the air navigation system of Ukraine. Analysis of procedural methods of increasing capacity in the approach zone. Calculation of the efficiency of implementation these methods into the air navigation system of Ukraine.
5. The list of mandatory graphic (illustrated) materials: graphs of results data, tables, formulas, algorithms.

6. Calendar schedule:

№	Completion Stages of Degree Thesis	Stage Completion Dates	Completion Mark
1.	Preparation of Charter 1: “Analysis of Factors Influencing Capacity in the Approach Zone”	23.10.2023 – 04.11.2023	Completed
2.	Preparation of Chapter 2: “Modern Methods of Increasing Capacity in the Approach Zone”	05.11.2023 – 11.11.2023	Completed
3.	Preparation of Chapter 3: “Development of Recommendations for the Implementation of Modern Methods to Increase Capacity in the Approach Zone at Kyiv Airport as a Case Study and Calculation the Efficiency of Application”	12.11.2023 – 24.11.2023	Completed
4.	Preparation of Chapter 5: “Automated Big Data Processing in Air Navigation”	25.11.2023 – 01.12.2023	Completed
5.	Preparation of Chapter 6: “Occupational Health and Environmental Protection”	02.12.2023 – 05.12.2023	Completed
6.	Designing and printing of the explanatory note	06.12.2023 – 08.12.2023	Completed
7.	Preparation of report and graphic materials	09.12.2023 – 12.12.2023	Completed
8.	Preliminary presentation of the graduate work	13.12.2023	Completed

7. Consultants from separate departments chapter

Chapter	Consultant (position, full name)	Date, signature	
		Task issued	Task accepted
Automated big data processing in air navigation	D. Sc., prof. Ivan Ostroumov	25.11.22	05.12.22

8. Assignment accepted for completion: “23” October 2023

Supervisor ________________________ Luppo O.E.
(signature) (Full Name)

Assignment Accepted for Completion ___________________ Erkinov O.D.
(signature) (Full Name)

ABSTRACT

Explanatory note to the graduation work “Modern Methods of Increasing Capacity in the Approach Zone”: 92 pages, 39 figures, 5 tables, 34 references.

PROCEDURAL METHODS OF INCREASING CAPACITY IN THE APPROACH ZONE, AIR TRAFFIC MANAGEMENT, IMPROVING THE QUALIFICATION OF AIR TRAFFIC CONTROLLER, AIR NAVIGATION SYSTEM OF UKRAINE.

The object of the research – the process of air traffic organisation in the approach zone.

The subject of the research – procedural methods of increasing capacity in the approach zone.

The purpose of the research – development of the comprehensive solution (approach) of improving of the efficiency of air traffic management and increasing of capacity in the approach area.

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

The increase in civil aviation flights creates the problem of air flows organisation in the approach zone, since a large number of flights converge at one point, namely near airports. Therefore, the implementation of modern methods of increasing capacity is one of the main priorities for the development of the air navigation system of any country. This will make it possible to service a larger number of flights in the same period of time while maintaining an acceptable level of flight safety.

This paper examines modern methods of increasing capacity. Procedural methods have been found to be the most cost-effective. The most effective methods and ways of their implementation have been chosen. The efficiency of using these methods was analytically calculated. Recommendations were also prepared for the training of air control controllers, considering the features of these methods.

CONTENTS

LIST OF ABBREVIATIONS

ABAS – Aircraft-Based Augmentation System

A/C – Aircraft

ACC – Area Control Centre

ADS-B – Automatic Dependent Surveillance **–** Broadcast

ADS-C – Automatic Dependent Surveillance **–** Contract

AFM – Aircraft Flight Manual

AIP – Aeronautical Information Publication

ANS – Air Navigation System

ANSP – Air Navigation Service Provider

ATC – Air Traffic Control

ATCO – Air Traffic Control Operator

ATCS – Air Traffic Control System

ATFM – Air Traffic Flow Management

ATM – Air Traffic Management

ATS – Air Traffic Service

CAA – Civil Aviation Authority

CCO – Continuous Climb Operations

CDM – Collaborative Decision-Making

CDO – Continuous Descent Operations

DME – Distance Measuring Equipment

EASA – European Aviation Safety Agency

ECAC – European Civil Aviation Conference

EUROCONTROL – European Organization for the Safety of Air Navigation

FAA – Federal Aviation Administration

FAF – Final Approach Fix

FAP – Final Approach Point

FIR – Flight Information Region

FIS – Flight Information Service

FMS – Flight Management System

GANP – Global Air Navigation Plan

GBAS – Ground-Based Augmentation System

GNSS – Global Navigation Satellite System

GPS – Global Positioning System

IATA – International Air Transport Association

IAF – Initial Approach Fix

ICAO – International Civil Aviation Organization

IF – Intermediate Fix

IFR – Instrument Flight Rules

ILS – Instrument Landing System

LNAV – Lateral Navigation

MSA – Minimum Sector Altitude

MSL – Mean Sea Level

NADP – Noise Abatement Departure Procedure

NAVAID – Navigation Aid

NM – Nautical Mile

PBN – Performance-based navigation

PSR – Primary Surveillance Radar

RNAV – Area navigation

RNP – Required navigation performance

SARPs – Standards and Recommended Practices

SESAR – Single European Sky ATM Research

SID – Standard instrument departure

STAR – Standard instrument arrival

TA – Transition Altitude

TL – Transition Level

TOC – Top of Climb

TOD – Top of Descent

VNAV – Vertical Navigation

INTRODUCTION

The significant growth in air travel has presented challenges for air traffic flow management. As more people choose air travel for their journeys, the number of flights taking off and landing at airports around the world has increased substantially. This surge in air traffic can put a strain on the existing air traffic management systems and infrastructure. According to the latest data from the International Civil Aviation Organization (ICAO), air traffic is projected to experience stable annual growth of approximately 3% since its peak demand year in 2019 [1].

To effectively manage this increased demand and maintain safety, efficiency, and reliability in air travel, air traffic flow management (ATFM) becomes crucial. ATFM is a process that optimizes the use of airspace and airport capacity while minimizing delays and ensuring the safe and orderly movement of aircraft.

With the growth in air travel, ATFM systems need to adapt and evolve to accommodate the higher volume of flights. This includes implementing advanced technologies and procedures to enhance airspace management, runway allocation, and the sequencing of aircraft arrivals and departures. Air traffic controllers and aviation authorities must work together to develop strategies that balance the increased demand for air travel with the need to prevent congestion, delays, and potential safety issues.

Efforts are ongoing to modernize ATFM systems and improve communication and coordination among all stakeholders in the aviation industry. This includes the use of automation, data sharing, and real-time monitoring to ensure the efficient movement of aircraft in congested airspace and at busy airports. Furthermore, the development of sustainable and eco-friendly practices in air travel is also integrated into ATFM, as it aims to address environmental concerns associated with the growth in air travel.

In air traffic control, a sector is a designated portion of airspace, often managed by a specific air traffic control facility or center. These sectors are strategically defined to efficiently handle air traffic within a particular region. The boundaries of sectors are established based on factors such as geographical features, air traffic flow, and the need for effective communication and coordination.

The capacity of a sector is a critical consideration in air traffic management. It refers to the maximum number of aircraft that a sector can handle safely and efficiently at any given time.

Sector capacity in air traffic control is influenced by a variety of factors. These factors include the complexity of the airspace being managed, the level of technological infrastructure and equipment available to controllers, the workload of air traffic controllers, and the efficiency of traffic flow management procedures. Weather conditions also play a significant role, as adverse weather can impact the capacity by requiring increased separation between aircraft to ensure safety. For a comprehensive overview of the factors influencing sector capacity, refer to Figure 1 below [7], which illustrates these key elements.

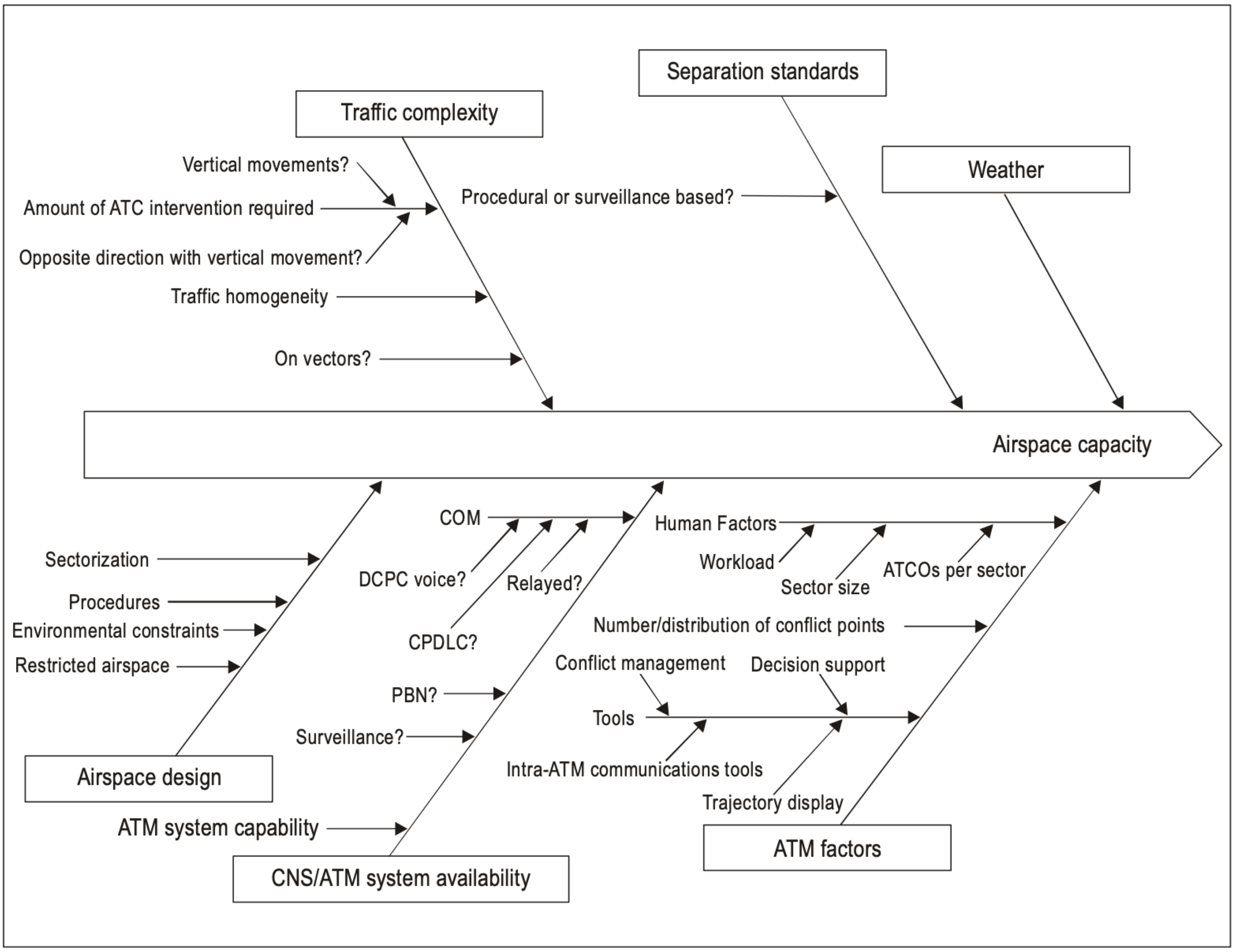

Figure 1 – Factors Influencing Sector Capacity

In the realm of air traffic management, the terminal area stands out as one of the busiest and most critical components of the airspace. This is where all arriving and departing flights converge, creating a high-density environment. Ensuring that the capacity of the terminal area can meet the ever-increasing demand is of paramount importance. Meeting this growing demand while maintaining safety and efficiency is a continuous challenge.

There are several strategies to increase the capacity of the terminal area. These strategies are essential to alleviate congestion and optimize the flow of aircraft, allowing for a more streamlined operation. In my thesis, we are focusing on analyzing procedural methods to increase capacity in the approach zone, which is often considered the most cost-effective approach. These methods do not involve extensive infrastructure changes, making them particularly attractive for airports and air traffic management authorities looking to enhance capacity without major capital expenditures.

CHAPTER 1. ANALYSIS OF FACTORS INFLUENCING CAPACITY IN THE APPROACH ZONE

1.1. Capacity Definition

Sector capacity, in the context of air traffic control, refers to the maximum number of aircraft that a specific air traffic control sector can safely and efficiently manage within a defined period, typically an hour. This capacity limit is established to ensure that the air traffic controller(s) responsible for that sector can maintain safe separation between aircraft and manage the flow of traffic effectively.

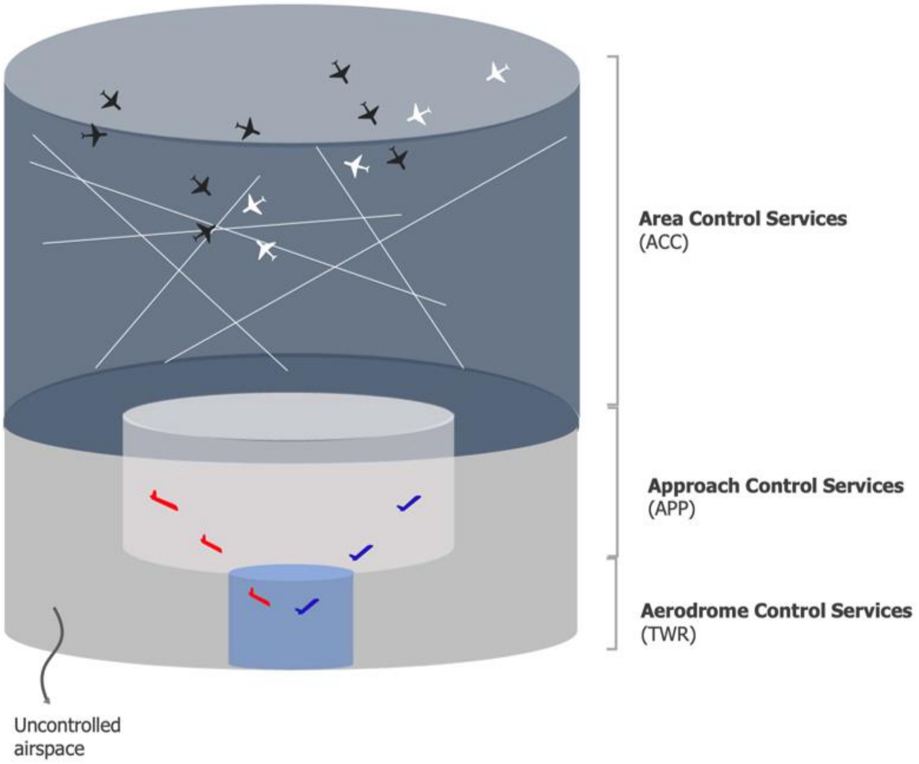

Figure 1.1 – Airspace Structure

Controlled airspace is categorized into different types, including CTR (Control zone), CTA (Control area), TMA (Terminal control area), ACC (Area control centre), each with its unique capacity considerations, such as airport capacity, terminal capacity, en-route capacity, and system capacity to effectively manage air traffic within their respective domains.

Airport Capacity: Airport capacity pertains to the ability of an airport to accommodate a specific number of aircraft landings, take-offs, and passengers within a given timeframe while maintaining safe and efficient operations. Key factors affecting airport capacity include runway availability, taxiway design, terminal facilities, and air traffic control procedures. Efficient airport capacity management is essential to minimize congestion and delays at airports.

Terminal Capacity: Terminal capacity focuses on the airspace in the vicinity of an airport, including approach and departure routes. It addresses the number of aircraft that can be managed safely and efficiently in this region, particularly in busy terminal areas. Factors influencing terminal capacity include airspace design, air traffic controller workload, available technology, weather conditions, and the mix of aircraft types.

En-Route Capacity: En-route capacity relates to the airspace between airports and includes airways and sectors managed by en-route air traffic control. It addresses the ability to safely manage the flow of aircraft flying at cruising altitudes. En-route capacity depends on the complexity of airspace design, available navigation aids, communication systems, the mix of aircraft, and controller workload.

System Capacity: System capacity encompasses the entire air traffic management system within a specific region or country, and it represents the collective performance of all elements in the aviation system. It involves coordination between airports, collaborative decision-making, airspace design, and the integration of various technologies. Effective management of system capacity aims to prevent congestion, optimize air traffic flows, and ensure the efficient use of resources.

The number of aircraft provided with an ATC service shall not exceed that which can be safely handled by the A TC unit concerned under the prevailing circumstances. In order to define the maximum number of flights which can be safely accommodated, the appropriate A TS authority should assess and declare the ATC capacity for control areas, for control sectors within a control area and for aerodromes [8].

ATC capacity should be expressed as the maximum number of aircraft which can be accepted over a given period of time within the airspace or at the aerodrome concerned [8].

1.2. Sector capacity estimation

ICAO [9] outlines the anticipated requirements of the air traffic management (ATM) community with respect to capacity:

“The global ATM system should exploit the inherent capacity to meet airspace user demands at peak times and locations while minimizing restrictions on traffic flow.

To respond to future growth, capacity must increase, along with corresponding increases in efficiency, flexibility and predictability, while ensuring that there are no adverse impacts on safety and giving due consideration to the environment.

The ATM system must be resilient to service disruption and the resulting temporary loss of capacity.”

Sector capacity estimation is a critical aspect of air traffic management, focusing on determining the maximum number of aircraft that a specific air traffic control sector can safely and efficiently handle within a given timeframe. Accurate sector capacity estimation is essential for ensuring the safety, efficiency, and orderliness of air traffic operations.

The aviation industry categorizes capacity into three types: declared, deployed, and planned.

Capacity performance: the provision of sufficient capacity to meet traffic demand is determined by the available capacity in specific sectors and by the configuration of sectors, which is influenced by operational factors like airspace structures, technical equipment, and air traffic controller staffing and expertise. An Air Navigation Service Provider (ANSP) may establish a declared capacity for an elementary sector, specifying the typical number of aircraft it can handle per hour based on these considerations.

At times, the permitted number of aircraft per hour in a sector may be lower than the declared capacity, potentially due to external factors like adverse weather, sovereign issues such as military activity, or internal factors within the Air Navigation Service Provider (ANSP), such as the serviceability of air traffic control (ATC) equipment. This reduced capacity is referred to as deployed capacity, and it only becomes problematic when the demand for air traffic exceeds the level of deployed capacity.

Additionally, ANSPs may consolidate elementary sectors into larger collapsed sectors for economic efficiency. This approach reduces the number of required air traffic controllers, allowing for a potentially higher deployment of controllers during peak traffic periods—an optimal utilization of resources. However, it's crucial to note that collapsed sectors have a lower declared capacity compared to their individual components operating simultaneously. Therefore, it is essential to ensure that the reduced deployed capacity is adequate to accommodate the prevailing traffic demand.

In order to meet the demands of future growth and, notably, to address existing capacity shortcomings, Air Navigation Service Providers (ANSPs) must proactively plan and implement additional airspace capacity wherever there is an exceeding or anticipated exceeding of the available capacity during peak periods.

Enhancing capacity may involve several actions, including:

- dividing existing elementary sectors into two or more separate sectors during peak traffic demand;
- ensuring consistent operational procedures among Air Traffic Control (ATC) units and optimizing the use of available infrastructure to facilitate sector capacity expansion;
- recruiting additional controllers if needed, especially when flexible opening schemes are already in place;
- adjusting sector opening schemes based on traffic demand patterns;
- increasing the declared capacity of elementary and collapsed sectors by applying effective solutions.

A sector's capacity is typically assessed using three primary methods:

- Entry counts.
- Frequency occupancy.
- ATCO workload.

Regardless of the chosen method, the fundamental principles of capacity management remain consistent:

Exceeding Capacity Forecast:

- If the projected traffic exceeds the sector's capacity, the appropriate response is to either open another sector or implement traffic restrictions.

Handling Increased Traffic:

- If the traffic forecast indicates the potential to handle more traffic, the appropriate actions involve closing excessive sectors and easing restrictions.

Incorrect capacity determination can lead to two distinct scenarios:

- Overload: This occurs when the traffic cannot be safely accommodated.
- Underload: This results in inefficiencies, such as operating surplus sectors (requiring more personnel) or imposing various restrictions on traffic, causing delays.

Hence, both extremes are considered undesirable, emphasizing the need to minimize their occurrence. With safety taking precedence in aviation, the primary focus typically centers on preventing overload situations.

Entry Counts

Capacity is defined as the maximum number of aircraft managed within a specified time period, typically one hour (e.g., 35 aircraft per hour). This metric considers a range of factors, including the dimensions and configuration of the sector, applicable procedures, anticipated traffic, proximity to aerodromes, seasonal variations, and other relevant considerations. This method offers several key benefits:

- Universality: It is versatile and applicable to various elements such as ATC sectors, runways, and more.
- Simplicity: The approach is straightforward, relying solely on the entry time of each aircraft, hence its name.
- Ease of Implementation: It is easily implementable, and even older systems can efficiently calculate a reasonably accurate medium-term forecast (e.g., 8 hours) based exclusively on the provided flight plans.

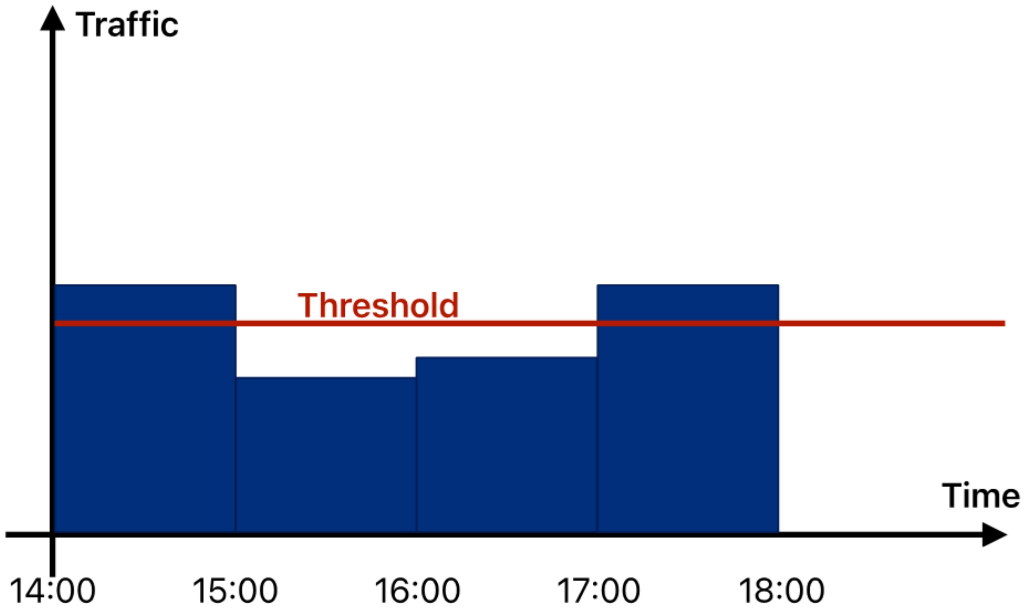

Figure 1.2 – Example of the Entry Counts Method

A significant disadvantage of this method is its failure to account for traffic distribution. To illustrate, suppose the sector's capacity is 35 aircraft per hour, and the actual entry count is 25 for the first hour and 25 for the second. Initially, it may appear that the sector can comfortably handle a 40% increase in flights. However, if the traffic is concentrated in the middle of the period, this results in a peak of very high workload (overload) surrounded by two extended periods of inactivity, as illustrated in the figure below.

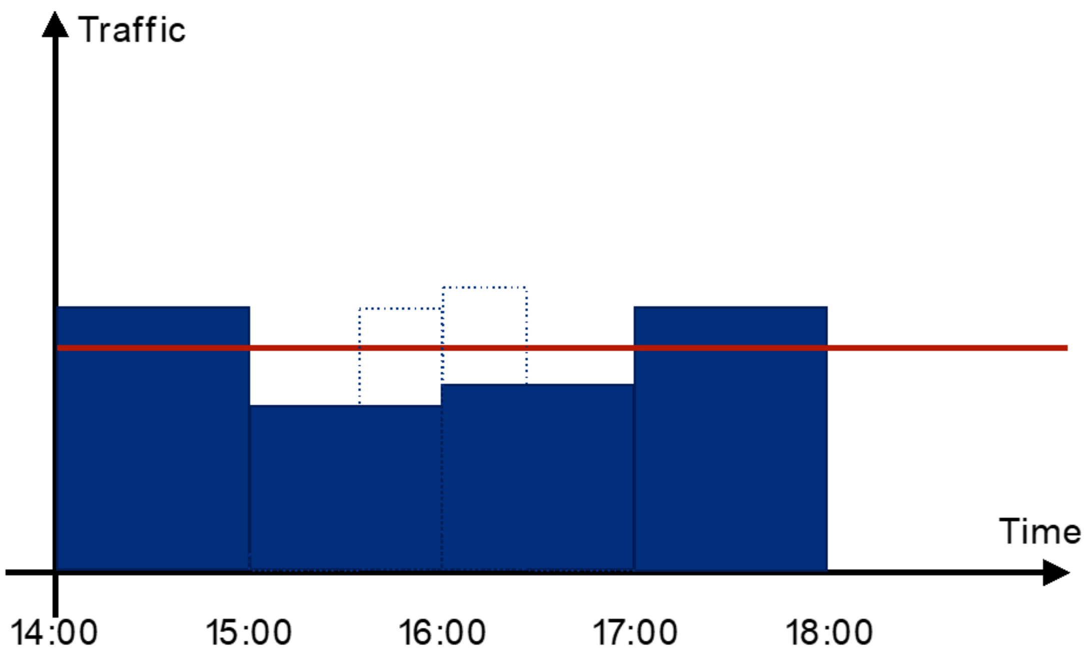

Figure 1.3 – Drawback of the Entry Counts Method

Another factor overlooked by this method is the consideration of traffic patterns. The calculation treats all aircraft equally, irrespective of their duration within the sector (whether 5 or 15 minutes), their vertical profiles (for instance, an aircraft descending from FL 320 to FL 140 is considered equivalent to one maintaining FL 290), or the attention they may demand from the controller (such as potential conflicts with other aircraft).

To address these limitations, capacities are computed with the inclusion of a buffer, aiming to mitigate these weaknesses.

Frequency Occupancy

The capacity is defined by the maximum number of aircraft concurrently occupying the frequency (e.g., 25 aircraft simultaneously). An aircraft is deemed to be on the frequency from its estimated time at the sector entry point until it reaches the sector exit point. If the quantity of aircraft surpasses a predetermined threshold, adjustments to the sector configuration or the imposition of traffic restrictions become necessary. Similar to the previous method, this threshold considers various factors and may be subject to variation based on the specific sector or other prevailing circumstances.

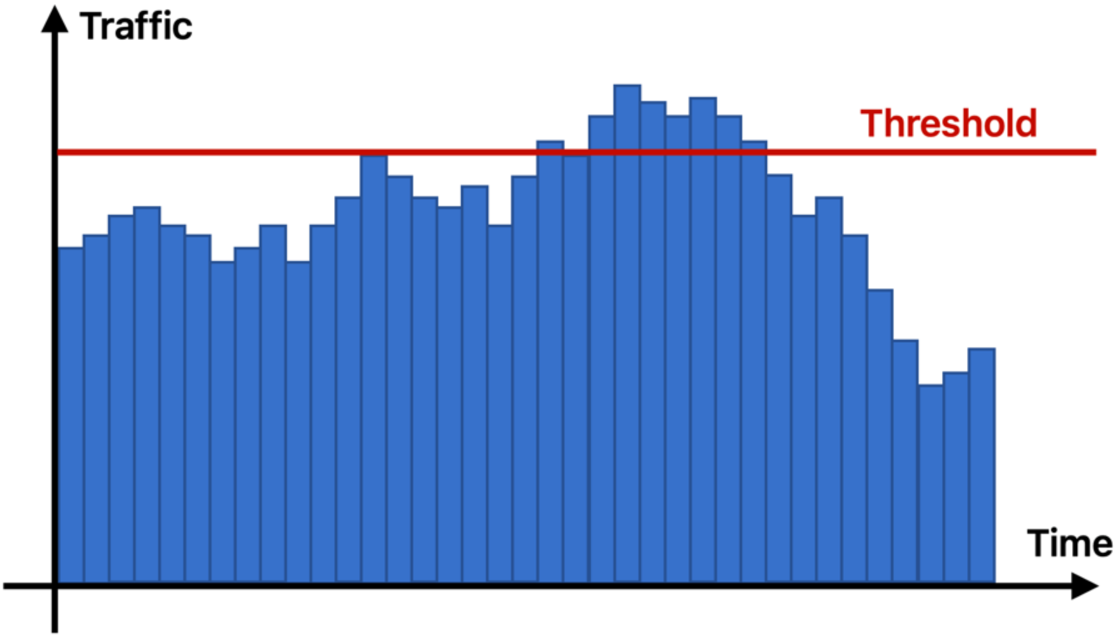

Figure 1.4 – Example of the Frequency Occupancy Method

This approach necessitates a more intricate computation due to the requirement for a forecast detailing the duration of each flight within the sector. This forecast must consider variables such as the aircraft's speed (i.e., type) and route, in addition to the entry time.

The benefit of this method is that it offers a more accurate understanding of the timing of peak traffic loads, effectively addressing a significant drawback of the entry counts method. However, it maintains a uniform treatment of each aircraft, irrespective of its actual impact on workload. It's essential to note that high traffic does not necessarily translate to a heavier workload. For instance, a scenario with numerous aircraft at cruising levels could be managed effortlessly, while another with fewer aircraft might be more demanding.

The responsibility of the Air Traffic Controller (ATCO) is to facilitate the safe and efficient movement of air traffic through their designated airspace. Controllers must maintain vigilance and effectiveness throughout their operational duty shift, remaining prepared to handle unexpected situations such as aircraft emergency declarations or severe weather conditions.

Controller Workload

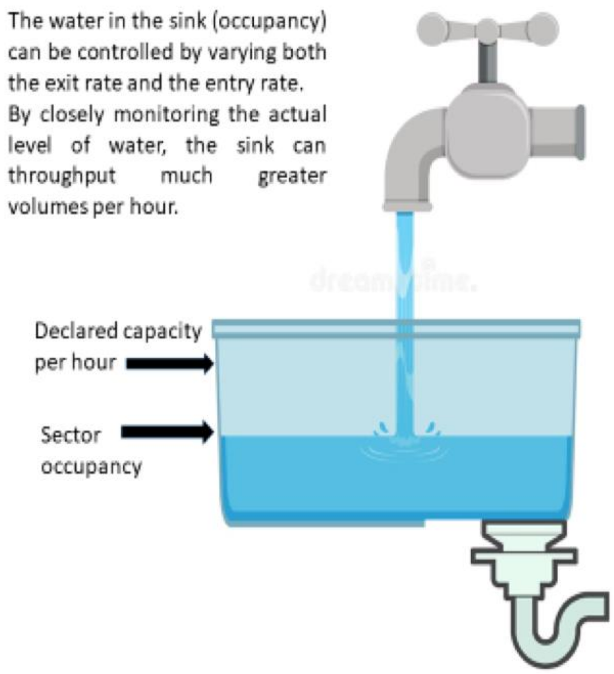

Figure 1.5 – Capacity and sector occupancy

In Figure 1.5 the level of Air Traffic Controller (ATCO) workload is a crucial determinant of sector occupancy. When the ATCO can efficiently manage the traffic, there is flexibility for an increase in occupancy. Maintaining a sustainable level of ATCO workload involves aligning the entry rate with the exit rate. In cases where the workload intensifies, it becomes necessary to decrease the entry rate to prevent overloading the ATCOs.

It's important to note that the sector occupancy value is generally considerably lower than the corresponding hourly declared capacity. For example, with a declared capacity of 45 aircraft per hour, the sector occupancy might be 15, even though this configuration results in a higher throughput. This discrepancy underscores the careful balance required in workload management, sector occupancy, and declared capacity to ensure optimal air traffic control efficiency.

The Controller Workload method to estimate sector’s capacity is grounded in evaluating the time needed by controllers to complete essential tasks, typically setting the threshold at 40-45 minutes. A spare time of 15-20 minutes functions as a buffer against abnormal situations and forecast inconsistencies. In contrast to the other two methods, this approach is linked to the controller and remains constant across all sectors. However, this constancy doesn't imply that all sectors can manage the same traffic volume. Instead, the forecast calculation automatically adapts to the specific airspace and traffic conditions. For instance, a shorter sector may necessitate more frequent communication, resulting in a shorter interval between the initial and final calls. Moreover, having the same number of aircraft in a smaller volume could potentially lead to more conflict situations, demanding additional time for resolution.

This method's primary strength lies in its comprehensive consideration of numerous factors, such as weather, military activities, flight vertical profiles, local procedures, and more, resulting in an exceptionally accurate forecast. Another advantage is its self-adjusting nature, eliminating the need for capacity recalculations when there are changes in sector configuration or traffic flow, as long as the model remains valid and all relevant factors are considered.

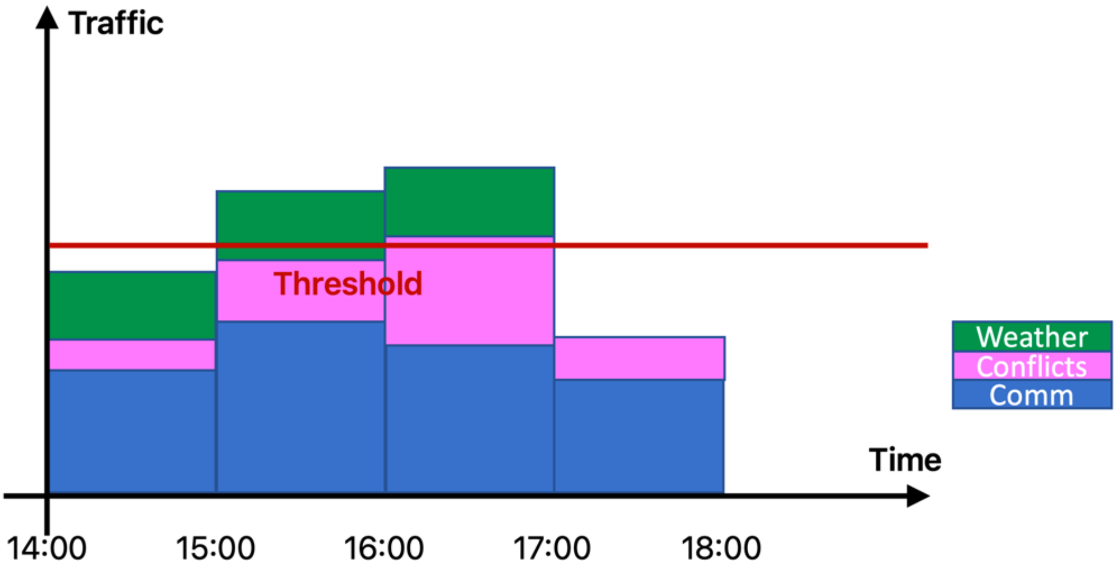

Figure 1.6 – Example of the Controller Workload Method

A possible drawback is that the accuracy of the forecast is contingent on the precision of its input data. Consequently, incorrect or missing estimates, weather forecasts, and other variables may lead to an unreliable assessment of the situation.

Accurate assessment of a controller's workload is crucial for achieving optimal efficiency. Prolonged periods of excessively high workload may lead to the controller being overstretched, while extended periods of low workload not only inefficiently utilize resources but also increase the likelihood of the controller becoming distracted from their primary task.

$$K_{wl} = \frac{T_{atc}}{T_{gen}} \tag{1.1}$$

Table 1.1 – Workload Coefficient Equation

$\boldsymbol{T_{atc}}$ (time of air traffic control)	Total time required to perform technological operations within the appropriate ATC sector which are set by ATC’s work manual, including time for radio communications, analysis of the situation and decision-making
$\boldsymbol{T_{gen}}$ (general time)	Total time of a standard ATC unit, the interval of which is required for evaluation of maximum allowable ATC sector capacity

The table 1.2 presents various levels of workload factors for reference.

The workload of an Air Traffic Controller (ATCO) is represented by the workload coefficient. This coefficient is established based on the time needed to perform technological operations at the specific workstation within the ATC sector.

Table 1.2 – Workload Factor

Threshold	Interpretation	Recorded Working Time during 1 hour
70% or above	Overload	42 minutes +
54% - 69%	Heavy Load	32 – 41 minutes
30% - 53%	Medium Load	18 – 31 minutes
18% - 29%	Light Load	11 – 17 minutes
0% - 17%	Very Light Load	0 – 10 minutes

The equation used to assess a sector’s capacity is presented below:

$$N = \frac{\varphi * T}{\eta * \tau m} \quad (1.2)$$

Table 1.3 – Sector’s Capacity Assessment Equation

N	The number of aircraft that can be controlled simultaneously by a single ATCO
φ	The ATCO availability factor (expressed as a %), defined as the percentage of time available for planning aircraft separation procedures
T	Average flight time of the aircraft in the sector (the unit of time needs to be the same as for τm below - the conversion is done automatically in this tool)
η	Number of communications for each aircraft in the sector, which must be limited to the least possible number required for an understanding between the pilot and the ATCO
τm	Mean duration of each message (the unit of time needs to be the same as for T above - the conversion is done automatically in this tool)

1.3. Factors influencing capacity

The capacity of ATC sector is influenced by factors such as the quantity of available controllers, the intricacy of the airspace, and the available equipment. The incorporation of innovative technologies, like satellite-based navigation systems, has elevated ATC sector capacity. These technologies empower aircraft to navigate more precise routes, leading to a reduction in separation distances and an overall enhancement of airspace efficiency.

As the overall volume of air traffic rises, there is a corresponding need to augment capacity. This increase in capacity can be achieved through various means, including the enhancement of ATC equipment, refining the skills of ATCOs through improved training, fostering better civil-military cooperation to alleviate congestion during peak periods, minimizing separation requirements within sectors or at entry and exit points, and redesigning airspace. The redesign may involve segmenting individual sectors into two or more parts, thereby expanding capacity.

When the demand for air traffic exceeds the capacity, an overload situation arises. In the case of an aerodrome, this is managed by instructing aircraft to enter holding area or, if the anticipated delay is projected to be longer than the aircraft's endurance, considering diversion to alternate aerodromes.

Several factors influence the capacity of an ATC sector, particularly in the terminal area or approach zone. These factors encompass a range of elements that collectively determine the sector's ability to efficiently manage air traffic. Here are key factors influencing ATC sector capacity:

1. **Air Traffic Volume:** The sheer volume of air traffic within the sector significantly impacts its capacity. Higher traffic volumes pose challenges in managing aircraft flow effectively.
2. **Controller Workload:** The workload on Air Traffic Controllers (ATCOs) is a critical factor. If the workload becomes too high, it can lead to reduced capacity as controllers may struggle to handle the traffic demand effectively.

3. **Aircraft Types and Performance:** The mix of aircraft types, each with its unique performance characteristics, influences the sector's ability to handle diverse traffic efficiently.
4. **Weather Conditions:** Adverse weather conditions, such as low visibility or severe turbulence, can impact capacity by requiring increased separation between aircraft or necessitating alternative routing.
5. **Equipment and Technology:** The availability and sophistication of ATC equipment and technology play a crucial role. Advanced systems, like radar and satellite-based navigation, can enhance the efficiency and capacity of the sector.
6. **Staffing Levels and Training:** Adequate staffing levels and well-trained controllers are essential. Insufficient staffing or lack of training can limit the sector's ability to manage increased traffic.
7. **Procedural Efficiency:** The efficiency of ATC procedures, including the management of arrival and departure routes, can influence capacity. Streamlined procedures help optimize traffic flow.
8. **Collaboration and Coordination:** Effective collaboration and coordination between ATC units, both civil and military, are vital. Seamless cooperation ensures smoother transitions and minimizes congestion.
9. **Airspace Design:** The design of the airspace, including sector boundaries and the arrangement of arrival and departure routes, affects capacity. Well-designed airspace can facilitate efficient traffic flow.

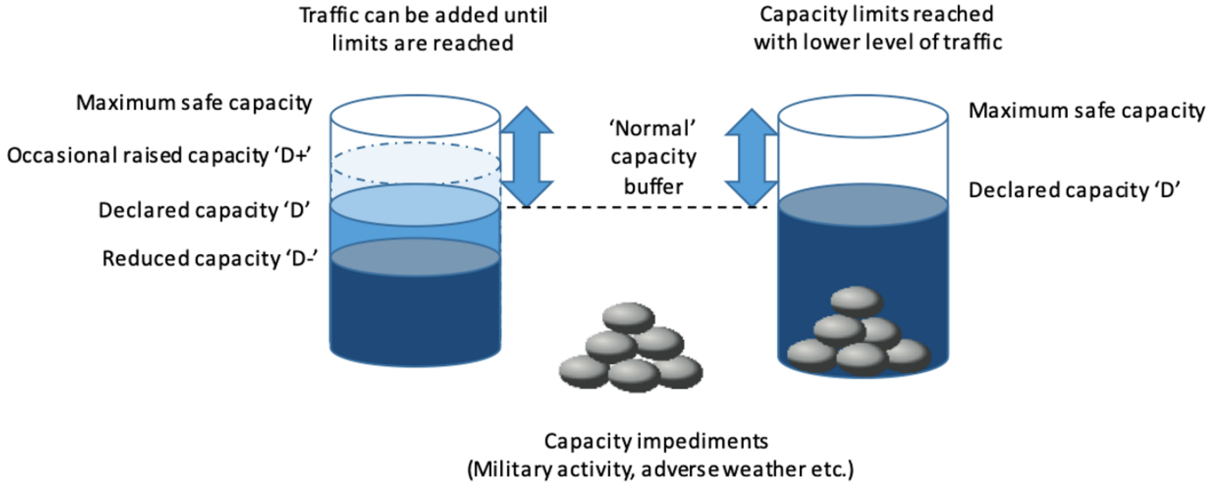

Figure 1.7 – The concept of capacity and traffic

Figure 1.7 demonstrates the variable liquid capacity of a container, with the ability to contain different amounts up to a maximum limit. The declared capacity, as depicted, is not a fixed minimum or maximum threshold. Additionally, the figure illustrates that factors hindering capacity can result in a decrease in the liquid volume (traffic) within the declared capacity.

Conclusions to Chapter 1

As the demand for air travel continues to grow, it becomes increasingly crucial to assess the capacity of Air Traffic Control (ATC) sectors. This assessment is essential to ensure the safe and efficient management of the escalating traffic flow. By proactively evaluating and optimizing the capacity of ATC sectors, aviation authorities can address the challenges posed by the surge in air traffic demand. This strategic approach enables the development of reliable systems and infrastructure to accommodate the growing needs of the aviation industry while upholding safety standards and enhancing operational efficiency.

There are three primary methods used to describe a sector's capacity: entry counts, frequency occupancy, and controller workload. Each of these methods provides unique insights into the operational dynamics and efficiency of an ATC sector. Entry counts involve tracking the number of aircraft entering the sector, frequency occupancy focuses on the maximum number of aircraft on the frequency at the same time, and controller workload assesses the level of demands on ATC personnel. By employing these methods, aviation authorities can comprehensively evaluate and manage the capacity of ATC sectors to ensure effective and safe air traffic management.

It is imperative to shift our focus towards methods dedicated to enhancing the capacity of ATC sectors, taking into careful consideration the multitude of factors that impact this capacity. In the next chapters, we will delve into modern methods of increase capacity, specifically within the approach zone. These discussions will explore cutting-edge methodologies and the practical implementation of strategies, addressing the intricate challenges inherent in optimizing the efficiency and throughput of ATC sectors. By delving into these contemporary techniques, our aim is to offer comprehensive insights into elevating sector capacity to effectively meet the escalating demands of air traffic management in an ever-evolving aviation landscape.

CHAPTER 2. MODERN METHODS OF INCREASING CAPACITY IN THE APPROACH ZONE

2.1. Continuous Climb and Descent Operations (CCO/CDO)

Continuous Climb Operations (CCO) is an aircraft operating procedure designed to optimize the climb phase of an aircraft's departure trajectory. Traditionally, aircraft follow a stepwise climb profile, where they level off at certain altitudes before resuming their climb to higher levels. In contrast, CCO allows for a continuous ascent without intermediate level-offs. This operational concept aims to enhance efficiency, reduce fuel consumption, and minimize environmental impact during the departure phase of a flight.

Benefits of Implementing CCO operations:

1. Fuel Efficiency and Emissions Reduction:
   - CCO reduces the need for level-offs, enabling a more direct and fuel-efficient climb. By minimizing thrust changes and maintaining a continuous climb, fuel burn decreases, resulting in lower emissions. This is particularly crucial in the approach zone, as it contributes to a more sustainable and environmentally friendly aviation sector.
2. Airspace Optimization:
   - By eliminating unnecessary level-offs, CCO contributes to improved airspace utilization. This optimization is vital in busy approach zones, where airspace congestion can lead to delays and reduced overall capacity. CCO, by streamlining the climb phase, helps alleviate congestion and enhances the overall flow of air traffic.
3. Reduced Noise Impact:
   - CCO can also contribute to noise reduction, especially in areas surrounding airports. The continuous climb minimizes the time an aircraft spends at lower altitudes with higher power settings, resulting in reduced noise exposure for communities near airports. This is a significant factor

in addressing environmental concerns and improving the relationship between airports and their surrounding areas.

4. Reduced Workload for Air Traffic Controllers and Pilots:
   - Continuous Climb Operations (CCO) contributes to a more streamlined and predictable climb phase, reducing the workload for both air traffic controllers and pilots. With fewer level-offs and smoother trajectory profiles, controllers can more efficiently manage traffic, leading to a more predictable and manageable workload. Pilots also experience a simplified ascent, with fewer altitude adjustments, allowing them to focus on other critical aspects of flight, thereby enhancing overall safety and operational efficiency in the approach zone. This reduction in workload for both controllers and pilots positively influences the capacity of the approach zone.
   - Additionally, the reduction in the number of level-offs in CCO leads to a decrease in radiotelephony communications between pilots and air traffic controllers. The continuous climb minimizes the need for frequent altitude clearances and reports, streamlining communication procedures. This reduction in radio frequency usage not only enhances the overall efficiency of air traffic communication but also contributes to a quieter and less congested communication environment.

Continuous Descent Operations (CDO) is an aircraft operating procedure designed to optimize the descent phase of an aircraft's approach to landing. Traditionally, aircraft descend in a stepwise manner, leveling off at various points during their approach. CDO, on the other hand, promotes a smooth and continuous descent from cruising altitude to the runway without intermediate level-offs. This operational concept is aimed at improving fuel efficiency, reducing emissions, minimizing noise, and enhancing overall environmental sustainability during the arrival phase of a flight.

Benefits of Implementing CDO operations:

1. Fuel Efficiency and Emissions Reduction:

- CDO promotes a more efficient and direct descent, minimizing the need for engine thrust adjustments and allowing aircraft to follow a continuous, optimized descent path. This results in reduced fuel consumption and lower emissions compared to traditional stepwise descent profiles. In the approach zone, where aircraft are transitioning from cruising altitude to landing, this fuel efficiency is critical for both economic and environmental reasons.

2. Noise Abatement:
    - Continuous Descent Operations contribute to noise abatement in the approach zone. By avoiding level-offs and maintaining a consistent descent angle, CDO minimizes the time spent at lower altitudes with higher power settings. This reduction in noise-generating activities is particularly important for communities near airports, as it helps mitigate the impact of aircraft noise during the descent phase.
3. Airspace Optimization:
    - CDO supports the optimization of airspace in the approach zone. The continuous descent allows for a more predictable and efficient management of arriving air traffic. Air traffic controllers can plan and sequence arrivals more effectively, reducing the likelihood of holding patterns and delays. This contributes to enhanced overall capacity in the approach zone and improves the flow of incoming air traffic.
4. Reduced Workload for Air Traffic Controllers and Pilots:
    - The continuous and predictable nature of CDO also leads to a reduction in workload for air traffic controllers and pilots. Controllers can anticipate and manage arriving aircraft more efficiently, and pilots experience a smoother and more straightforward descent profile. This reduction in workload supports safer and more streamlined operations in the busy environment of the approach zone.
5. Integration with Arrival Management Systems:
    - CDO can be integrated with advanced Arrival Management Systems

(AMAN) to further optimize the sequencing and spacing of arriving aircraft. By providing accurate arrival times and descent profiles, CDO enhances the capabilities of these systems, contributing to improved overall efficiency and capacity in the approach zone.

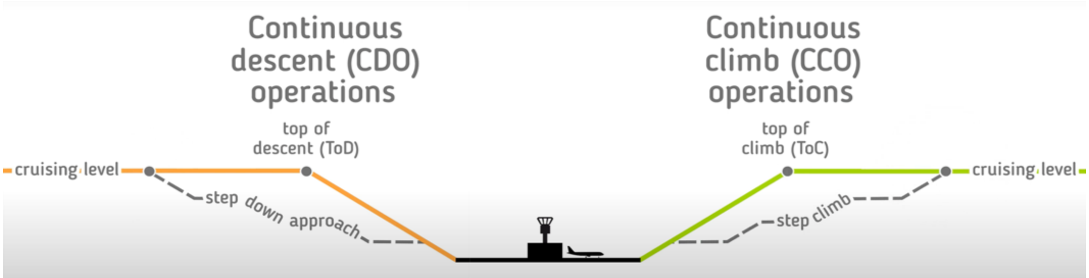

Figure 2.1. – Representation of CCO/CDO [11]

In conclusion, both CCO and CDO demonstrate advantages over traditional stepwise descent in terms of fuel efficiency, emissions reduction, and airspace capacity (Fig 2.1). The choice between CCO and CDO may depend on specific operational considerations and the unique characteristics of the airspace and airport infrastructure. Implementing these continuous operations can contribute significantly to optimizing the approach zone and improving the overall efficiency and sustainability of air transportation systems.

2.2. Point Merge

Point Merge is an air traffic management concept designed to optimize the sequencing and spacing of arriving aircraft in the approach phase. In traditional air traffic control methods, aircraft follow predefined routes and are sequenced individually for landing. However, Point Merge introduces a more dynamic and collaborative approach.

In Point Merge, arriving aircraft are directed to merge at specific points in the airspace before entering the final approach phase to the runway. These merging points are strategically located at a distance from the airport, allowing for a smoother and more efficient flow of traffic towards the landing runway.

Key features of Point Merge include the establishment of merge points, the utilization of automation to assist in sequencing, and improved collaboration between different stakeholders in the air traffic management process. By implementing Point Merge, air navigation service providers aim to increase the overall capacity of the approach zone, minimize delays, enhance safety, and reduce fuel consumption through more efficient flight paths.

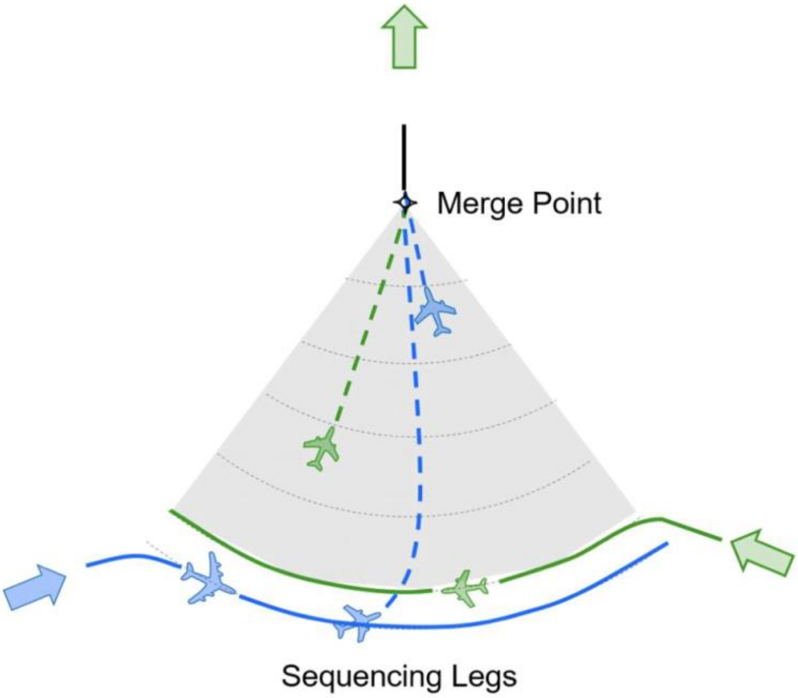

Figure 2.2 – Representation of the Point Merge procedure [14]

Benefits of Implementing Point Merge:

1. Increased Capacity:

- **Optimized Sequencing:** Point Merge facilitates more efficient sequencing of arriving aircraft, allowing air traffic controllers to handle a higher volume of traffic in the approach zone.
- **Simultaneous Operations:** By streamlining arrival streams at merge points, airports can accommodate a greater number of arrivals simultaneously.

2. Reduced Delays:

- **Predictable Trajectories:** The use of merge points contributes to more predictable and streamlined aircraft trajectories, minimizing the need for extensive vectoring and reducing delays.

- **Enhanced Predictability:** Improved predictability in aircraft spacing and sequencing results in reduced holding patterns and overall shorter approach times.

3. Fuel Savings and Environmental Impact:

- **Optimized Flight Paths:** The streamlined approach provided by Point Merge leads to more direct and fuel-efficient flight paths, reducing fuel consumption and greenhouse gas emissions.
- **Eco-Friendly Operations:** By minimizing delays and improving efficiency, Point Merge supports environmentally sustainable air traffic management practices.

4. Enhanced Safety:

- **Reduced Controller Workload:** Automation and optimized procedures in Point Merge contribute to a reduction in controller workload, allowing for more focused and effective management of air traffic.
- **Minimized Conflicts:** Clear merge points and collaborative procedures help minimize conflicts between arriving aircraft, enhancing overall safety in the approach zone.

Through the implementation of Point Merge, a noticeable enhancement in traffic flows is observed, characterized by reduced delays, optimized sequencing, and a substantial decrease in the utilization of holding procedures, as illustrated in the comparative figure (2.3) depicting Dublin Airspace.

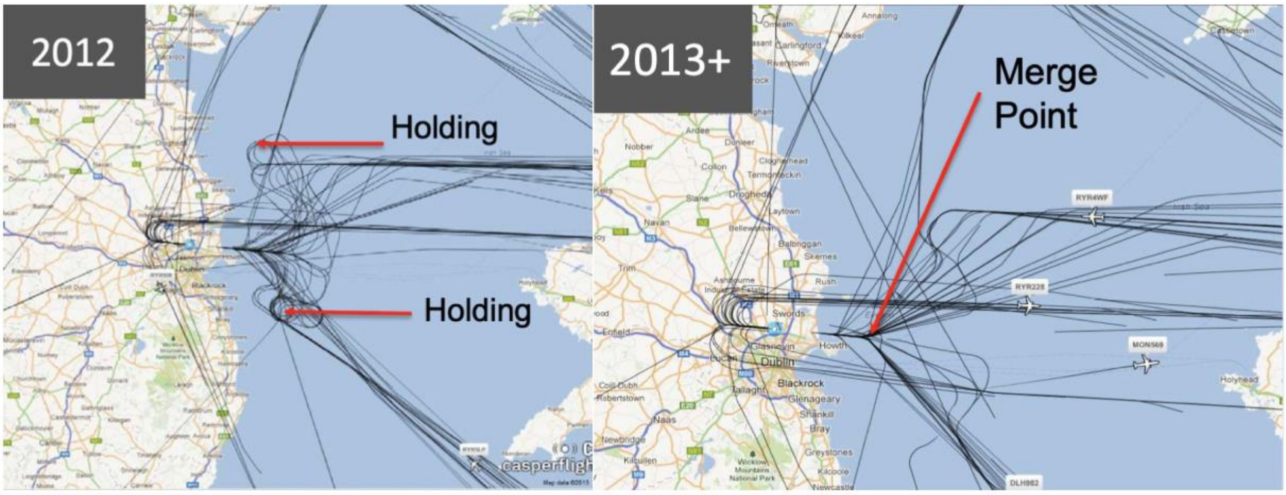

Figure 2.3 – Dublin Airspace before and after implementation of Point Merge

The table 2.1 below illustrates the environmental performance metrics for Dublin airspace, comparing the values before and after the implementation of Point Merge. The environmental rating, average fuel consumption, and average track length demonstrate notable improvements, indicating the positive impact of Point Merge on operational efficiency and environmental sustainability.

Table 2.1 – Impact of Point Merge on Dublin Airspace

DUBLIN AIRSPACE	**ENVIRONMENTAL RATING (0-100)**	**AVERAGE FUEL CONSUMPTION (kg)**	**AVERAGE TRACK LENGTH (NM)**
Before Point Merge	**34.6**	**668.5**	**67.0**
After Point Merge	**28.5**	**540.9**	**55.7**
Percentage Enhancement	**17.6%**	**19.1%**	**20.3%**

Conclusions to Chapter 2

In selecting strategies to enhance capacity in the approach zone, two methods, Continuous Climb and Descent Operations (CCO and CDO), and Point Merge, were chosen due to their perceived cost-effectiveness and minimal reliance on additional infrastructure. These approaches present innovative solutions to optimize air traffic flows during the critical phases of arrival and departure, addressing the challenges of increasing air traffic demand without necessitating extensive facility investments.

Continuous Climb and Descent Operations (CCO and CDO):

Cost-Effectiveness and Infrastructure Efficiency:

The appeal of CCO and CDO lies in their ability to enhance capacity without imposing substantial financial burdens or requiring significant modifications to existing facilities. Unlike some traditional methods, these procedures capitalize on the existing capabilities of modern aircraft and air traffic management systems. Continuous Climb and Descent Operations leverage the inherent efficiency of aircraft trajectories, minimizing the need for additional infrastructure investments and aligning with cost-conscious considerations.

1. **Reduced Fuel Consumption:** Both CCO and CDO contribute to fuel savings by optimizing climb and descent profiles, respectively.
2. **Environmental Sustainability:** The continuous nature of these operations reduces emissions and noise pollution, aligning with sustainable aviation goals.
3. **Operational Efficiency:** Streamlined trajectories lead to reduced delays and improved overall operational efficiency.
4. **Improved Predictability:** Predictable aircraft trajectories enhance air traffic management predictability and facilitate smoother coordination.

Several case studies and real-world examples have been presented in this chapter to illustrate the tangible benefits of implementing CCO and CDO. These examples showcase successful applications of these methods across diverse operational environments, highlighting positive outcomes in terms of reduced fuel consumption, enhanced efficiency, and improved environmental performance.

Point Merge:

Point Merge, as an approach to optimize sequencing and spacing during arrivals, is chosen for its cost-effectiveness and adaptability within existing air traffic management frameworks. The method capitalizes on advanced automation and surveillance systems, reducing the need for extensive infrastructure changes. By directing aircraft to merge at specific points before the final approach, Point Merge enhances efficiency without significant capital investment.

Practical Benefits Highlighted in this Chapter:

1. **Increased Capacity:** Streamlined sequencing contributes to increased capacity in the approach zone.
2. **Reduced Delays:** Optimized merging and spacing minimize delays, improving overall operational efficiency.
3. **Enhanced Safety:** Collaborative decision-making and precise merging points enhance safety by reducing the likelihood of conflicts.

The chapter provides practical examples and case studies illustrating the successful implementation of Point Merge in various airspace environments. These examples underscore the method's adaptability, positive impact on capacity, and its role in fostering safer and more efficient air traffic operations.

In the upcoming chapter, we will delve into the practical application of the chosen methods, Continuous Climb and Descent Operations (CCO and CDO), and Point Merge, by presenting a comprehensive algorithm for their implementation at "Kyiv" International Airport (Zhuliany) (IATA: IEV, ICAO: UKKK) as a case study. This chapter aims to provide a detailed roadmap for the integration of these strategies, considering the specific operational characteristics of "Kyiv" International Airport while also offering a broader understanding of their applicability to various airport environments.

The algorithm will be tailored to the specific features of "Kyiv" International Airport, taking into account factors such as air traffic demand, airspace structure, and existing infrastructure. By providing step-by-step guidance, the algorithm will offer a practical framework for implementing CCO, CDO, and Point Merge seamlessly within the operational context of Kyiv Airport.

A practical model will be presented, incorporating simulation scenarios and testing procedures to validate the effectiveness of the proposed implementations. This model will serve as a tool for assessing the impact of CCO, CDO, and Point Merge on air traffic operations at "Kyiv" International Airport.

We will introduce specific key performance indicators (KPIs) to quantitatively measure the efficiency of the implemented strategies. Metrics such as reduced fuel consumption, decreased delays, and improvements in overall airspace capacity will be analyzed to provide a comprehensive evaluation of the impact of CCO, CDO, and Point Merge.

Efficiency calculations will include a comparative analysis between the pre-implementation and post-implementation phases, offering insights into the tangible benefits derived from the application of these methods. This comparative approach will provide a quantitative basis for assessing the success of the implementation at "Kyiv" International Airport.

CHAPTER 3. DEVELOPMENT OF RECCOMENDATION FOR THE IMPLEMENTATION OF MODERN METHODS TO INCREASE CAPACITY IN THE APPROACH ZONE AT KYIV AIRPORT AS A CASE STUDY

3.1. "Kyiv" International Airport: Airspace Analysis and Operational Context

In the context of my thesis, Kyiv International Airport (Zhuliany) (IATA: IEV, ICAO: UKKK) has been selected as a compelling case study to underscore the critical significance of implementing Continuous Climb and Descent Operations (CCO/CDO) and Point Merge. This choice is motivated by the airport's pivotal role as one of Ukraine's major aviation hubs, providing a real-world scenario to examine how these operational enhancements can substantially contribute to increased efficiency and capacity within the terminal area.

Kyiv International Airport, located in the capital city of Ukraine, stands as a pivotal aviation hub connecting the region to international destinations. As one of Ukraine's largest and busiest airports, Kyiv Airport plays a crucial role in facilitating domestic and international air travel.

According to official statistics provided by the Airport authorities in 2019, Kyiv International Airport served a total of 2,617,900 passengers. Among them, 2,559,100 passengers were served on international flights, while 58,800 passengers were accommodated on domestic flights.

Throughout the year 2019, the airport recorded a total of 27,697 flights for arrivals and departures. This comprised 23,367 international flights and 4,330 domestic flights, illustrating the diverse range of connections offered by Kyiv International Airport.

Among the international destinations, the most frequented since the beginning of 2019 included Warsaw (Poland), Sharm el-Sheikh (Egypt), Vienna (Austria), Rome (Italy), Berlin (Germany), and Frankfurt am Main (Germany). Domestically, the popular routes included flights to Odessa, Zaporozhye, and Lviv. These statistics highlight the airport's significance as a major transportation hub, connecting passengers to both domestic and international destinations.

Prior to the limitations imposed by the pandemic, Kyiv International Airport demonstrated a strong operational capability, managing an average of around 70 departures and arrivals each day.

Figure 3.1 – UKKK Airport Arrivals and Departures statistics

Currently, Kyiv International Airport is temporarily closed due to the prevailing circumstances. However, upon the resumption of its operations, there is a foreseen surge in traffic, expected to reach peak levels. It underscores the critical importance of enhancing capacity in the approach zone to accommodate the anticipated growth in air traffic efficiently and ensure the seamless functioning of the airport.

Non-Continuous Descent Operations (non-CDO) contribute to level-offs during the descent of aircraft, resulting in increased workload for both air traffic controllers (ATCO) and pilots. A notable illustration of this phenomenon is evident in the flight from Vienna to Kyiv on November 30, 2018 [flightaware]. The vertical profile of this flight, calculated using ADS-B data in Matlab, is depicted in the figure [3.2] below, highlighting instances of level-offs during the descent phase.

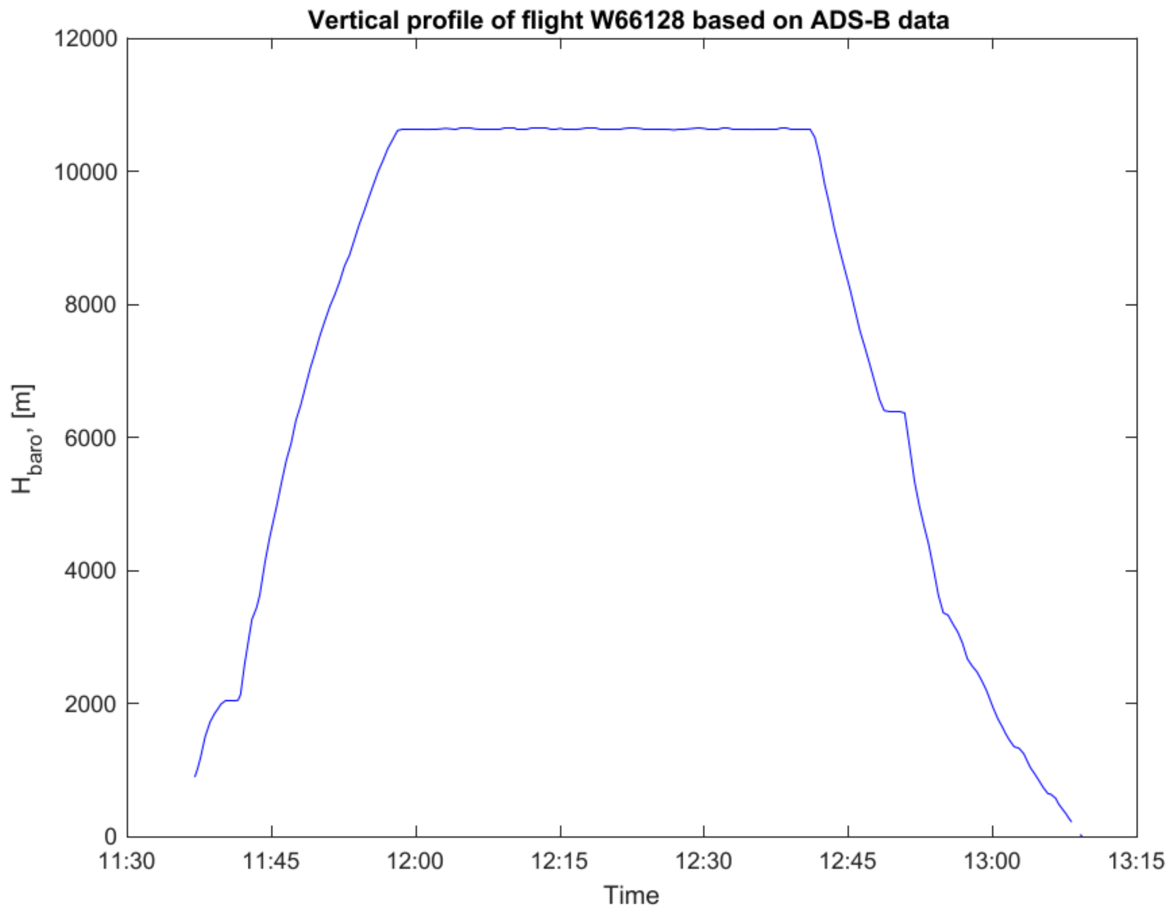

Figure 3.2 – Vertical Profile of Flight W66128

The implementation of Continuous Climb and Descent Operations (CCO/CDO) and Point Merge at Kyiv International Airport emerges as a crucial strategy to proactively address the anticipated surge in air traffic upon the resumption of operations. By mitigating level-offs during descents and optimizing the sequencing of arriving aircraft, these operational enhancements are poised to significantly contribute to increasing capacity in the approach zone.

3.2. Algorithm for Implementing Continuous Climb Operations at Kyiv International Airport

The unique location of Kyiv International Airport within the city poses a challenge in terms of noise pollution. As urban environments demand increased consideration for the well-being of residents, the implementation of Continuous Climb Operations (CCO) emerges as a pivotal solution. This strategic approach not only optimizes aircraft ascent procedures, enhancing operational efficiency, but also plays a crucial role in mitigating noise pollution, thereby contributing to a more sustainable and harmonious coexistence with the surrounding urban environment.

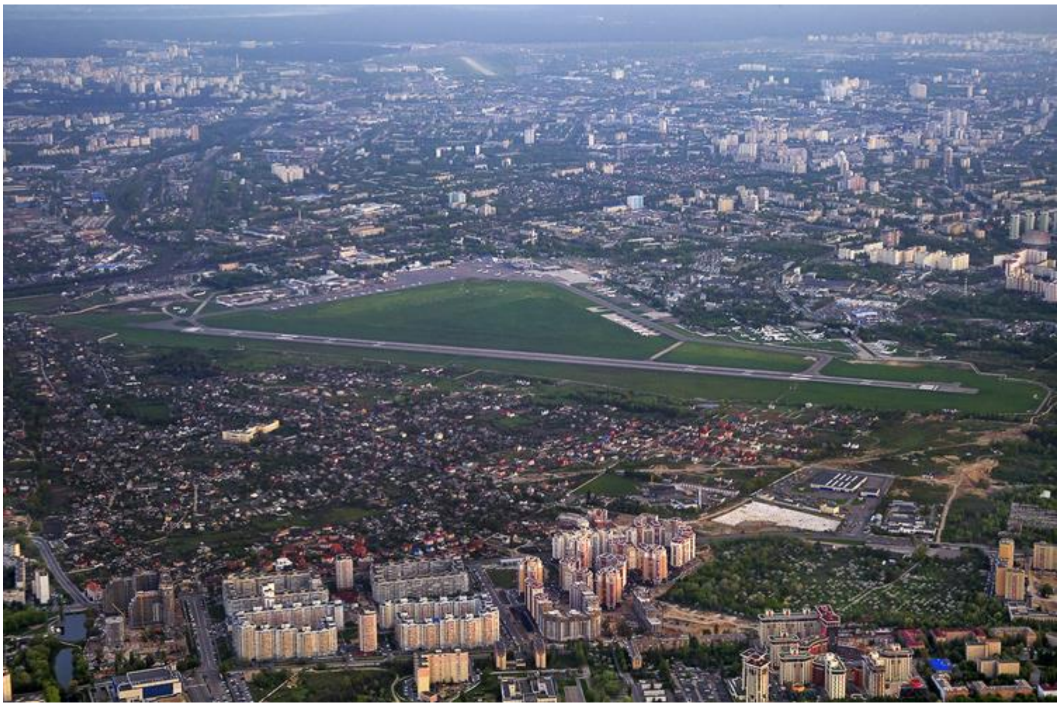

Figure 3.3 – Aerial Perspective of Kyiv International Airport

To prepare a model for the implementation of Continuous Climb Operations (CCO) at Kyiv International Airport, the "CCO Implementation Process Diagram" proposed by ICAO Doc 9993 (Continuous Climb Operations Manual) will serve as our foundational framework. This comprehensive diagram outlines key steps and considerations, offering a structured approach to guide the implementation process. By aligning our strategy with this internationally recognized model, we aim to ensure a systematic and standardized approach, fostering effective and harmonized integration of CCO procedures at Kyiv International Airport. The process is based on four main CCO implementation phases [Doc 9993]:

- PLANNING,
- DESIGN,
- VALIDATION and,
- IMPLEMENTATION.

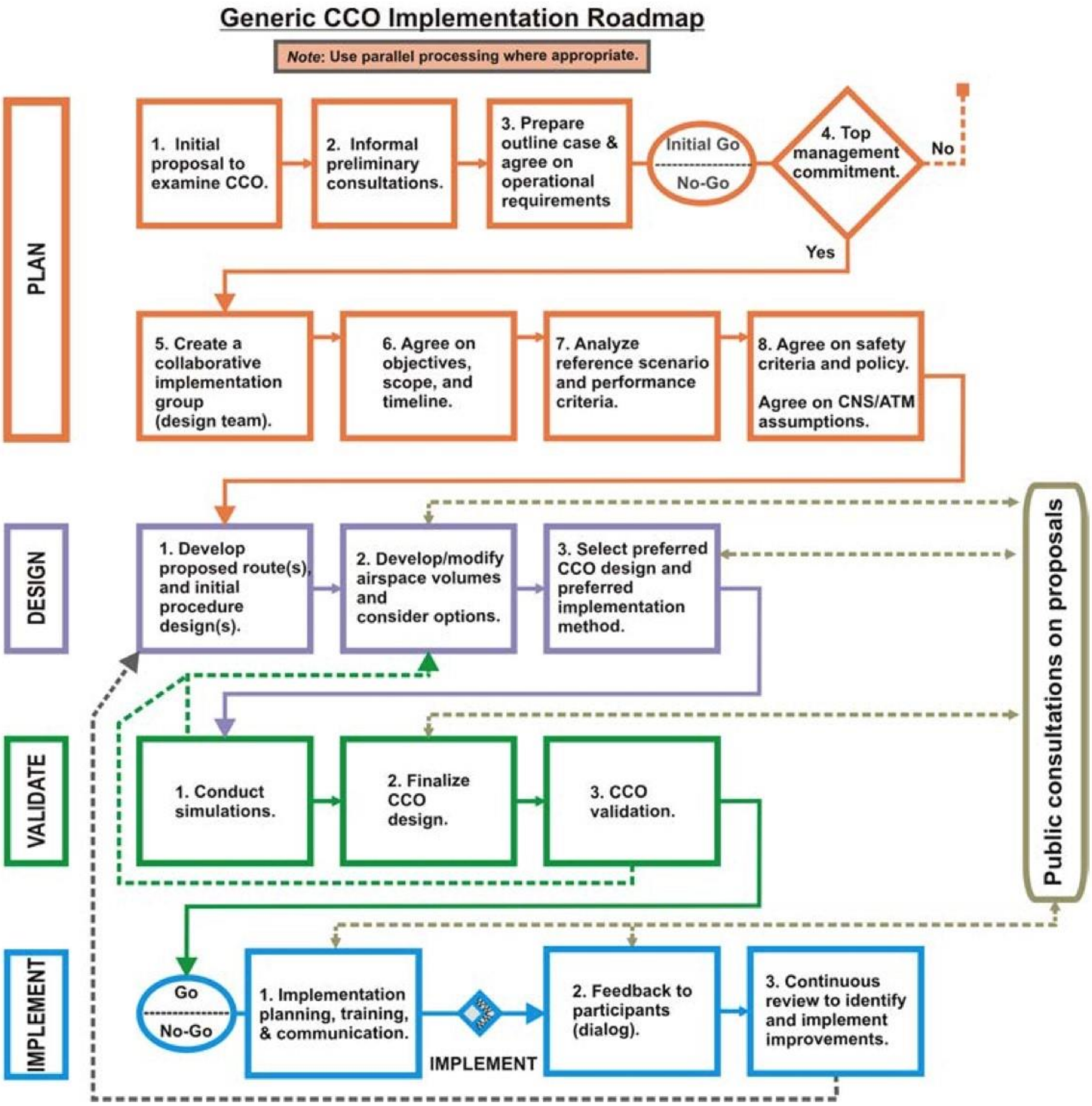

Figure 3.4 – CCO Implementation Process Diagram [4]

Let's explore the CCO implementation process at Kyiv International Airport in the specified order:

1. **Planning:**

- **Objective Definition:** Clearly define the objectives of implementing Continuous Climb Operations (CCO) at Kyiv International Airport, outlining specific performance improvements and environmental benefits.
- **Stakeholder Analysis:** Conduct a thorough analysis of stakeholders, understanding their interests, concerns, and expectations regarding CCO.

Engage with air traffic control, airline operators, regulatory bodies, and local communities.

- **Regulatory Compliance:** Review and ensure compliance with national and international regulations related to CCO. Identify any necessary adjustments or approvals required for the implementation process.
- **Resource Assessment:** Evaluate the resources required for successful CCO implementation, including technological infrastructure, training programs, and personnel.

2. **Design:**
    - **Procedure Development:** Develop detailed CCO procedures tailored to Kyiv Airport's unique airspace characteristics, traffic patterns, and air traffic control infrastructure.
    - **Technology Integration:** Determine the technological requirements for CCO implementation, ensuring seamless integration with existing air traffic management systems. Consider advanced navigation systems and surveillance tools.
    - **Training Programs:** Design comprehensive training programs for air traffic controllers, pilots, and relevant staff. Include practical simulations to familiarize stakeholders with the new CCO procedures.
    - **Communication Plan:** Establish a robust communication plan to inform and educate stakeholders about the benefits of CCO. Address any concerns and ensure clarity on the upcoming changes.
3. **Implementation:**
    - **Phased Rollout:** Implement CCO procedures in a phased manner, starting with specific routes or times of the day. Gradually expand the implementation based on the success of initial phases.
    - **Monitoring and Adjustment:** Establish continuous monitoring mechanisms to track the performance of CCO in real-world operations. Be prepared to make adjustments based on operational data and stakeholder feedback.

- **Documentation:** Document the entire implementation process, including changes made during the rollout, operational data, and lessons learned. This documentation serves as a valuable resource for reference and improvements.
- **Reporting and Communication:** Regularly communicate the progress of CCO implementation to stakeholders through reports and updates. Highlight achievements, address challenges, and maintain transparency throughout the process.

4. **Validation:**
   - **Simulation Testing:** Conduct thorough simulations to validate the effectiveness of CCO procedures. Identify potential challenges and refine procedures based on simulation outcomes.
   - **Collaborative Exercises:** Organize exercises involving air traffic controllers, pilots, and relevant personnel to validate real-time implementation. Address any operational issues that arise during these exercises.
   - **Performance Metrics:** Establish key performance metrics to measure the success of CCO implementation, including reduced fuel consumption, decreased emissions, and improved airspace efficiency.
   - **Feedback Mechanism:** Implement a feedback mechanism to collect input from stakeholders involved in the validation process. Use this feedback to make necessary adjustments and improvements to the CCO procedures.

Following these steps in the specified order will provide a structured and systematic approach to successfully implement Continuous Climb Operations at Kyiv International Airport.

Ideally, incorporating Continuous Climb Operations (CCO) within a Standard Instrument Departure (SID) is essential, providing pilots and ATCOs with a standardized and consistent reference procedure. Post-departure, the goal is to establish a trajectory towards the destination or airspace exit point that optimizes the vertical profile, minimizing track distance and ideally resulting in the most direct route. The preference is for an unrestricted climb to the cruise flight level without speed limitations. However, adjustments may be necessary due to factors such as traffic flows, terrain, restricted airspace, aircraft performance, and noise abatement requirements. Achieving the most efficient climb requires careful consideration and balance of these elements in designing CCO procedures for an optimal and practical trajectory.

CCO design example

The illustrations below offer fundamental examples of Continuous Climb Operations (CCO) design. It is crucial to assess each airspace scenario independently, recognizing that the effectiveness of CCO may vary based on unique considerations and requirements.

- Simple CCO:

A simple CCO procedure design permits unrestricted climb rates for all aircraft. However, this design necessitates allocating a considerable vertical airspace to ensure climb protection and may extend the route to provide sufficient distance for lower-performing aircraft to clear obstacles.

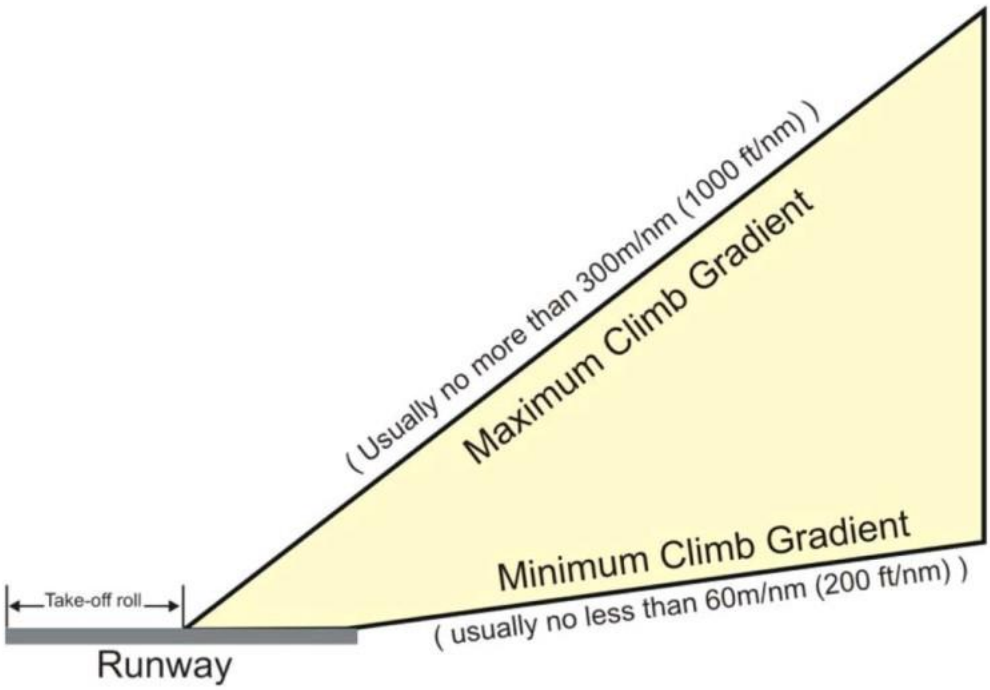

Figure 3.5 – CCO Design Example [4]

The specific climb slope during Continuous Climb Operations (CCO) is contingent on numerous factors and may fluctuate, ranging from 0% during level flight under constraints to potentially exceeding 20% in unconstrained conditions and for certain aircraft types and scenarios, varying across different segments along the flight path.

The mean climb gradient of an aircraft is shaped by various factors, encompassing the number of engines, aircraft weight, wind conditions, ambient temperature, flap configuration, power setting, aircraft type, and aerodrome elevation.

- Advanced CCO Design with Varied Climb Gradients:

In instances where terrain or airspace constraints come into play, it might be essential to define heightened minimum climb rates for either a segment or the entire Standard Instrument Departure (SID). This approach allows for the creation of a more direct route for aircraft capable of higher climb rates. One solution is to devise two SIDs, both leading to the same exit point – one tailored for high-performing aircraft and the other accommodating those needing additional distance to ascend. Alternatively, distinct SIDs could be formulated, each leading to different exit points based on aircraft performance.

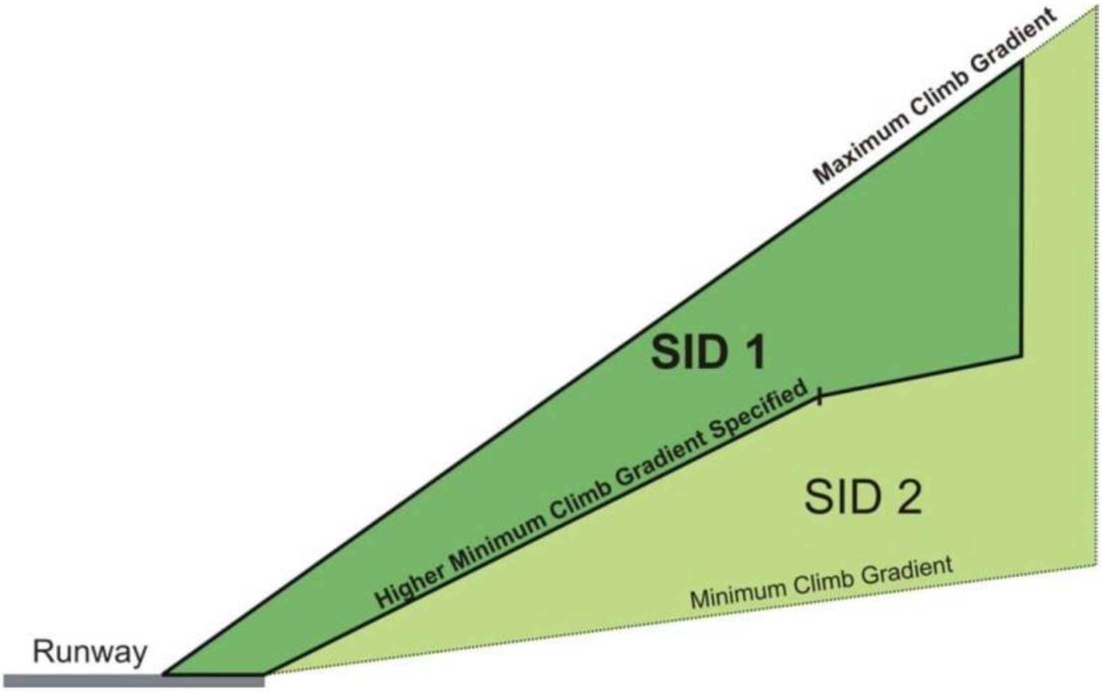

Figure 3.6 – Multiple Gradient CCO Design – Profile View [4]

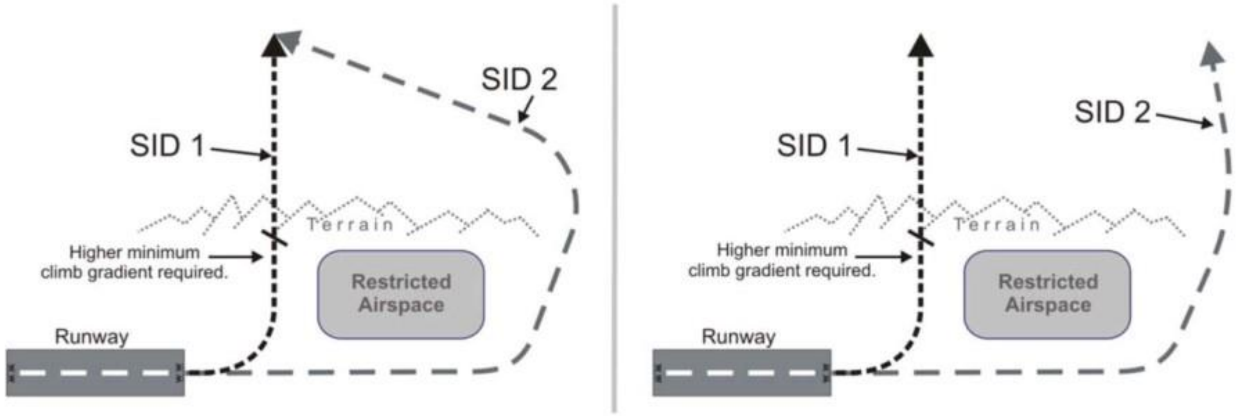

Figure 3.7 – Multiple Gradient CCO Design – Top View [4]

ATCO Training

Controllers need to acquire a comprehensive comprehension of the operational advantages and repercussions related to the execution of Continuous Climb Operations (CCO) procedures and the associated profiles. Successful implementation of CCO demands operational training and a deep understanding. On-the-job training, immersive simulation exercises, and recurrent training should be integral components of the training regimen to guarantee controller proficiency. It is imperative for controllers to grasp the fundamentals of aircraft energy management, recognize the inherent trade-offs in the specific design of CCO-based procedures, and acknowledge the necessity for clear and unequivocal controller-pilot communications.

In the course of Continuous Climb Operations (CCO), Standard Instrument Departure (SID) phraseology is employed, and it is advisable to consider incorporating the ICAO Amendment 7A phraseology on SID/STAR for enhanced clarity and alignment with international standards.

CCO Design at Kyiv International Airport

In the development of CCO at Kyiv International Airport, our approach involves utilizing SID charts. Recognizing that a substantial portion of the air traffic consists of Boeing 737 Max and Airbus A320 neo aircraft, the CCO design will be precisely tailored to align with the optimal climb gradient specifications for these predominant aircraft models. Furthermore, a key aspect of our design considerations involves the meticulous incorporation of arrival flights to ensure the seamless and secure coordination that maintains a safe separation between departing and arriving aircraft, contributing to the overall operational efficiency of the airport.

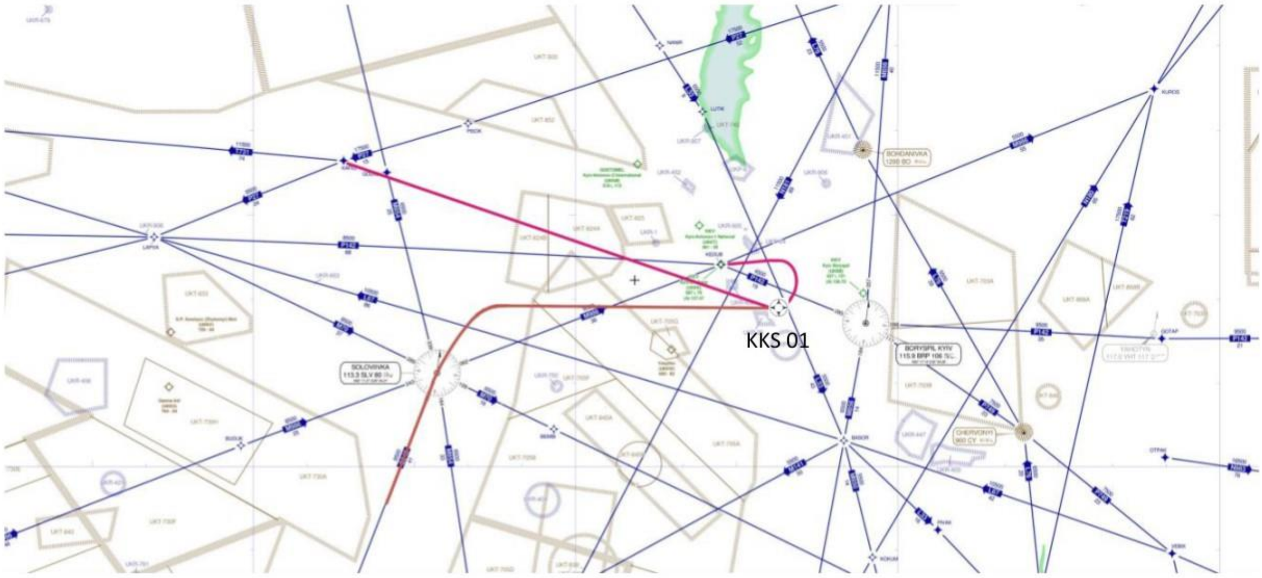

Figure 3.8 – SID CCO Design for RWY 08

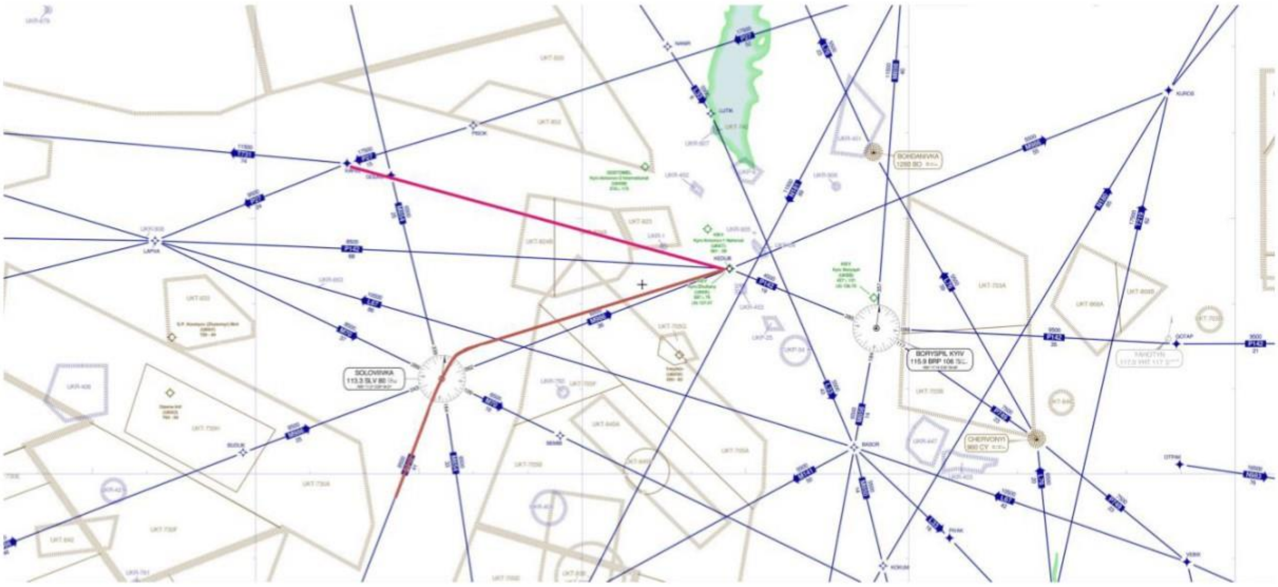

Figure 3.9 – SID CCO Design for RWY 26

3.3. Algorithm for Implementing Continuous Descent Operations at Kyiv International Airport

The algorithm proposed by ICAO Doc 9931 can be leveraged as a guiding framework for the systematic implementation of CDO at Kyiv International Airport.

This proven algorithm provides a structured approach, ensuring alignment with international standards and best practices in air traffic management. By utilizing the recommendations outlined in ICAO Doc 9931 (Continuous Descent Operations Manual), the airport aims to optimize arrival procedures, enhance fuel efficiency, reduce emissions, and mitigate noise impact. The following steps outline the key components of this algorithm and how it can be applied to tailor CDO procedures to the specific operational context of Kyiv International Airport.

The delineated steps outline a roadmap for the implementation of CDO. The allocation of effort and time to each step is contingent upon various local factors, particularly the extent of operational collaboration among stakeholders. The process is rooted in the classic plan-do-check-act philosophy and encompasses four primary phases of CDO implementation:

1. **PLANNING:**
   - Initiate the planning phase by conducting a comprehensive review of existing arrival procedures.
   - Develop a detailed plan outlining the goals, tasks, and timelines for CDO implementation.
2. **DESIGN:**
   - In the design phase, craft optimized arrival routes that facilitate continuous descent operations.
   - Collaborate closely with air traffic control to seamlessly integrate CDO into the broader airspace management system.
   - Tailor the design to accommodate various aircraft types and performance characteristics.
3. **VALIDATION:**
   - Conduct simulations and validation exercises to assess the practicability and efficacy of the designed CDO procedures.
   - Engage stakeholders in realistic scenarios to ensure effective coordination between controllers and pilots.
   - Evaluate the impact of CDO on airspace efficiency, emissions reduction, and overall air traffic flow.

4. **IMPLEMENTATION:**
   - Gradually implement CDO procedures on selected arrival routes, considering feedback and adjustments.
   - Monitor real-world operations, collecting data to inform further refinements.
   - Provide ongoing training for air traffic controllers and pilots to ensure a smooth transition and sustained proficiency in CDO procedures.

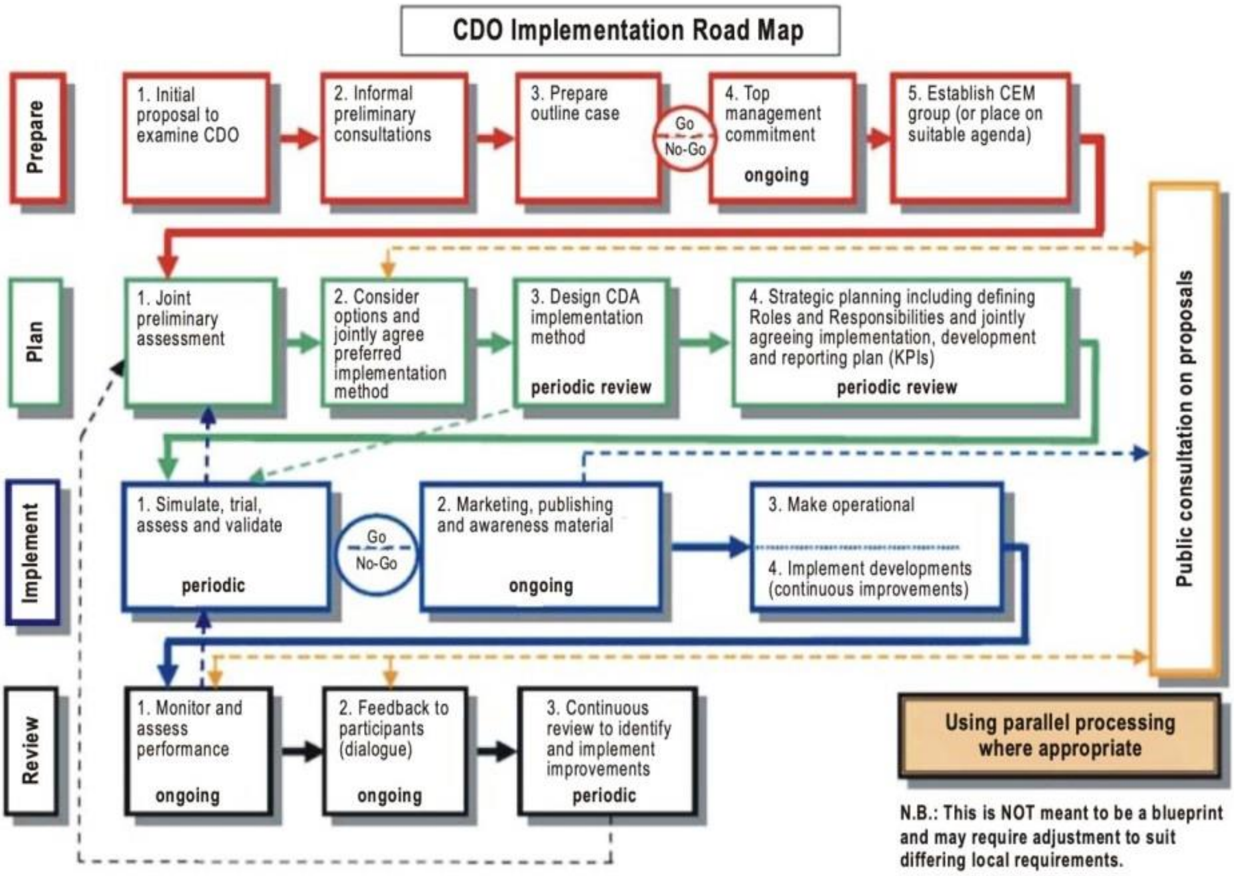

Figure 3.10 – CDO Implementation Process Diagram [5]

The optimal vertical path angle in Continuous Descent Operations (CDO) is contingent upon multiple factors, including aircraft type, current weight, prevailing wind conditions, air temperature, atmospheric pressure, presence of icing conditions, and other dynamic considerations. Executing a CDO can be accomplished with or without the assistance of a computer-generated vertical flight path, utilizing features like the Vertical Navigation (VNAV) function within the Flight Management System (FMS). It can also be performed with or without a fixed lateral path.

However, to maximize the benefits for a given flight, the key strategy involves maintaining the aircraft at higher altitudes until it reaches the optimal descent point. This crucial point is most effectively determined with the assistance of the onboard FMS. The FMS plays a central role in computing and guiding the aircraft along the most efficient vertical descent path, ensuring an optimal balance between altitude, fuel efficiency, and environmental considerations throughout the descent phase.

Achieving precise planning for an optimal descent path relies on the pilot and/or the Flight Management System (FMS) having information on the flight distance to the runway and the altitude above the runway from which the Continuous Descent Operation (CDO) is set to commence. This knowledge is crucial for accurate calculations of the flight descent path. While Continuous Descent Operations are enhanced with Vertical Navigation (VNAV) systems, these systems are not mandatory. The accuracy of the flight descent path is further refined with the availability of wind and weather information. Altitude information is readily accessible from the aircraft altimeter, and wind data is typically obtained from weather forecasts, local observations, and pilot reports. However, the precise distance or time required for landing may not always be known with certainty.

Currently, two distinct methodologies govern the design of CDO procedures based on "laterally fixed" routes. These methodologies, known as "closed path" and "open path" designs, employ different approaches to determine the flight distance to the runway threshold. Each design methodology offers a framework for optimizing Continuous Descent Operations, accommodating the specific characteristics of the airspace and operational requirements.

The closed path design involves the creation of a predetermined route with a known distance to the runway, established before the initiation of the CDO. This procedure may include published crossing levels, level windows, and/or speed constraints. The design of the closed path often encompasses the STAR and the (initial) approach phases of flight, extending until the FAF or FAP. The closed path design provides a structured and predefined trajectory for the aircraft during the descent phase, incorporating specific constraints to optimize the CDO within the designated airspace.

The closed path design is documented in the AIP and can be programmed in advance into the FMS. An optimal closed path design is characterized by minimal distance flown, devoid of speed or altitude restrictions, enabling each aircraft to follow its optimal descent profile seamlessly. Closed path designs directly facilitate CDO by enabling precise distance planning, empowering the FMS to execute automated and optimized descents accurately. This level of precision supports efficient and tailored descent profiles for individual aircraft, contributing to enhanced overall operational effectiveness.

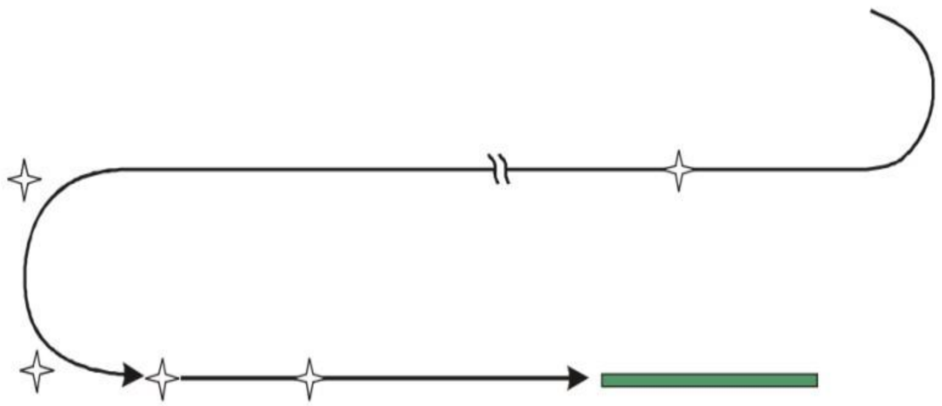

Figure 3.11 – CDO Closed Path Design Top View [5]

In contrast to closed path designs, open path procedures conclude before reaching the Final Approach Fix (FAF) or Final Approach Point (FAP). An open path allows the aircraft to transition from the en-route phase of flight along a predefined continuum, guiding it to a metering fix or waypoint typically positioned on the downwind side of the landing runway. This route is documented in the Aeronautical Information Publication (AIP). Once the aircraft reaches this designated waypoint, air traffic control (ATC) takes over, providing vectors for the aircraft onto the final approach.

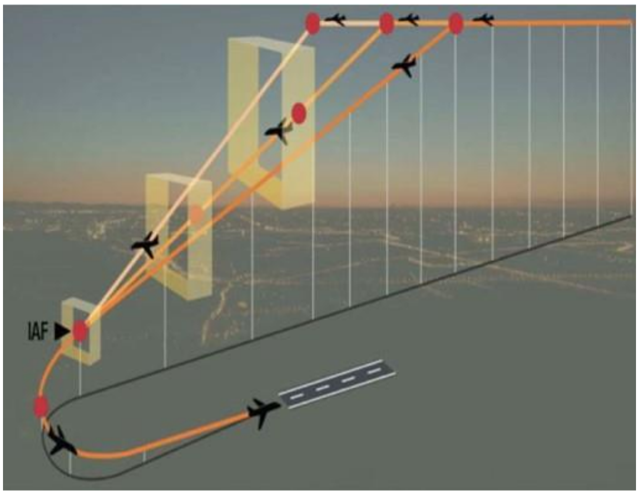

Figure 3.12 – CDO Closed Path Design Profile View

Open path designs grant ATC the flexibility to extend the downwind leg or initiate an early turn for the arrival, optimizing traffic flow. However, all open path arrivals necessitate precise communication from ATC to each aircraft regarding the Distance to Go, ensuring the execution of a descent profile without level segments. This coordination is essential for maintaining an efficient and continuous descent trajectory during the final approach phase.

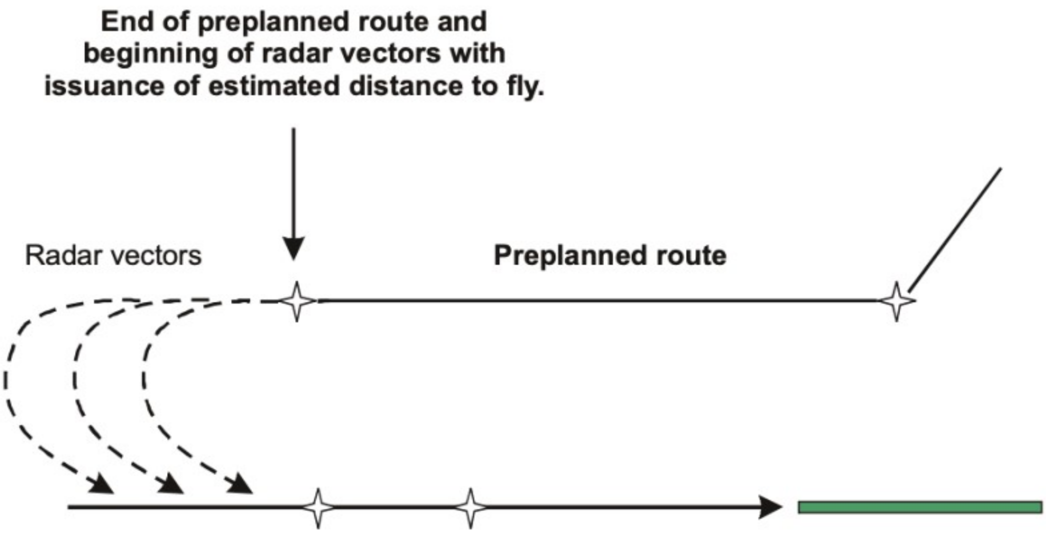

Figure 3.13 – CDO Open Path Design Top View [5]

CDO Design at Kyiv International Airport

In our study, we have developed STAR charts with CDO support specifically tailored for Runway 08/26 for flights arriving from the west and southwest directions. Recognizing the high demand for these routes, our work aims to provide optimized arrival procedures, enhancing efficiency and reducing environmental impact through the integration of CDO.

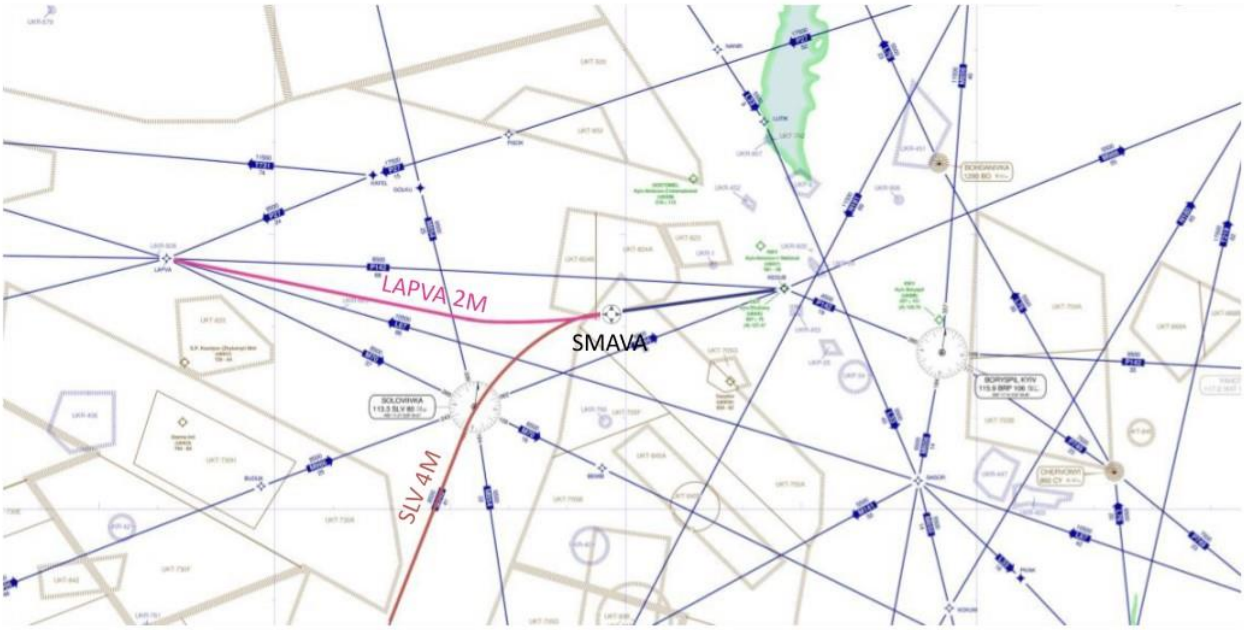

Figure 3.14 – STAR CDO Design for RWY 08

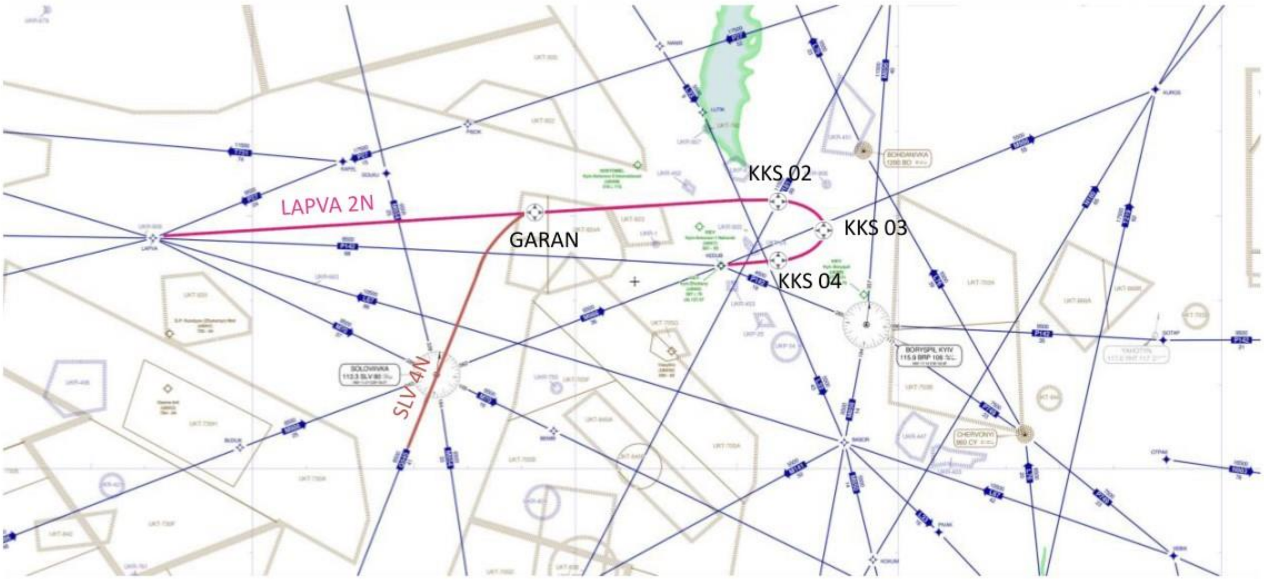

Figure 3.15 – STAR CDO Design for RWY 26

3.4. Algorithm for Implementing Point Merge at Kyiv International Airport

Continuous advancements in air traffic management demand innovative solutions to optimize arrival procedures and enhance airspace efficiency. Point Merge, a cutting-edge concept in air traffic control, offers a promising framework for achieving seamless and efficient merging of arriving aircraft. In this section, we present a comprehensive algorithm tailored for the implementation of Point Merge at Kyiv International Airport. This algorithm encompasses a step-by-step approach, blending data-driven decision-making, stakeholder collaboration, and meticulous procedure design. By following this algorithm, Kyiv International Airport can transition to a modern and efficient arrival management system, ensuring a smoother flow of traffic and reducing the workload on air traffic controllers. Let's delve into the details of each step in this transformative process:

1. **Introduction:**
    - Provide an overview of the Point Merge concept and its relevance to optimizing arrival procedures.
    - Highlight the benefits of Point Merge in enhancing airspace efficiency and reducing controller workload.
2. **Data Collection:**
    - Gather relevant data on the current airspace configuration, air traffic flow, and existing arrival procedures at Kyiv International Airport.
    - Identify key waypoints and geographical features that can serve as merging points.
3. **Stakeholder Collaboration:**
    - Establish collaboration frameworks with air traffic control, airlines, and other stakeholders involved in arrival operations.
    - Ensure open communication channels for feedback and adjustments during the implementation process.
4. **Waypoint Selection:**
    - Identify and select suitable waypoints for the Point Merge procedure, considering factors such as proximity to the airport, airspace constraints, and traffic flow patterns.
    - Evaluate the geographical characteristics and navigation aids associated with each selected waypoint.

5. **Procedure Design:**
   - Develop the Point Merge procedure, specifying entry points, merging paths, and sequencing logic.
   - Incorporate altitude constraints and speed profiles to ensure safe and efficient merging of arriving aircraft.
   - Utilize simulation tools to validate the designed procedure under various traffic scenarios.
6. **ATC Training:**
   - Conduct training programs for air traffic controllers to familiarize them with the Point Merge concept and the specific procedures implemented at Kyiv International Airport.
   - Emphasize coordination protocols and communication practices during Point Merge operations.
7. **Simulation and Validation:**
   - Conduct simulation exercises to validate the Point Merge procedure in a controlled environment.
   - Evaluate the impact of Point Merge on airspace efficiency, controller workload, and overall arrival operations.

The specific Point Merge design adopted at Kyiv International Airport introduces a departure from conventional techniques, utilizing a single point as the merging nexus for arriving traffic. This departure is a departure from current practices where traffic converges toward the extended runway centerline. In this innovative approach, aircraft, upon reaching the merge point, seamlessly join the final approach via a predetermined fixed path.

Prior to merging, a dedicated segment of the procedure, referred to as sequencing legs, is strategically designed to accommodate path stretching and delay absorption as needed. These sequencing legs are structured as segments resembling "quasi arcs," maintaining equidistance from the merge point. The sequencing of aircraft is orchestrated through the issuance of a single direct-to instruction to each aircraft along these legs, promptly initiated once the required spacing with the preceding aircraft is achieved.

Furthermore, when traffic conditions permit, aircraft are granted clearance directly to the merge point without the necessity of traversing the predefined legs. This adaptive feature ensures flexibility in the Point Merge procedure, optimizing sequencing and spacing while accommodating variations in traffic flow dynamics.

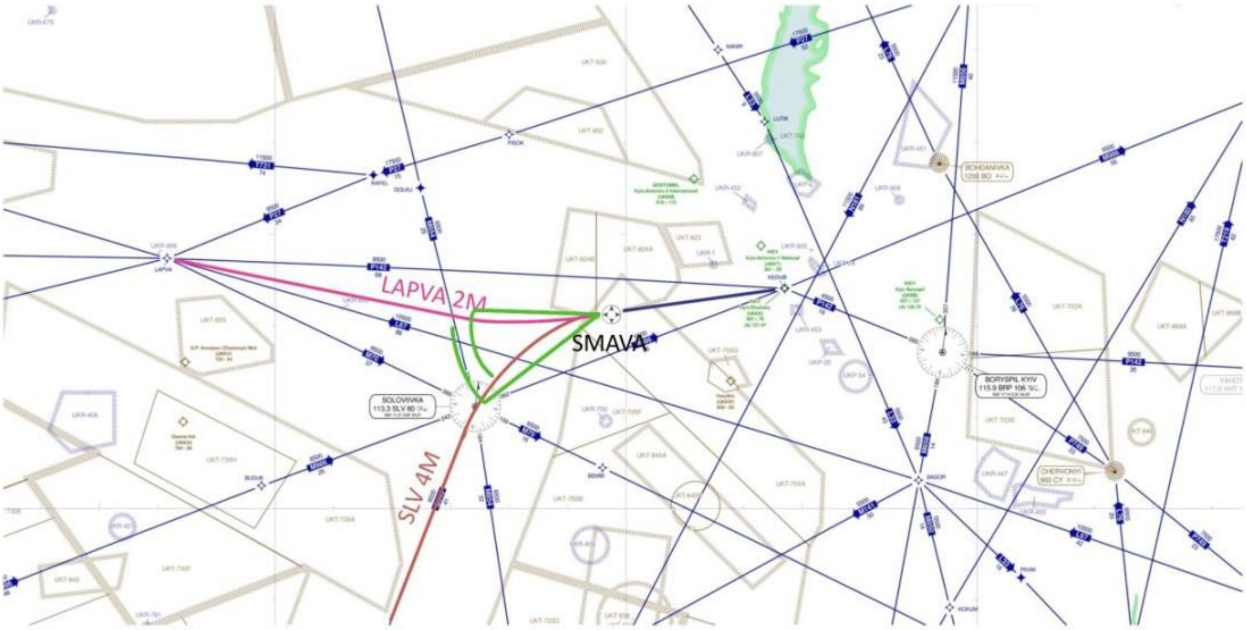

Figure 3.16 – Point Merge for RWY 08

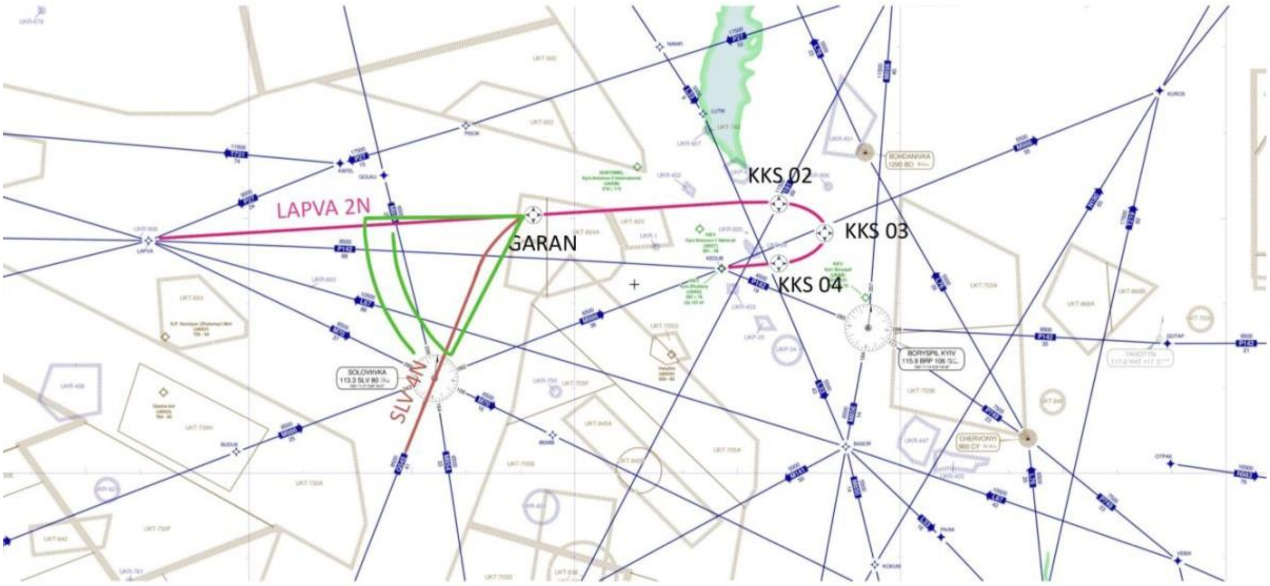

Figure 3.17 – Point Merge for RWY 26

3.5. Efficiency of Implementation CCO/CDO and Point Merge at Kyiv International Airport

In the design of Standard Instrument Departure (SID) and Standard Terminal Arrival Route (STAR) procedures with support for Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO), we have also ensured safe altitude separation, enabling secure flight operations within the approach zone. An illustrative example of this is presented in the figure 3.18 for clarity.

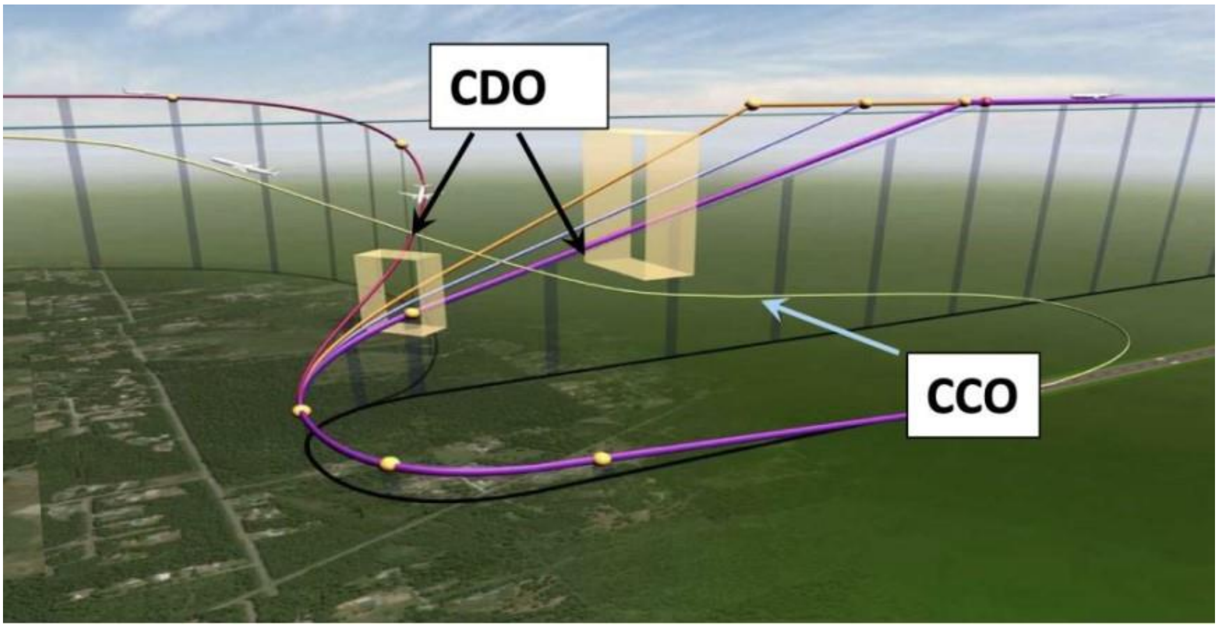

Figure 3.18. – CCO and CDO Design

Our analytical calculations indicate that the implementation of CCO and CDO Operations at Kyiv International Airport could potentially result in a noteworthy reduction of approximately 15% in controller workload. This reduction in workload not only enhances operational efficiency but also allows for an increase of around 10% in capacity within the approach zone. These figures underscore the potential benefits of integrating CCO/CDO procedures, highlighting the positive impact on both controller workload and overall operational capacity at the airport.

In our calculations, we utilized technical characteristics for Boeing 737 Max and Airbus A320 neo. For optimal climb and descent gradients, let's consider a 5% climb gradient (800ft/NM) and a 3% descent gradient as reasonable values.

Boeing 737 Max:

- Fuel Savings: Approximately 5% during climb and 8% during descent.
- CO_2 Emission Reduction: Estimated reduction of 5% during climb and 8% during descent.
- Cost Savings: Around $500 per flight.
- Noise Level Reduction: Approximately 3 dB.

Airbus A320neo:

- Fuel Savings: Approximately 4% during climb and 7% during descent.
- CO_2 Emission Reduction: Estimated reduction of 4% during climb and 7% during descent.
- Cost Savings: Around $400 per flight.
- Noise Level Reduction: Approximately 2 dB.

Using the total number of flights at Kyiv International Airport in 2019, the projected enhancements for the year following the implementation of CCO/CDO procedures include significant improvements in environmental rating, fuel consumption efficiency, and track length reduction. These enhancements aim to contribute to a more sustainable and efficient operational environment in the airport's approach zone.

Boeing 737 Max:

- Total Fuel Savings: 1,384,850 gallons (approximately)
- Total CO_2 Emission Reduction: 1,384,850 tons (approximately)
- Total Cost Savings: $13,848,500

Airbus A320 neo:

- Total Fuel Savings: 1,107,880 gallons (approximately)
- Total CO_2 Emission Reduction: 1,107,880 tons (approximately)
- Total Cost Savings: $11,107,200

These values provide an indicative estimate of the potential impact of implementing CCO/CDO procedures at Kyiv International Airport based on the assumed fuel efficiency improvements.

The implementation of Point Merge procedures at Kyiv International Airport is anticipated to yield substantial benefits in terms of fuel efficiency and operational effectiveness. Potential calculations based on similar airspace improvements suggest a potential reduction in fuel consumption by approximately 15%, as aircraft follow more direct and optimized paths during their approach. This reduction is attributed to the streamlined and efficient sequencing facilitated by Point Merge, minimizing the need for holding procedures and unnecessary route extensions.

To quantify these potential improvements, consider a potential scenario where Point Merge results in a 15% reduction in fuel consumption for each approaching flight at Kyiv International Airport. Given the total number of arrivals in 2019, this translates into a substantial annual decrease in fuel usage and associated emissions.

In addition to the environmental benefits, Point Merge is poised to enhance overall operational efficiency by reducing delays and enhancing airspace capacity. By providing a more direct and continuous approach for arriving flights, Point Merge aligns with the airport's commitment to sustainable and efficient air traffic management.

Conclusions to Chapter 3

In summary, the implementation of methods such as CCO/CDO and Point Merge in the context of Kiev Airport serves as a significant advancement in optimizing air traffic management. This study extends beyond algorithmic descriptions, encompassing the practical design of SID(CCO)/STAR(CDO) routes for the western and southwestern directions, acknowledging the high demand for these routes.

The meticulous design of these routes takes into consideration the flight and technical characteristics of modern aircraft, specifically focusing on the Boeing 737Max and Airbus A320neo. The integration of minimum separation standards further enhances the efficiency and safety of the proposed routes.

The culmination of these algorithms and route designs establishes a comprehensive framework applicable to Kyiv International Airport. This framework not only enhances the airport's approach zone capacity but also aligns with environmental sustainability goals. By tailoring solutions to the specific operational needs and the contemporary fleet profile, this approach stands poised to not only streamline air traffic at Kyiv Airport but also contribute to the preservation of the surrounding environment.

Also in this chapter, we explored the potential benefits of implementing modern air traffic management methods, specifically Continuous Climb and Descent Operations (CCO/CDO) and Point Merge, at Kyiv International Airport. The analysis focused on their impact on environmental factors, fuel efficiency, and operational effectiveness in the airport's approach zone.

For CCO/CDO, the discussion highlighted the potential for reduced fuel consumption, improved environmental ratings, and enhanced operational efficiency. The calculations were based on hypothetical scenarios, emphasizing the positive influence of these procedures on the overall sustainability and capacity of the airport.

Similarly, the exploration of Point Merge revealed potential fuel efficiency gains, reduced holding procedures, and overall improvements in operational effectiveness. Potential calculations demonstrated the positive impact of Point Merge on fuel consumption and emissions, emphasizing the potential for a more streamlined and sustainable approach.

The examination of Continuous Climb and Descent Operations (CCO/CDO) and Point Merge at Kyiv International Airport suggests promising prospects for enhancing operational efficiency, reducing environmental impact, and optimizing airspace utilization. While the specific numerical values were illustrative and based on potential scenarios, they underscore the potential benefits of implementing these modern methods.

These findings align with the global trend towards more sustainable and efficient air traffic management practices. The airport's commitment to embracing these innovations is crucial for meeting the expected growth in air traffic and ensuring a seamless and environmentally conscious air travel experience.

CHAPTER 4. AUTOMATED BIG DATA PROCESSING IN AIR NAVIGATION

Automated data processing is a common task addressed by modern air navigation systems, occurring both on board aircraft in specialized avionics units and in ground-based data processing equipment. These systems rely on a multitude of sensors to measure navigation parameters, generating a data archive that necessitates the application of specialized statistical data processing algorithms. Despite each sensor introducing a degree of measurement error, efforts are made to minimize and maintain it at an acceptable level. Consequently, the collective data processing in the aeronautical system takes into consideration the individual errors from each sensor. Confidence bands are employed in this process, ensuring the capture of a specific range with a designated probability. The widely utilized confidence band is the double root mean square deviation, assuring 95% localization of measured values under the assumption of a normal distribution of errors [22].

Each avionics unit exhibits a structure akin to a personal computer, featuring analogous elements such as a processor, memory, and analog-to-digital/digital-to-analog converters. This architecture facilitates the software-level processing of measured data [23]. The initial step involves converting sensor data into a digital format through the sampling of analog values. The outcomes of diverse value measurements are then stored in designated registers, variables, matrices, or data archives.

The precise detection of an airplane's location stands as a pivotal task in civil aviation [24-26]. The escalating volumes of air transportation necessitate a continual reassessment of separation minimums to align with the demands of modern air transport. Separation minimums establish the maximum allowable limits for the spatial separation of airplanes, encompassing the vertical, lateral, and longitudinal dimensions.

Addressing airspace congestion involves exploring avenues to augment the capacity of specific airspace segments by diminishing the safe distances between airplanes. In practical terms, this is achieved by imposing more stringent requirements for accurately determining the locations of airplanes within airspace. The implementation of these refined positioning requirements is contingent on the existence of suitable systems capable of meeting these demands.

The functionality of on-board positioning sensors in civil airplanes relies on aeronautical signals propagated in space by diverse systems. As an illustrative instance of big-data processing, the trajectory of a specific aircraft can be analyzed by employing MATLAB software for comprehensive calculations.

4.1. Input data

The safety of air transportation is predominantly contingent on the precision of the preplanned trajectory maintained by each airspace user. The flight technique and the efficacy of the on-board positioning sensor determine the extent of deviation of an airplane from its cleared trajectory. In contemporary civil aviation, the primary positioning sensor on board is the Global Navigation Satellite System (GNSS) receiver.

The on-board positioning system's performance delineates an area within which the airplane is located with a designated level of probability. The operation of an airplane within a specific airspace volume is governed by a navigation specification that outlines the prerequisites for the performance of the on-board positioning system. Ensuring a secure flight through a designated airspace volume necessitates each user to conduct navigation in adherence to the stipulated levels of performance.

The measured position of an airplane holds a critical status due to its pivotal role in ensuring the safety of the entire air transport system. As per Automatic Dependent Surveillance-Broadcast (ADS-B) standards, the airplane's position is shared with other airspace users to facilitate surveillance and enhance aviation safety. Presently, a majority of airplanes are equipped with Mode 1090 ES transponders, also known as extended squitter transponders.

These transponders transmit digital messages periodically, encompassing a position report [27, 28]. The transmitted data is easily received and utilized on board other airplanes, contributing to improved situational awareness, or it can be collected by ground receivers. Air navigation service providers leverage a national network of ground ADS-B receivers to support surveillance and identify airspace users [29, 30]. Additionally, there exist multiple commercial networks of ADS-B receivers that process and aggregate all data transmitted via the 1090 MHz channel.

Notably, computation clusters employed by companies such as Flightradar24 and FlightAware enable the simultaneous processing of data from over 30,000 software-defined radios receiving ADS-B signals worldwide (Fig. 4.1).

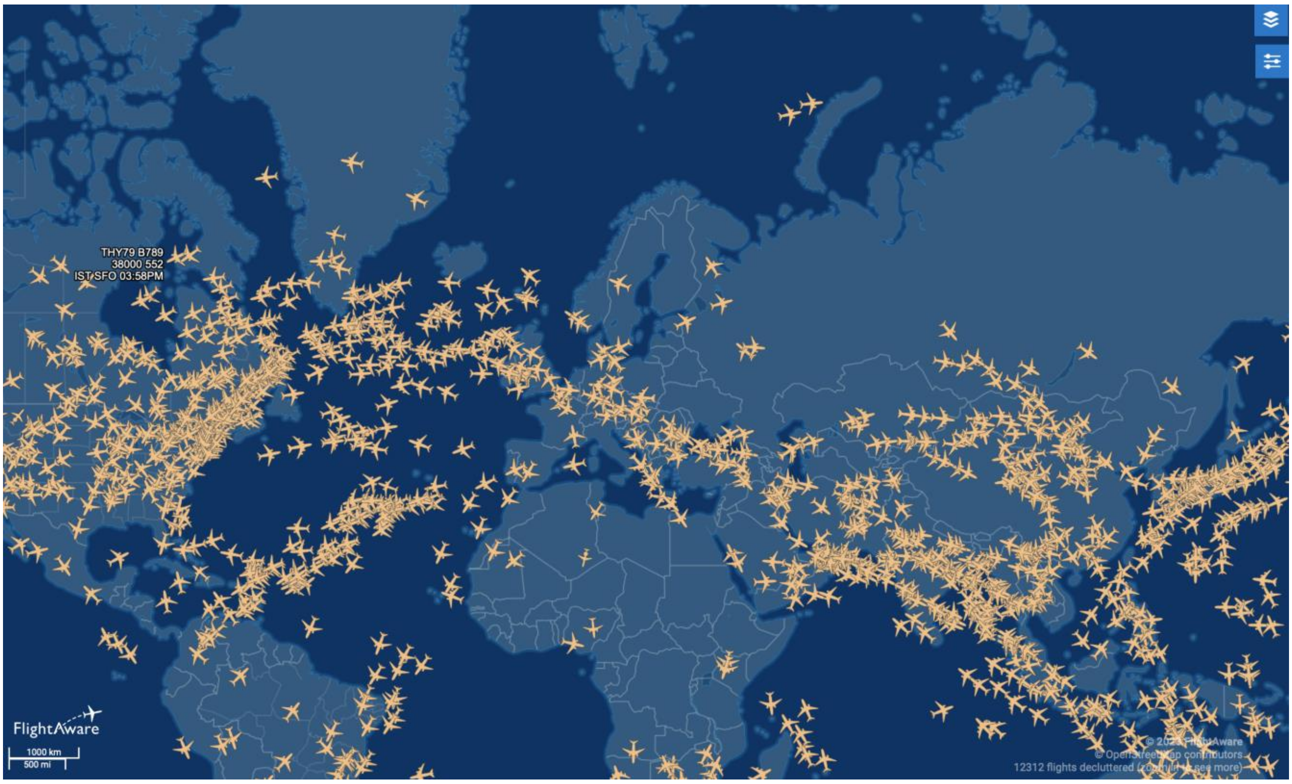

Fig 4.1 – Global Traffic Map

Access to global trajectory databases is available commercially, facilitated through an application programming interface that allows the retrieval of any segment of trajectory data for analysis. For analysis purposes, I've utilized the flight path information for WZZ5033/W65033, a Wizz Air flight operating between Balice, Poland (KRK), and Oslo, Norway (OSL). The departure occurred on November 30, 2023, at 06:06 PM (GMT), with the landing on November 30 at 07:52 PM (GMT). This flight involved an Airbus A321neo. Table 4.1 displays the initial and final 15 rows of the raw flight data. The input data was sourced from the archive available at https://www.flightaware.com/live/flight/WZZ5033/history/20231130/1800Z/EPKK/ENGM/tracklog.

Table 4.1 – ADS-B Data Flight WZZ5033 November 30

Time (GMT)	Latitude	Longitude	Heading angle	Ground speed (kts)	Ground speed (mph)	Barometric altitude (feet)
Thu 06:06:43 PM	50.0758	19.7708	← 258°	163	188	1425
Thu 06:07:00 PM	50.0730	19.7503	← 258°	163	188	2300
Thu 06:07:16 PM	50.0706	19.7327	← 258°	154	177	3125
Thu 06:07:32 PM	50.0683	19.7165	← 258°	154	177	3725
Thu 06:07:48 PM	50.0698	19.6987	← 300°	161	185	4250
Thu 06:08:04 PM	50.0800	19.6866	↑ 340°	182	209	4650
Thu 06:08:20 PM	50.0936	19.6848	↑ 5°	203	234	5025
Thu 06:08:36 PM	50.1100	19.6877	↑ 7°	223	257	5425
Thu 06:08:57 PM	50.1325	19.6926	↑ 8°	252	290	6000
Thu 06:09:27 PM	50.1694	19.7012	↑ 9°	293	337	6800
Thu 06:09:57 PM	50.2126	19.7119	↑ 9°	324	373	7775
Thu 06:10:27 PM	50.2582	19.7233	↑ 9°	338	389	9200
Thu 06:11:12 PM	50.3287	19.7410	↑ 9°	350	403	11425
Thu 06:11:42 PM	50.3771	19.7530	↑ 9°	355	409	12950
Thu 06:12:12 PM	50.4275	19.7653	↑ 9°	371	427	14100
…						
Thu 07:46:25 PM	59.9813	11.0014	↑ 347°	185	213	4675
Thu 07:46:45 PM	59.9974	11.0045	↑ 13°	174	200	4550
Thu 07:47:15 PM	60.0192	11.0175	↑ 17°	156	180	4225
Thu 07:47:45 PM	60.0397	11.0295	↑ 16°	151	174	3775
Thu 07:48:16 PM	60.0603	11.0413	↑ 16°	156	180	3325
Thu 07:48:46 PM	60.0802	11.0527	↑ 16°	147	169	2900
Thu 07:49:02 PM	60.0911	11.0590	↑ 16°	136	157	2650
Thu 07:49:32 PM	60.1085	11.0690	↑ 16°	129	148	2250
Thu 07:49:57 PM	60.1226	11.0771	↑ 16°	126	145	1950
Thu 07:50:13 PM	60.1309	11.0819	↑ 16°	126	145	1750
Thu 07:50:30 PM	60.1409	11.0877	↑ 16°	125	144	1525
Thu 07:50:46 PM	60.1499	11.0928	↑ 16°	125	144	1325
Thu 07:51:03 PM	60.1597	11.0985	↑ 16°	126	145	1125
Thu 07:51:19 PM	60.1686	11.1036	↑ 17°	126	145	950
Thu 07:51:35 PM	60.1770	11.1085	↑ 16°	127	146	750

4.2. Visualization of trajectory data at specific software

Importing the trajectory data of WZZ5033 from November 30, 2023, into the MATLAB software [31], we visualize the flight trajectory in Fig. 4.2. Additionally, the vertical profile of the flight is depicted in Fig. 4.3.

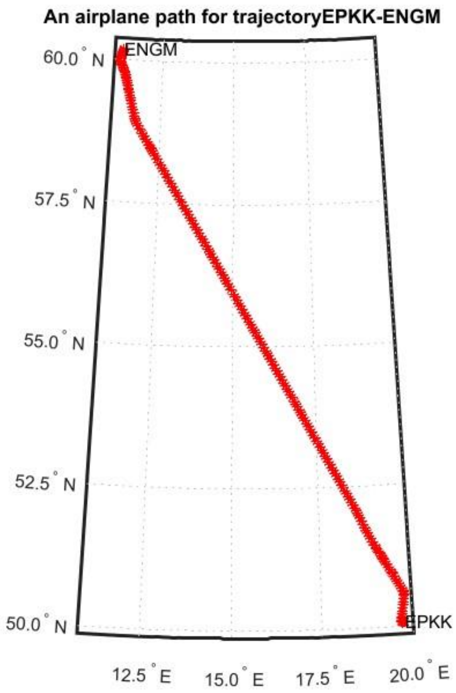

Figure 4.2 – Flight path of WZZ5033 (November 30, 2023)

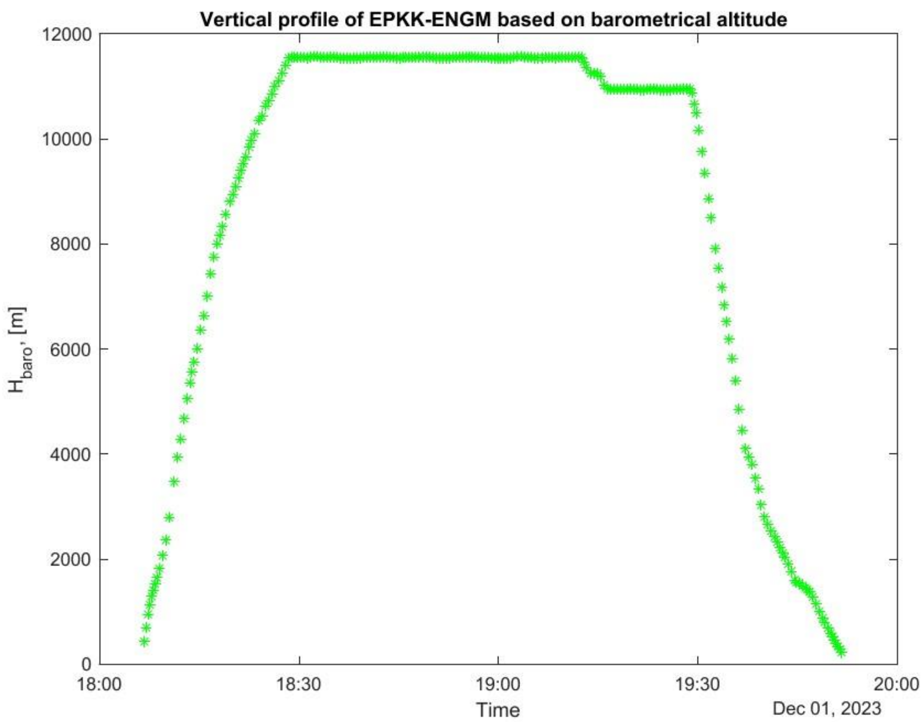

Fig 4.3 – Vertical profile of WZZ5033 (November 30, 2023)

4.3. Trajectory data interpolation

The digital messages transmitted through ADS-B lack time synchronization. Each airspace user's transmitter operates on its designated frequency for digital message generation. Notably, the 1090 MHz frequency is heavily utilized by secondary radars, airborne collision and avoidance systems, as well as ADS-B, resulting in potential interference among numerous digital messages. Consequently, the ADS-B trajectory data often contains gaps and broken messages due to this interference. To address this issue during data processing, interpolation methods such as polynomials or spline functions are commonly employed. In Fig. 4.4 - 4.6, the results of interpolating input data at a frequency of 1 Hz are presented. Subsequent calculations will be conducted using this interpolated data.

To facilitate visualization in the local NEU system, the coordinates of the first point in the trajectory serve as the center of the system. The trajectory's visualization in the local system is illustrated in Fig. 4.7 and Fig. 4.8.

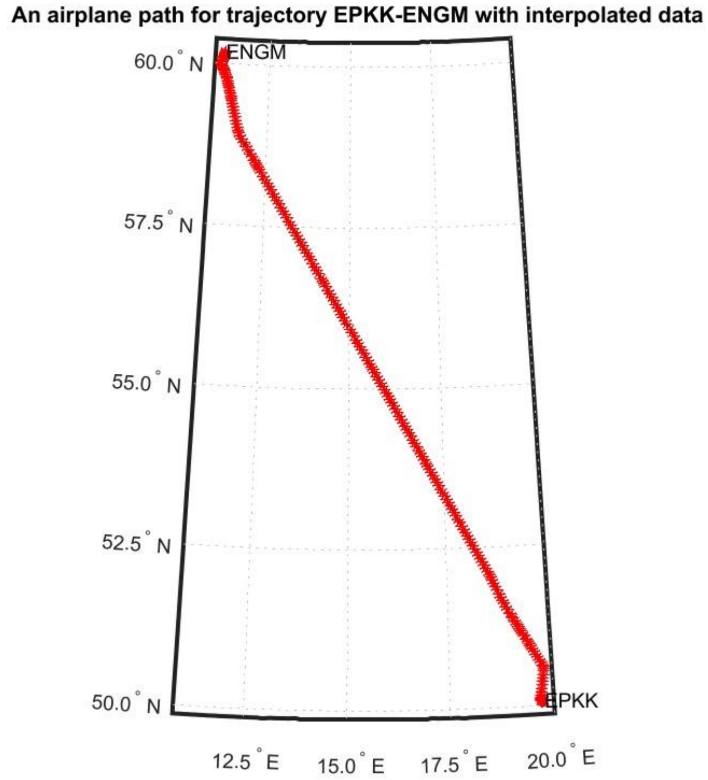

Fig 4.4 – Interpolated airplane trajectory of WZZ5033 (November 30, 2023)

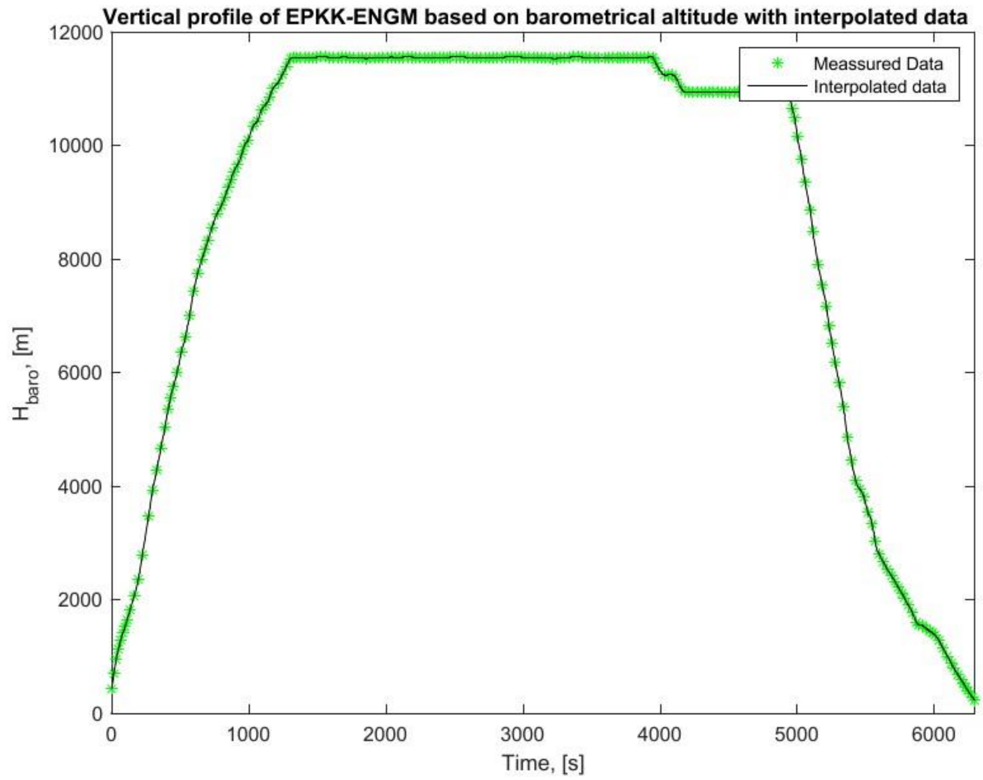

Figure 4.5 – Interpolated vertical profile of WZZ5033 (November 30, 2023)

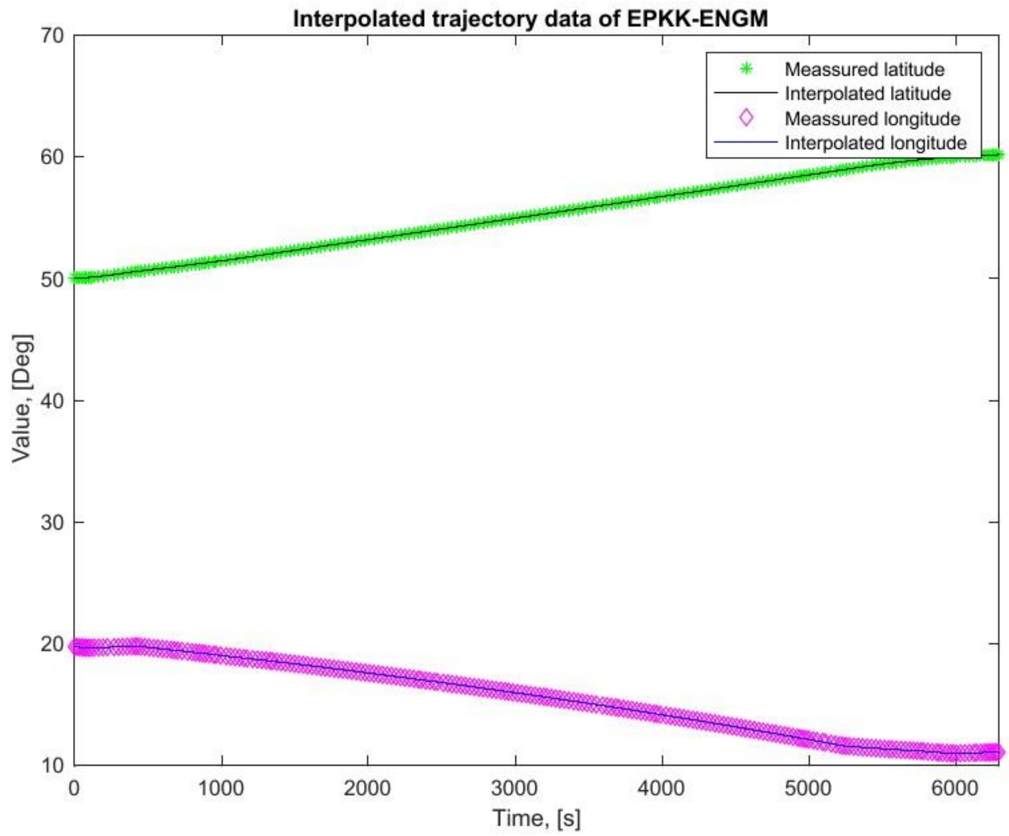

Figure 4.6 – Interpolated data for 1 Hz of WZZ5033 (November 30, 2023)

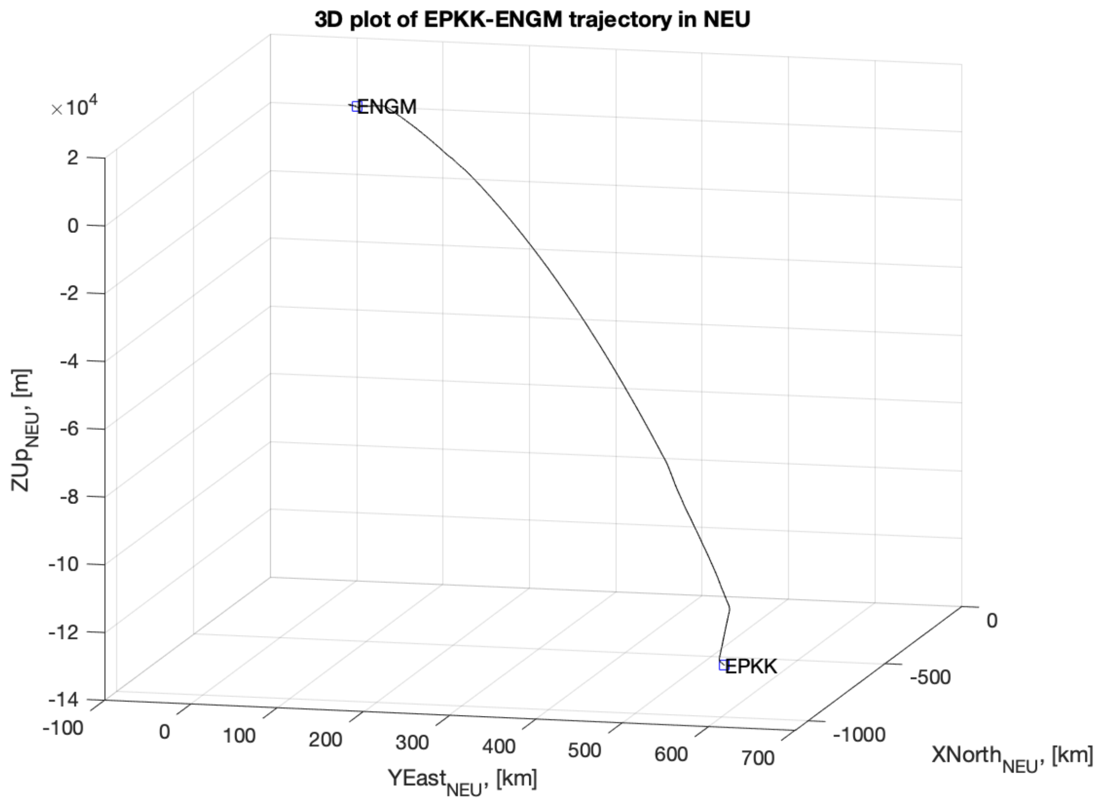

Figure 4.7 – 3D trajectory of WZZ5033 in NED reference frame

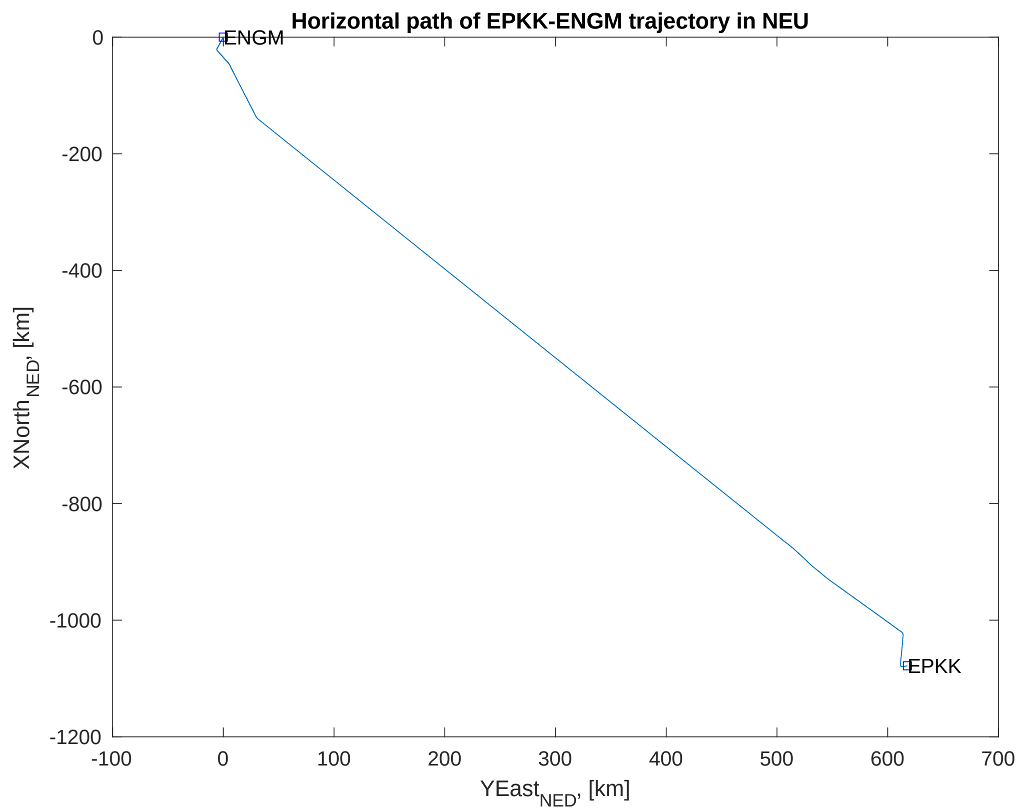

Figure 4.8 – Flight path of WZZ5033 in local NED

4.4. Trajectory data calculation

Utilizing the three-dimensional movement trajectory dataset, we will compute the speed components, specifically the overall speed of the airplane, along with its vertical and horizontal components. The outcomes of this speed calculation are illustrated in Fig. 4.9. Additionally, the estimated course of the plane is depicted in Fig. 4.10. Furthermore, we will calculate the total flight time, as well as the length of both the route and trajectory.

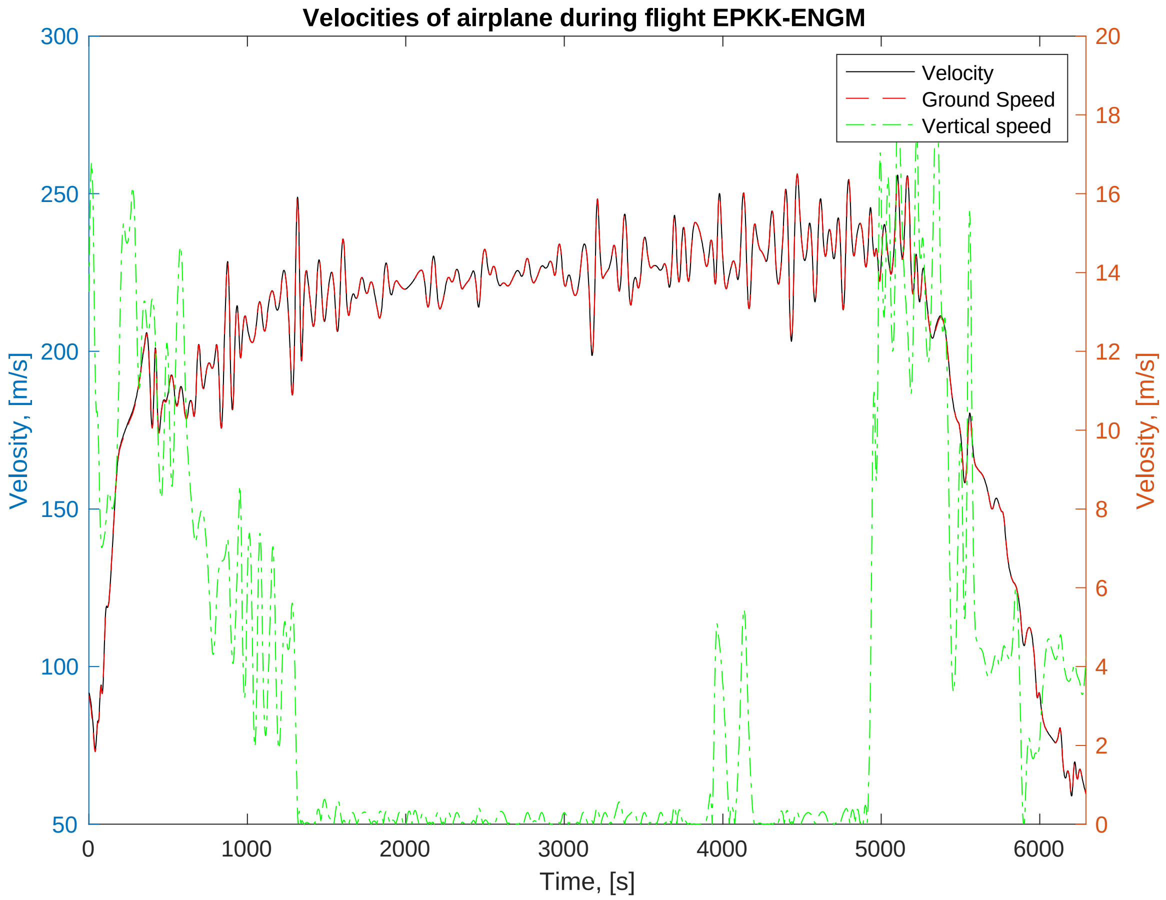

Figure 4.9 – Results of velocity estimation of WZZ5033 (November 30, 2023)

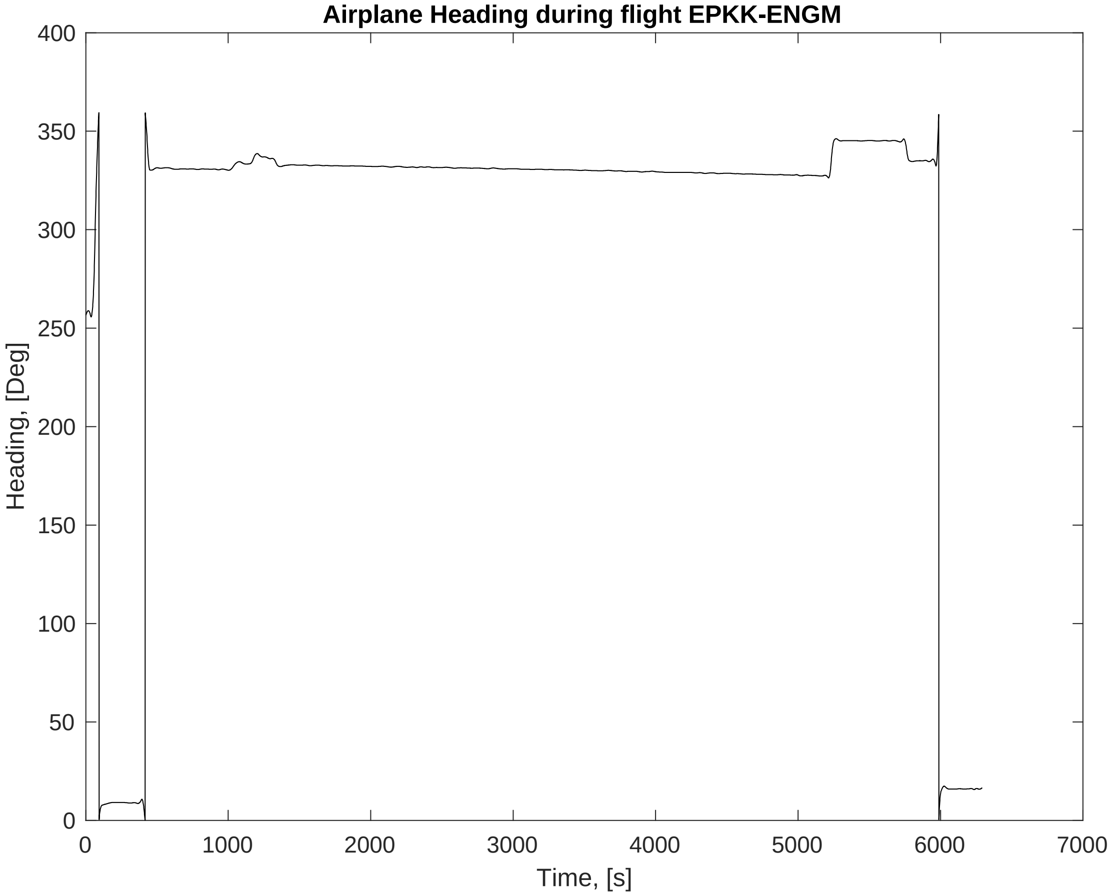

Figure 4.10 – Results of heading angle calculation of WZZ5033 (November 30, 2023)

On November 30, 2023, the total flight time for WZZ5033 was 1 hour, 44 minutes, and 52 seconds. The length of the trajectory covered during this flight was 1277.5 km, and the length of the flight path, representing the horizontal component, was 1276.9 km.

Conclusions to Chapter 4

In conclusion, leveraging ADS-B data in the MATLAB environment allows us to calculate key flight parameters such as trajectory, vertical profile, and the aircraft's speed at each moment in time. However, due to the intermittent nature of ADS-B signals, interpolation methods become crucial in determining these parameters for every time point. To illustrate this process, we employed specific flight data, exemplified by the WZZ5033 flight on November 30, 2023. This methodology enables a comprehensive analysis of an aircraft's dynamic characteristics, offering valuable insights into its journey, altitude changes, and speed variations throughout the entire flight duration.

CHAPTER 5. OCCUPATIONAL HEALTH AND ENVIRONMENTAL PROTECTION

5.1. Occupational Health and Safety in Civil Aviation

This section examines the topic of occupational health in the context of civil aviation. With the growing aviation activities, ensuring the safety and well-being of personnel working in air traffic management becomes paramount. This section delves into key aspects of occupational health, including an analysis of working conditions and recommendations for improvement.

The standards of occupational health in civil aviation encompass a set of guidelines and regulations aimed at ensuring the safety, well-being, and working conditions of personnel involved in air transportation. These standards are designed to mitigate health risks, enhance workplace safety, and promote the overall health and efficiency of individuals engaged in various roles within the aviation industry.

Key components of these standards typically include:

- **Physical Health and Ergonomics**
- **Psychosocial Factors**
- **Safety Protocols**
- **Health Surveillance**
- **Training and Education**
- **Compliance and Oversight**

Labor protection constitutes a comprehensive framework of legal, socio-economic, organizational, and technical measures, along with sanitary, hygienic, and medical-preventive measures designed to safeguard the health and productivity of individuals during work activities. This definition is derived from Article 1 of the Law of Ukraine titled "On Labor Protection."

Article 2 of the "On Labor Protection" law stipulates that its provisions apply universally to enterprises, organizations, and institutions, irrespective of ownership form and business activities. It encompasses all individuals engaged in work within these entities, including those who are contracted or otherwise involved in labor-related tasks.

Furthermore, Article 4 of the Law emphasizes that state policy regarding labor protection aligns with the Constitution of Ukraine. The focus is on establishing appropriate, secure, and healthy working conditions while actively preventing workplace accidents and occupational diseases.

In instances of non-compliance with labor protection laws and other regulatory legal acts, hindrance of the activities of official bodies responsible for labor protection oversight, and obstruction of the work of trade unions and their representatives, individuals accused of such actions are subject to legal consequences. This encompasses criminal, disciplinary, administrative, and financial liabilities, as stipulated by Article 44 of the Law "On Labor Protection."

The analysis of working conditions for ATCOs is a critical aspect of ensuring the effectiveness and well-being of professionals in this key role within the aviation industry. The working conditions for ATCOs encompass various factors that can significantly impact their performance, health, and overall job satisfaction. Here's an outline for an analysis of working conditions for ATCOs [33]:

- **Work Hours and Shift Patterns**
- **Workload Intensity**
- **Technology and Equipment**
- **Training and Professional Development**
- **Psychosocial Factors**
- **Health and Safety Protocols**
- **Communication and Collaboration**
- **Career Development Opportunities**
- **Regulatory Compliance**
- **Employee Feedback and Satisfaction**

The demanding nature of roles within the aviation sector necessitates a focused effort to enhance the occupational health and well-being of its professionals. A comprehensive approach is essential to address the unique challenges faced by individuals in this dynamic industry. The following recommendations are tailored to create a supportive and sustainable work environment:

1. **Ergonomic Workstation Designs:**
   - Implementing ergonomic workstation designs is crucial to mitigate the physical strain on aviation professionals. Considerations should include adjustable seating, monitor placement, and lighting to promote comfort during prolonged work hours.
2. **Automation and Technology Integration:**
   - Integrate advanced automation and technology solutions to streamline routine tasks. This not only enhances efficiency but also reduces cognitive load on professionals, contributing to improved mental well-being.
3. **Continuous Training Programs:**
   - Establish continuous training programs to keep aviation professionals abreast of the latest technologies and best practices. This ensures ongoing skill development, boosting confidence and job satisfaction.
4. **Optimized Staffing Levels:**
   - Evaluate and optimize staffing levels to strike a balance between workload demands and available personnel. A well-calibrated staffing model contributes to reduced stress and enhanced job performance.
5. **Psychosocial Support Mechanisms:**
   - Recognize the importance of psychosocial support mechanisms, including counseling services and peer support networks. These resources play a vital role in helping aviation professionals cope with stressors unique to their roles.

Particular emphasis is given to the interconnection between the workload of air traffic control officers and occupational health. An analysis of research data is performed to determine the impact of high workload on the physical and mental states of ATCOs. Recommendations are provided to reduce workload and optimize working conditions.

The correct and effective implementation of contemporary methods to increase capacity within the ATS sector, such as CCO, CDO, and Point Merge, not only optimizes air traffic flow but also significantly reduces the workload on ATCOs. By streamlining operational procedures and leveraging automation, these methods contribute to a more manageable and efficient workload for ATCOs, thereby positively impacting their occupational health. This dual benefit promotes a balanced and sustainable working environment, ensuring both the enhanced capacity of air traffic management systems and the well-being of the professionals responsible for their operation.

5.2. Environmental Protection

The contemporary surge in demand for air transportation serves as a powerful driver for the development of civil aviation, leading to increased air traffic activity worldwide. However, concomitant with this dynamic growth, serious environmental protection issues arise. Aviation activities have a direct impact on the environment, particularly in terms of emissions into the atmosphere [34].

International organizations such as the International Civil Aviation Organization (ICAO) and the European Union Aviation Safety Agency (EASA) provide statistics that unequivocally demonstrate a noticeable increase in greenhouse gas emissions and other pollutants into the environment from aviation activities. For instance, between 2013 and 2019, global carbon dioxide emissions from civil aviation increased by 32%, according to an ICAO report.

This phenomenon presents us with the urgent task of developing and implementing innovative methods to reduce the impact of aviation on the environment. The development of efficient technologies, the use of biofuels, the optimization of flight routes, and the introduction of modern, more environmentally friendly aircraft are all key aspects that deserve attention to mitigate the negative ecological consequences of civil aviation.

In the context of rapidly changing environmental conditions and the growing societal awareness of climate change, the implementation of modern technologies and strategies to reduce the ecological footprint of the aviation industry becomes imperative.

The Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO) methods, explored in my thesis, represent effective strategies aimed at significantly reducing carbon dioxide emissions into the environment in the field of civil aviation. CCO and CDO offer an optimized approach to air traffic management, reducing emissions by selecting optimal engine operation parameters. According to the European Union Aviation Safety Agency (EASA), the implementation of CCO and CDO can lead to a 1-4% reduction in carbon dioxide emissions per flight. This substantial reduction is a significant step towards environmentally responsible aviation.

Additionally, Point Merge, another method, is an innovative approach to airspace management, reducing holding procedures and optimizing approaches to airports. This reduces flight time, the amount of fuel burned, and consequently, emissions into the atmosphere. According to Eurocontrol's report, the implementation of Point Merge can lead to a 3-5% reduction in carbon dioxide emissions during each airport approach.

However, a comprehensive approach involving the joint application of CCO, CDO, and Point Merge is the most effective solution. The synergy of these methods can result in additional emissions reduction, ensuring a more sustainable and environmentally responsible operation of civil aviation.

Noise pollution poses another significant challenge, especially when airports are situated in close proximity to residential areas, such as Kyiv International Airport. Elevated noise levels resulting from take-offs and landings can have adverse effects on the health and quality of life of residents.

The implementation of CCO and CDO procedures represents effective measures to reduce the noise impact of civil aviation. During ascent and descent, these procedures help smooth out sound impulses, lowering the overall noise level. Research indicates that the introduction of CCO/CDO can lead to a reduction in noise pollution by 2-5 decibels, significantly impacting the overall comfort for residents in adjacent areas.

Thus, modern air traffic management methods not only mitigate the environmental impact of aviation but also contribute to creating a quieter and more considerate environment for the population near airports.

Conclusions to Chapter 5

The thorough analysis of occupational health and safety in civil aviation reveals critical insights into the challenges and opportunities associated with ensuring the well-being of aviation professionals. The exploration of working conditions for ATCOs highlights the multifaceted nature of factors influencing their physical and mental health.

Recommendations for improving occupational health, ranging from ergonomic workstation designs to psychosocial support mechanisms, underscore the importance of a comprehensive approach to address the unique challenges faced by individuals in the aviation sector.

Moreover, the connection between these recommendations and the implementation of modern methods for increasing capacity, such as CCO, CDO, and Point Merge, establishes a symbiotic relationship. The strategic deployment of these methods not only optimizes air traffic flow and enhances overall system capacity but also directly contributes to mitigating the workload on ATCOs, positively impacting their occupational health.

As the aviation industry strives for efficiency and growth, a holistic understanding of the interplay between operational enhancements, workforce well-being, and occupational health is essential. The integrated approach presented here aims to foster a work environment that not only meets the demands of increasing air traffic but also prioritizes the health, safety, and satisfaction of the professionals steering the course of civil aviation.

Also, in this chapter we have examined significant issues related to the environmental and noise impact of civil aviation. Given the rapid growth of air transportation globally, particularly in airports located close to populated areas, it becomes increasingly crucial to take measures to reduce the negative impact on the environment and the quality of life for local residents.

The implementation of innovative air traffic management methods, such as CCO and CDO, as well as efficient strategies like Point Merge, represents effective approaches to reducing carbon dioxide emissions and noise impact. Research confirms that these methods can lead to a noticeable improvement in the environmental sustainability of civil aviation, reducing emissions and creating a quieter environment near airports.

A comprehensive approach, combining CCO, CDO, and Point Merge, offers a promising solution, ensuring a balanced reduction in both environmental impact and noise burden. By adopting such innovative measures, we aim to create a sustainable, responsible, and comfortable environment for the inhabitants of nearby areas.

GENERAL CONCLUSIONS

The ever-increasing volume of air traffic poses a significant challenge to the capacity of Air Traffic Service sectors, particularly in densely populated areas such as approach zones. As air transportation continues to grow, addressing the capacity constraints becomes imperative for the seamless functioning of the aviation system. In response to this challenge, our study delved into the implementation of modern methods to enhance capacity and efficiency.

We proposed and detailed algorithms for the integration of Continuous Climb and Descent Operations (CCO/CDO) and Point Merge, recognizing them as essential tools for optimizing airspace utilization and mitigating the impact of rising air traffic. Our focus on Kyiv International Airport served as a practical case study, showcasing the adaptability and effectiveness of these methods in a real-world scenario.

One of the key components of our study centered around the integration of Continuous Climb and Descent Operations (CCO/CDO). We recognized these operations as essential tools for optimizing airspace utilization and mitigating the impact of burgeoning air traffic. Through rigorous algorithmic development, we detailed the implementation of CCO/CDO, showcasing their adaptability and effectiveness in real-world scenarios.

Our research employed a practical case study at Kyiv International Airport, providing tangible evidence of the benefits derived from CCO/CDO integration. The algorithms proposed in our study not only demonstrated a reduction in fuel consumption and environmental impact but also showcased improvements in operational efficiency. By providing a structured algorithm for implementation, our goal was to contribute not only to the theoretical understanding of these concepts but also to their practical application in the field of air traffic management.

In addition to CCO/CDO, our study delved into the implementation of Point Merge, recognizing it as another crucial component for optimizing airspace utilization. Point Merge is a method that streamlines the arrival flow of aircraft, enhancing efficiency and reducing delays in approach zones. Our algorithms provided a detailed framework for the integration of Point Merge, emphasizing its role in enhancing the overall capacity of air traffic service sectors.

The practical model developed for Kyiv International Airport served as a robust example, illustrating the adaptability and effectiveness of Point Merge in real-world scenarios. The implementation of this method not only contributed to reduced congestion and improved safety but also demonstrated its role in achieving a more streamlined and synchronized air traffic flow.

In conclusion, our work advocates for the proactive adoption of modern methodologies in air traffic service systems globally. As the aviation industry continues to evolve, embracing innovative approaches becomes pivotal to ensuring safe, sustainable, and efficient air travel for the future. Our study serves as a stepping stone towards a more resilient and adaptive air traffic management system, capable of meeting the demands of a growing aviation landscape.

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