МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
Факультет аеронавігації, електроніки та телекомунікацій
Кафедра аеронавігаційних систем

ДОПУСТИТИ ДО ЗАХИСТУ
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ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ «МАГІСТР»
за освітньо-професійною програмою
«ОБСЛУГОВУВАННЯ ПОВІТРЯНОГО РУХУ»

Тема:

ПОЛІПШЕНЕ ВИЗНАЧЕННЯ НОВИХ ОСНОВНИХ ТОЧОК FRA У ІНТЕРФЕЙСАХ УКРАЇНИ

Виконавець: Пархоменко Надія Максимівна
Керівник: Чинченко Юрій Володимирович
Керівники спеціального розділу д.т.н. проф. Шмельова Тетяна Федорівна

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Київ-2023

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра аеронавігаційних систем

Спеціальність: 272 «Авіаційний транспорт»

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ЗАТВЕРДЖУЮ

Завідувач кафедри АНС

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ЗАВДАННЯ

на виконання дипломної роботи

Пархоменко Надії Максимівни

Тема дипломної роботи: **«Поліпшене визначення нових основних точок FRA у інтерфейсах України»** "22" серпня 2023 р. № 1443/ст

Термін виконання роботи: 23.10.2023 – 31.12.2023

Вихідні дані до роботи: керівні документи Міжнародної організації цивільної авіації та національні документи у сфері організації та здійснення польотів.

Зміст пояснювальної записки: загальна ситуація з потоками повітряного руху в європейському повітряному просторі, формальні моделі для вдосконалення FRA, функціональність NEST для застосування FRA, пробне моделювання нових основних точок FRA за допомогою програмного забезпечення NEST, ефективність авіаційної системи, охорона праці та захист навколишнього середовища

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

6. Календарний план-графік

№п/п	Завдання	Термін Виконання	Відмітка про виконання
	Підготовка та написання 1 розділу Загальна ситуація з потоками повітряного руху в європейському повітряному просторі»		виконано
	Підготовка та написання 2 розділу Формальні моделі для вдосконалення FRA та функціональність NEST»		виконано
	Підготовка та написання 3 розділу Пробне моделювання нових основних точок FRA за допомогою програмного забезпечення NEST»		виконано
	Підготовка та написання 4 розділу Спеціальний розділ»		виконано
	Підготовка та написання 5 розділу Охорона праці та охорона навколишнього середовища»		виконано
	Підготовка презентації та доповіді	0 7	виконано

Консультанти з окремих розділів

Розділ	Консультант (посада, П.І.Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Ефективність авіаційної системи	д.т.н. проф. Шмельова Тетяна Федорівна	З	

8. Дата видачі завдання: «_23_ » _жовтня_ 2023 р.

Керівник дипломної роботи ____________ Чинченко Юрій Володимирович

(підпис керівника) (прізвище, ім'я, по батькові)

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РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Поліпшене визначення нових основних точок FRA у інтерфейсах України»: 98 сторінок, 48 рисунків, 4 таблиці,

Об'єкт розробки – структура повітряного простору вільних маршрутів України в межах контрольованого повітряного простору.

Предмет розробки – нові основні точки входу/виходу FRA в інтерфейсах України з сусідніми державами.

Мета роботи – розробити прикладні методики для оптимального розподілу нових основних точок вільних маршрутів у повітряному просторі України та на кордонах із суміжними державами.

Метод дослідження – аналіз документів Eurocontrol і ICAO з організації потоків повітряного простору, що є у відкритих джерелах, моделювання у програмі NEST.

Авіаперельоти стали важливою частиною сучасної мобільності в усьому світі. Оскільки обсяги авіаперевезень продовжують зростати, важливим рушієм цього розвитку є виконання заходів з використанням повітряного простору вільних маршрутів (FRA), спрямованих на покращення маршрутів польотів, зменшення використання палива, скорочення викидів озоноруйнівних речовин. Впровадження FRA відкриває потенційні можливості для безперешкодного повітряного руху, але водночас супроводжується розвитком спеціалізованих, функціональних та адміністративних труднощів.

Ця робота передбачає дослідження, аналіз та пропонування прогресивних відповідей на завдання, які зосереджені в межах FRA, що сприятиме покращенню управління повітряним рухом та послідовній координації FRA в складних місцевих умовах. Подолавши ці виклики, ми зможемо забезпечити безпечніші, продуктивніші та екологічніші повітряні перевезення в цьому критично важливому міжнародному регіоні.

FRA, EUROCONTROL, AIR FLOWS, EUROPEAN AIRSPACE STRUCTURE, ATFCM

АРКУШ ЗАУВАЖЕНЬ

MINISTRY OF EDUCATION AND SCIENCE, OF UKRAINE

Faculty of Air navigation, Electronics and Telecommunication

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__________V.Yu. Larin

“__”_____________2023

MASTER’S DEGREE THESIS

Theme:

“ADVANCED NEW FREE ROUTE AIRSPACE RELEVANT POINTS ASSIGNMENT IN UKRAINE'S INTERFACES”

Parkhomenko N.M.

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y Supervisors of special chapter Shmelova T.F.

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NATIONAL AVIATION UNIVERSITY

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Air Navigation Systems Department

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APPROVED BY

Head of the Department

____________ V.Y. Larin

“__”___________________2023

Graduate Student’s Degree Thesis Assignment

“Aviation transport” **Nadiia Parkhomenko**

navigation, Electronics and Telecommunication

1. *The Project topic:* “Advanced Free Route Airspace Relevant Points Assignment in Ukraine's Interfaces” approved by the Rector’s order of 23.10.2023 № 1443/ст.

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3. *Initial data to the project:* the regulatory documents of the International Civil Aviation Organisation and national documents in the field of flight operations.

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6. Calendar timetable

№	Completion stages of Degree Project	Stage completion dates	Remarks
1	Preparation of chapter 1: “General Situation with Air Traffic Flows in European Airspace”		completed
2	Preparation of chapter 2: “Formal Models of Free Route Airspace Improvement And The Eurocontrol Network Strategic Tool functionality”	1 2	completed
3	Preparation of chapter 3: “Trial Simulations of New Free Route Airspace Relevant Points using NEST software”		completed
4	Preparation of chapter 4: “Special chapter”		completed
5	Preparation of chapter 5: “Labor precaution and environment safety”		completed
6	Preparation of report and graphic materials		completed

7. Consultants from separate departments chapters

Efficiency of the aviation system	D. Sc., prof. Tetyana Shmelova	3	

8. Assignment accepted for completion “23” October 2023

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u Assignment accepted for completion ____________________ Parkhomenko N.M.

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Explanatory note to the master's thesis, “Advanced New Free Route Airspace Relevant Points Assignment in Ukraine's Interfaces”: 98 pages, 48 figures, 4 tables, 20 references.

Object – structure of Free Route Airspace of Ukraine within controlled airspace.

Development subject – new relevant points for entry/exit FRA in interfaces of Ukraine with adjacent states.

Purpose of the work – to develop applied techniques for optimal new Free Route Airspace relevant points assignment in interfaces with adjacent states.

– analysis of Eurocontrol and ICAO documents on the organisation of airspace flows available in open sources, modelling in NEST software.

NOTES

CONTENT

LIST OF ABBREVIATIONS

ACC - Area Control Centre

ATC - Air Traffic Control

ATM - Air Traffic Management

ATS - Air Traffic Services

CDM - Collaborative Decision Making

CTR - Control Zone

CTZ - Control Zone

CTA - Control Area

EUROCONTROL – The European Organization for the Safety of Air Navigation

FIR - Flight Information Region

FRA - Free Route Airspace

FUA - Flexible Use of Airspace

ICAO - International Civil Aviation Organization

IFR - Instrument Flight Rules

NM - Network Manager

NEST - Network Strategic Tool

SES - Single European Sky

SID - Standard Instrument Departure

STAR - Standard Terminal Arrival Route

TMA - Terminal Control Area

TRA - Temporary Reserved Area

TSA - Temporary Segregated Area

UIR - Upper Flight Information Region

UTA - Upper Control Area

VFR - Visual Flight Rules

INTRODUCTION

Free Route Airspace (FRA) is a concept that allows aircraft to fly user-preferred routes between defined entry and exit points without following predefined airways. This approach provides more flexibility for flight planning and allows airlines to optimize their routes based on fuel efficiency and operational considerations.

The Free Route Airspace implementation includes such processes as Direct Routing (reducing flight distances and fuel consumption), Increased Flexibility (greater flexibility in choosing preferred routes), Regional Collaboration and Coordination (cross-border FRA application), but also encounters **multiple challenges** in the long process of implementation (for example, in Ukraine FRA is under implementation since 2016, still ongoing process with not defined date of final implementation).

The new FRA relevant points establishment is a **natural evolution process** during growth and development of any national FRA project structures (including points in FRA interfaces with adjacent states). One of issues here, with the **high topicality and priority**, is the verification (including Eurocontrol validation) of assignment of New Free Route Airspace relevant points. This process is an actual challenge in many European countries, including the Ukrainian airspace. To solve this problem, it is necessary to establish efficient interfaces with all FRA areas of adjacent states. The successful solution of abovementioned includes:

- **International Coordination**, which consists of establishing effective communication channels and agreements on FRA procedures and airspace design, which are essential to ensure seamless cross-border operations (LoA and regional meetings);
- **Harmonization of Procedures**, which covers areas of aligning air traffic management procedures and regulations across neighbouring states, that helps to create a consistent and standardized environment for airspace

users (harmonizing route planning, communication protocols and contingency procedures);

- **Common (Seamless) Airspace Design**, that is a work towards a common airspace design, which optimizes route efficiency and minimizes restrictions (coordinating the design of entry and exit points, waypoints to facilitate smooth transitions between neighbouring states).

The assignment of New Free Route Airspace relevant points covers both safety and efficiency aspects of Air Navigation Service provider activities.

The **safety aspect** means that the reasonable placement of FRA relevant points (especially intermediate points) regulates traffic flows and might help potential conflict situations solution and reduce total airspace structure complexity.

The **efficiency aspect** means that optimal placement of FRA relevant points (especially exit points) regulates transit traffic flows and might attract new airlines to use the national airspace. That will highly probably increase number of aircraft in national airspace and, accordingly, increase route charges for the Air Navigation Service provider.

The purpose of the work is to develop applied techniques for optimal new Free Route Airspace relevant points assignment in interfaces with adjacent states.

In order to achieve the purpose of the work, it is necessary to **solve the following tasks**:

1. Analyse the general principles of new Free Route Airspace relevant points assignment in interfaces with adjacent states (based on Eurocontrol manuals and applicable to the Ukrainian airspace).
2. Review the theoretical models of traffic flows distribution and their optimisation in Free Route Airspace. There is a need to select among them the relevant to the purpose of the work.
3. Develop the applied techniques for optimal new Free Route Airspace relevant points assignment in interfaces with adjacent states (using

the Eurocontrol NEST software). The full compatibility of the techniques to Ukrainian airspace conditions and limitations is required.

The solution of these tasks might result in both **theoretical and practical benefits** in Air Navigation Service Provider activities. From the practical point of view, it might help in revealing the critically weak areas (gaps on the state border), that might possibly require the additional FRA relevant points placement in the appropriate interface with the certain adjacent state. Also, it will simplify the process of traffic flows calculations, based on which (cost-efficiency wise) the selection and approval on new FRA relevant points will be performed. It will be realistic task to approximately assess the reconfiguration in transit traffic flows (increase or decrease of them) resulted from the establishment of the new FRA relevant point. The process of putting in place the new point is expected to be simple and clear, based on some standardised calculations and obligatory considering the safety standards (to achieve the target safety level of the FRA procedures).

From the **theoretical point of view**, it might help in formal approaches to assessment of the transit traffic flows and based on this information, establishing the basic principles of choosing FRA points in interfaces with adjacent states. Also, might be used in discussion with adjacent states requesting the new FRA relevant points on border from Ukraine’s party (establishment of formal validation procedure for approval or reject of such request).

CHAPTER 1. GENERAL SITUATION WITH AIR TRAFFIC FLOWS IN EUROPEAN AIRSPACE

1.1 Structure of the European airspace

The structure of European airspace is a complex and well-organized system that includes various components and organizations responsible for managing and ensuring the safe and efficient flow of air traffic across the continent.

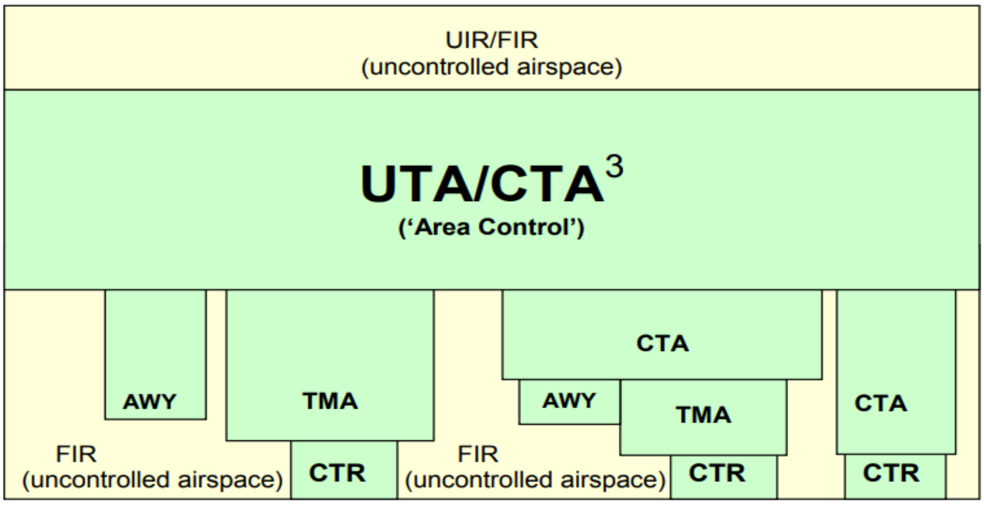
In aeronautics, airspace is part of the atmosphere controlled by a country above its territory. There are two kinds of airspace controlled and uncontrolled.

Controlled airspace.

Controlled airspace is a term that includes types of airspace classifications. Each classification has its dimensions and air traffic control (ATC) services are provided according to the requirements of each classification. [1]. The International Civil Aviation Organization (ICAO) specifies a standard airspace classification system that most countries follow, which includes Class A, B, C, D, E, F and G airspace.

In general, airspace classification is based on several factors, including the density and complexity of air traffic, availability and type of air traffic control, and a defined set of rules and procedures. Airspace classification also affects aircraft operating procedures and requirements within each class of airspace. For instance, in controlled airspace, pilots flying under IFR must have a clearance from air traffic control to enter the airspace. Additionally, different airspace classes have different minimum visibility and cloud clearance requirements.

According to the guidelines outlined in ICAO Annex 11 when deciding on which areas of airspace will receive air traffic services it is necessary to designate these areas based on the type of services offered[2]. This involves Flight Information Regions (FIRs) to provide flight information and alerting services ensuring coverage of the air route structure. Control Areas (CTAs) and Control Zones (CTRs) are also designated for airspace that requires air traffic control services, for IFR flights. These include Airways (AWYs) and Terminal Control Areas (TMAs) ensuring coverage, for the desired ATC services. Upper Flight Information Regions (UIRs) and Upper Control Areas (UTAs) are established for airspace limiting the number of FIRs or CTAs required for high altitude aircraft operations. The boundaries, both laterally and vertically of these designated airspace areas (UTA, CTA, AWY, TMA, CTR) where ATC services are provided are determined by States governing their territories.



1 – ECAC Airspace vertical organization

This refers to airspace where no governing authority carries out air traffic control functions, although it may provide advice or guidance in an advisory capacity. Uncontrolled airspace is typically used for low-altitude flights such as general aviation and private flights.

Due to the potential threats that certain airborne activities pose to GAT, and the necessity to safeguard sensitive ground areas from potential disruptions caused by overflight, ECAC states typically enforce varying levels of airspace restrictions.

Within CACD Restricted Airspace (RSAs), there are two system types: Elementary RSA (ERSA) and Composed RSAs (CRSA). These ERSA and CRSA categories are further subdivided into eight types, aligning with the classification of these airspaces as specified in the official State AIP publications. [13]:

a) Danger Area (D);

b) Restricted Area (R);

c) Prohibited Area (P);

d) Temporary Reserved Area (TRA);

e) Temporary Segregated Area (TSA);

f) Reduced Coordination Airspace (RCA);

g) Military Reserved Area (MRA);

h) Military Training Area (MTA);

i) Cross Border Area (CBA).

Flexible Use of Airspace

The concept of Flexible Use of Airspace (FUA) is rooted in the perspective that airspace should be considered a unified continuum and used adaptively on a daily basis,

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The FUA concept's actual implementation is dependent on Centralized Airspace Data Function (CADF) in the Network Manager (NM) and National or Subregional Airspace Management Cells (AMCs) for the daily distribution and enactment of flexible airspace structures. NM is in responsibility of communicating the daily distribution of areas and the availability or unavailability of ATS routes, together with any related information (such as obligatory intermediate points, limitations, etc.), which is especially pertinent in the Free Route Airspace. The tactical management, which includes activation and deactivation, tactical rerouting, and bypasses across regions, is the responsibility of ATC Units, both civil and military[19].

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The fundamental airspace structures governed by the FUA process in connection to FPL procedures are ATS routes and areas. Furthermore, the procedure suggests the

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administration of certain entities like FBZ, regions that are considered as such, and FUA/EU limitations.

FLs should be employed, specifically for the regions, to describe vertical limitations above the Transition Altitude; the identified FLs should consider the previously documented local QNH changes.

Furthermore, the organization and management of European airspace involve various entities, such as the European Union Aviation Safety Agency (EASA), E

Single European Sky (SES) is an initiative that aims to improve the performance and efficiency of air traffic management (ATM) in Europe. It was launched by the European Commission in 2004 to reduce the fragmentation of European airspace and

Some of the key objectives of SES are:

a) To increase the capacity and safety of ATM by creating a harmonized and integrated airspace that is managed at a European level rather than a national level.

b) To reduce the environmental impact of aviation by optimizing flight routes and minimizing fuel consumption and emissions.

c) To modernize ATM systems and technologies by implementing the Single European Sky ATM Research (SESAR) project, which develops innovative solutions for ATM.

d) To enhance the competitiveness and sustainability of the European aviation sector by lowering the costs of ATM services and increasing the operational flexibility of airspace users.

Another key component of the SES is the development of Free Route Airspace (FRA). FRA is implemented in different regions of Europe, with different shapes, sizes, and governance structures. The goal is to achieve free routing across European airspace by 2029, in line with the Single European Sky (SES) initiative and the SESAR project[20].

FRA offers significant benefits to both airspace users and air navigation service providers, such as:

a) Increased capacity and safety of ATM by creating a harmonized and integrated airspace that is managed at a European level rather than a national level.

b) Reduced environmental impact of aviation by optimizing flight routes and minimizing fuel consumption and emissions.

c) Lowered costs of air navigation services and increased operational flexibility of airspace users.

d) Improved traffic predictability and conflict detection tools for controllers.

Over the decade the implementation of Local Free Route Airspace (FRA) has resulted in benefits.

1.2 Factors and trends impacting on ATFCM in Europe

Flow and capacity management systems are at the foundation of the Air Traffic Flow and Capacity Management (ATCM) services performed by the Network Manager. Their aim is to provide information on actual and potential air traffic demands and capacity in European airspace, and to provide guidance to support the design, implementation, and monitoring of ATM activities.

Objectives of ATFCM:

a) Improved safety in the ATM system.

b) Advanced operational efficiency and predictability of the system.

c) Efficient capacity and demand management through data analysis and planning.

d) Decreased fuel consumption and operational expenses.

e) Elevated air travel quality and boosted economic development through cost-effective services to accommodate the anticipated rise in air traffic levels.

Air Traffic Flow and Capacity Management (ATFCM) is a component of Air Traffic Management (ATM). The Network Manager Operations Centre (NMOC) delivers ATFCM services to airspace users across the European Civil Aviation Conference (ECAC) states. The NMOC is the follow-up to the Central Flow Management Unit (CFMU). According to the International Civil Aviation Organization (ICAO), ATM is defined as [5]:

a) Airspace Management (ASM).

b) Air Traffic Flow and Capacity Management (ATFCM).

c) Air Traffic Control (ATC).

Because the airspace is a fixed area, ASM is an important activity, involving planning, sectoring, using, and managing airspace to meet user needs effectively and efficiently.

However, raised economic activity and occasional peaks in demand necessitate the protection and implementation of smoothing mechanisms for the available air traffic control capacity to prevent overloads. The goal is to optimize airspace utilization through dynamic flow management[5]. In this context, ATFCM strives to align airspace and aerodrome capacity with traffic demand. When the latest capacity opportunities are exhausted, the objective shifts to aligning demand with the maximum available capacity. This final aspect can influence flow measures, such as the allocation of individual aircraft departure times (slots), to minimize safety hazards and risks as much as possible.

The design of the ATFCM CDM process aims to facilitate discussions among affected stakeholders, including service providers and airspace users. Regular sessions are organized to address airspace, capacity/demand, and flight efficiency issues comprehensively. Through these sessions, participants can formulate plans that consider various aspects and viewpoints. The ultimate goal of the CDM activities is to reach a consensus view and solution, signifying an official commitment from each participant.

The capacity and efficiency of European airspace

The capacity and efficiency of European airspace are important aspects of ATM and ANS in Europe. They affect the safety, cost, and environmental impact of aviation in the region.

The capacity of European airspace is the maximum number of flights that can be safely and efficiently handled by the ATM system in Europe.

The efficiency of European airspace is the degree to which the ATM system optimizes the use of airspace and minimizes the delays, costs, and emissions of flights.

As demand for air services increases, capacity optimization is an ongoing challenge for air traffic management organizations and airlines as they strive to ensure air traffic safety and

Airspace has finite capacity, yet optimization is achievable based on various factors, including:

a) Design and flexibility of airspace.

b) Capacity of the ATC system.

c) Complexity and quantity of sectors.

d) Segregation of airspace.

e) Personnel availability, training, and response capability.

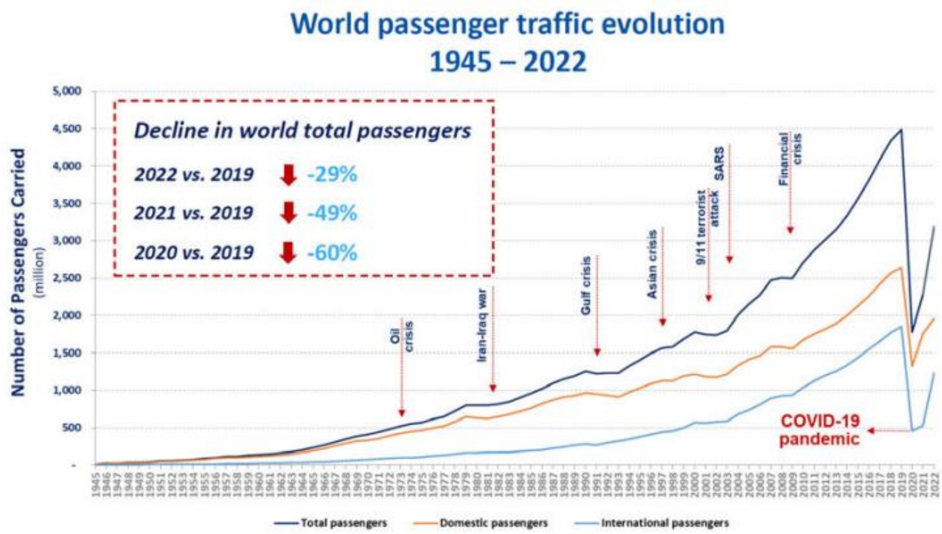
f) Existing CNS (Communication, Navigation, and Surveillance) infrastructure.

g) Level of automation.

h) Aircraft equipage and fleet composition.

The start of the COVID-19 pandemic in Europe in March 2020 led to a rapid decrease in air traffic, prompting a shift in the industry's priorities from addressing the European en-route capacity crisis to dealing with the repercussions of the global health emergency. In the subsequent two years, rising vaccination rates and the easing of COVID restrictions have contributed to a steady growth in demand.

In 2022, the International Civil Aviation Organization (ICAO) projected that global passenger levels remained 29% lower than the levels recorded in 2019. Figures 1.2 and 1.3 shows how traffic and average amount of flight changed in past years.



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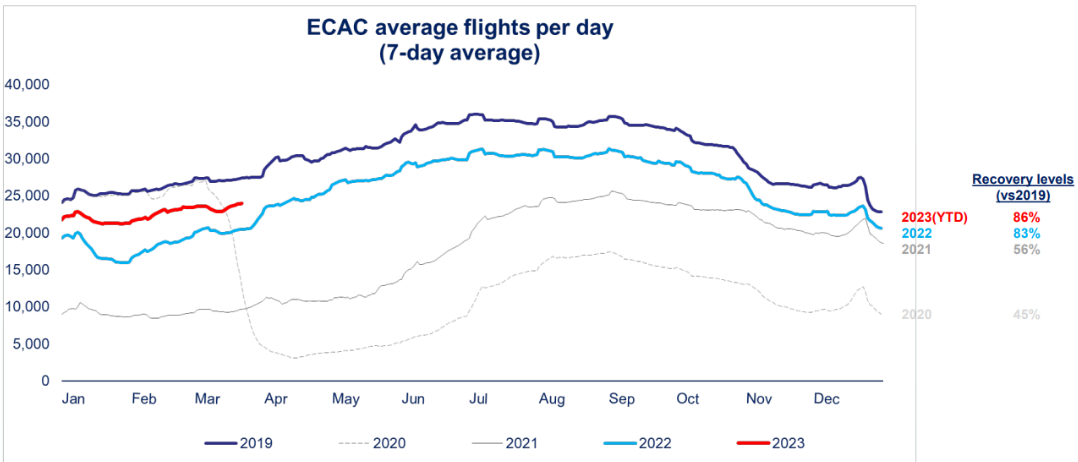

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Figure 1.3 – The daily average number of flights (ECAC)

– Evolution of global passenger traffic from 1945 to 2022 according to ICAO

An equally important aspect is Russia’s invasion of Ukraine in February 2022 and the unfolding economic and energy crisis in Europe. The closure of Ukraine's airspace for commercial flights and the imposition of airspace bans by Western nations and Russia have disrupted crucial east-west air routes connecting Europe and Asia for numerous Western airlines. Although the majority of European air traffic remains unaffected by the airspace bans, flights originating in Europe or Eastern Asia that traditionally passed through Russian airspace now face the need to reroute either to the south or north. This diversion results in increased travel time and fuel consumption, subsequently reducing both flight and fuel efficiency.

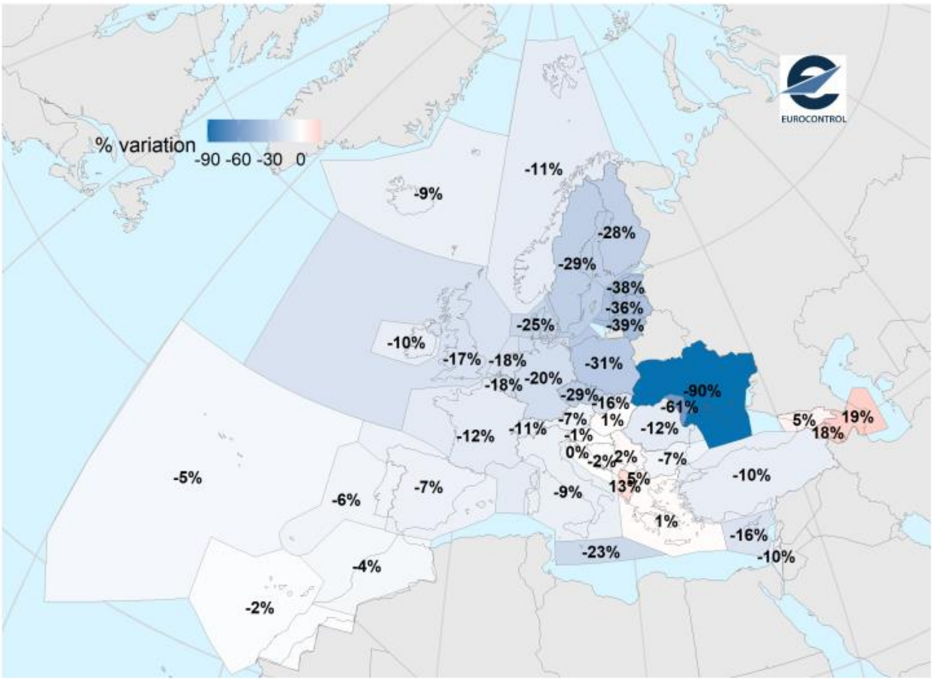

Figure 1.4 – Traffic zone (based on FIR) % total flights variation

As we can see on a graph above traffic approaching the pre-pandemic levels. But also have some disparities between different countries in Europe. Most of South-Eastern European countries exceeded 2019 levels, while Southern and North-Western Europe were 2% to 20% below 2019 levels. Northern Europe was severely impacted by major flight reductions in Ukraine (thus changing to routing through South-Eastern countries) and Ukraine (down 90% in 2022, as it was normal until Feb. 24) and Moldova.

In 2022, air traffic within the EUROCONTROL area continued its rebound from the impact of the COVID-19 pandemic, registering a 48.3% increase compared to 2021. However, it still remained 16.7% below the levels observed in 2019. When compared to the pre-pandemic year of 2019, there were 1.8 million fewer flights in 2022, with a cumulative total of 12.7 million fewer flights since the onset of the pandemic in 2020. The peak in traffic for 2022 occurred on July 8th, with 32,115 flights, representing a 12.9% decrease from the all-time peak recorded on June 28,

2019. The first half of 2022 saw traffic more than double compared to the same period in 2021, which was still impacted by COVID restrictions. Despite the recovery, the heightened traffic during the summer of 2022 posed significant challenges for various service providers, leading to unacceptable delays. During the last two quarters of 2022, traffic remained approximately 13% below the pre-pandemic levels of 2019. Growth rates at the state level exhibited considerable variation in 2022, influenced by differences in COVID recovery patterns and changes in traffic flows due to the war in Ukraine.

Europe has one of the busiest and most complex air traffic management systems in the world because of the variety of flights, ranging from short haul to intercontinental flights. Ensuring the smooth flow of air traffic while maximizing airspace utilization is an ongoing challenge that requires the cooperation of multiple stakeholders.

ATFM delay is a concept that measures the amount of time that an aircraft has to wait on the ground before taking off due to the congestion or constraints in the airspace or at the airport. It serves as a method for assessing the effectiveness and efficiency of air traffic management (ATM) systems and operations. The calculation of ATFM delay involves comparing the requested last take-off time by the aircraft operator with the take-off slot allocated by the Network Manager, which is determined based on regulations communicated by the Flow Management Position (FMP). The cause for the regulation is indicated by the FMP and can be related to an airport (airport delay) or a sector (en-route delay) location. The delay is expressed in minutes and is attributed to the most constraining ATC unit.

ATFM delay can be influenced by various factors, such as weather conditions, air traffic demand, aircraft types and size, airspace capacity, airports and runway capacity, ATC systems, regulations and airspace management, security measures, and technological advancements. ATFM delay is an important indicator for monitoring and improving the environmental impact, cost, and safety of aviation in Europe and beyond. It is part of the performance scheme regulation under the initiative of Single European Sky (SES), which aims to reform and modernize the ATM system in Europe by creating a harmonized and integrated airspace that is managed at a European level rather than a national level. The SES is required to increase the capacity and efficiency of ATM, reduce the environmental impact and costs of aviation, and enhance the competitiveness and sustainability of the European aviation sector.

As per EUROCONTROL's analysis, there was a 48.3% rise in air traffic in 2022 compared to 2021, yet it remained 16.7% below the 2019 levels. Concurrently, en-route ATFM delays experienced a notable increase, especially during the summer of 2022, accumulating to a total of 15.9 million minutes with an average en-route ATFM delay of 1.74 minutes per flight.

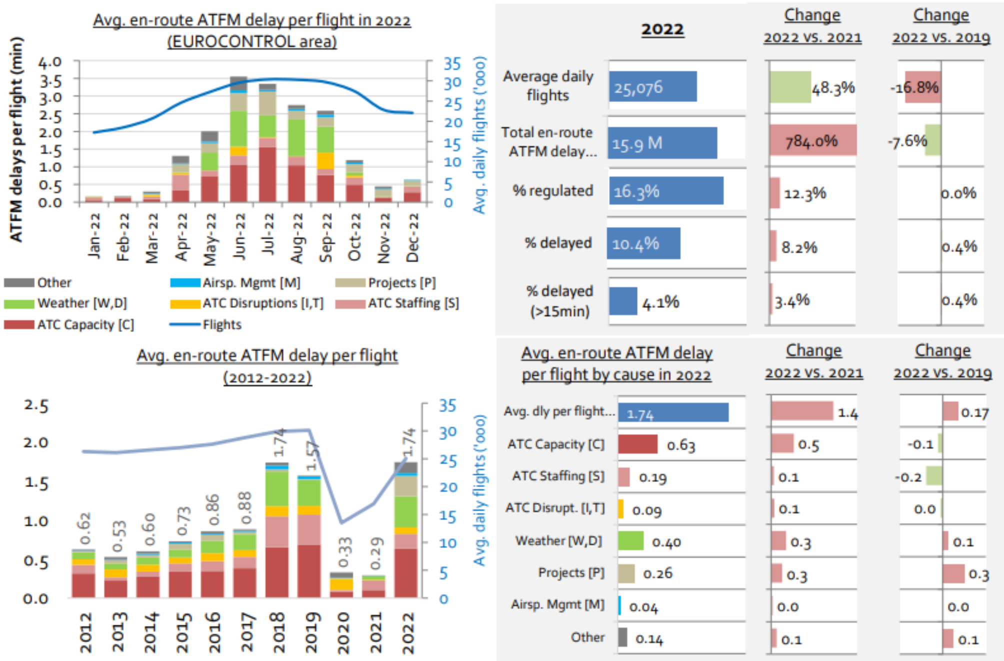

Figure 1.5 – En-route ATFM delays in the area of EUROCONTROL

In 2022, en-route ATFM restrictions resulted in delays for 10.4% of all flights, with 4.1% of these delays lasting 15 minutes or more. The primary cause for over one-third (36%) of the delays was ATC capacity, followed by adverse weather conditions at 23%, and ATC staffing at 11%. Additionally, around 25% of delays were linked to "special events," including the implementation of various capacity projects requiring temporary capacity reductions and airspace restrictions due to the war in Ukraine categorized as "other."

As well, there is a close relationship between flight efficiency and environmental performance.

Flight efficiency is the degree to which a flight follows the shortest possible route and altitude between its origin and destination. Flight efficiency can be measured by various indicators, such as the horizontal en-route flight efficiency, the vertical flight efficiency, and the 3D flight efficiency. Environmental performance is the degree to which a flight minimizes its environmental impact, such as fuel consumption, carbon emissions, noise pollution, and air quality degradation. Environmental performance can be measured by various indicators, such as the fuel efficiency, the CO_2 intensity, the noise exposure.

There are a strong relationship between flight efficiency and environmental performance, as improving one can also improve the other. For example, reducing the additional distance flown by an aircraft can save fuel and reduce CO_2 emissions. Similarly, optimizing the flight level and speed of an aircraft can reduce fuel burn and noise impact.

However, there might also to be trade-offs or conflicts between flight efficiency and environmental performance, as improving one may worsen the other. For example, increasing the quantity of direct flights may increase the capacity and efficiency of air traffic management, but it may also increase the noise exposure and air quality degradation near airports. Similarly, reducing the vertical separation between aircraft may increase the airspace capacity and efficiency, but it may also increase the risk of contrail formation and climate impact.

For every additional ton of unused fuel, the equivalent of 3.15 tons of CO_2 is saved. Flight efficiency during the enroute phase is influenced by a considerable number of factors involving different stakeholders. For example, economic tradeoffs, adverse weather, safety, segregated airspace, operational tradeoffs, TMA entry points, route network. While not all these factors are under the direct control of the ANS (weather, military exercises), it is clear that the ANS has a role to play in maximizing the use of airspace and ensuring safe separation of flights while reducing constraints to the minimum necessary. Given external factors such as adverse weather and necessary and desirable tradeoffs, there will always be a certain level of flight inefficiency.

Horizontal flight efficiency (HFE) is a concept that measures how close the actual flight path of an aircraft is to the shortest possible distance between its origin and destination. It is a way of assessing the performance and optimization of air traffic management (ATM) systems and operations.

HFE is calculated by comparing the length of the trajectory flown by an aircraft with the achieved distance, which is the shortest distance that can be flown between the endpoints of the trajectory, considering the airspace structure and constraints. The difference between the trajectory length and the achieved distance is called the additional distance, which represents the inefficiency or deviation from the optimal path. HFE is expressed as a percentage of additional distance per achieved distance.

HFE can be measured at different levels, such as local, regional, or global, depending on the scope and purpose of the analysis. HFE can also be measured for different portions of the flight, such as en-route, terminal, or whole flight. HFE can be influenced by various factors, such as weather conditions, air traffic demand, aircraft types and size, airspace capacity, airports and runway capacity, air traffic control systems, regulations and airspace management, security measures, and technological advancements.

HFE is an important indicator for monitoring and improving the environmental impact, cost, and safety of aviation in Europe and beyond. It is part of the performance scheme regulation under the Single European Sky (SES) initiative, which aims to reform and modernize the ATM system in Europe by creating a harmonized and integrated airspace that is managed at a European level rather than a national level. The SES is expected to increase the capacity and efficiency of ATM, reduce the environmental impact and costs of aviation, and enhance the competitiveness and sustainability of the European aviation sector.

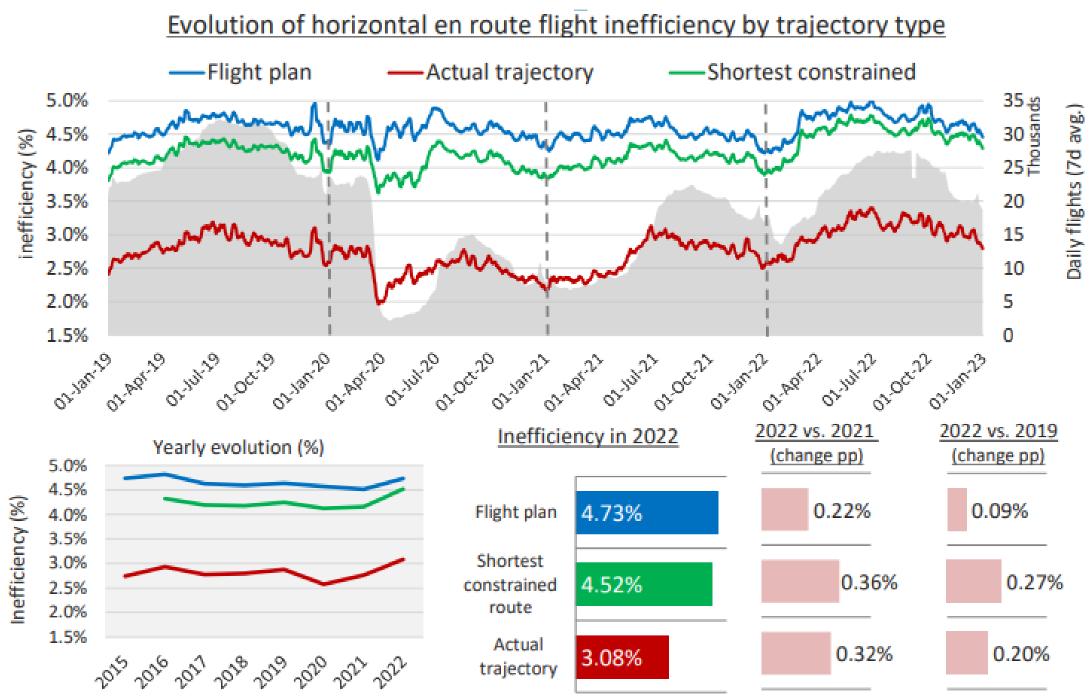

Figure 1.6 – Horizontal en-route flight inefficiency

1.3 Prospects for the improvements of air traffic in Europe

Air traffic in Europe is a complex and dynamic phenomenon that is influenced by various trends and factors, such as the economic situation, the environmental impact, the technological innovation, the regulatory framework, and the consumer behavior. The COVID-19 pandemic has had a severe and unprecedented impact on air traffic in Europe, causing a sharp decline in flights and passengers in 2020 and 2021. The recovery of air traffic depends on the evolution of the pandemic, the vaccination campaigns, the travel restrictions, and the consumer confidence. However, there are also prospects for the improvements of air traffic in Europe in the medium and long term, based on the initiatives and actions taken by various stakeholders, such as the European Commission, EUROCONTROL, EASA, IATA, and others.

The implementation of operational ATM improvements that can provide an important contribution to reducing CO2 emissions with progress achieved in both airspace design and deployment of interoperable technologies. For example, improving horizontal flight efficiency (HFE), vertical flight efficiency (VFE), 3D flights efficiency (3DFE), free route airspace (FRA), functional airspace blocks (FABs), and other concepts that optimize the use of airspace and minimize the delays, costs, and emissions of flights.

The development and adoption of new technologies and innovations that can improve the efficiency and safety of aviation, such as navigation systems, communication tools, aircraft design, digitalization, automation, artificial intelligence, big data analytics, blockchain, biometrics, cybersecurity, etc. These technologies can enhance the capabilities and performance of aircraft operators, air navigation service providers, airport operators, regulatory authorities, and other stakeholders.

The promotion of sustainable aviation fuels (SAF) that can reduce the carbon footprint of aviation by replacing conventional jet fuel with alternative fuels derived from renewable sources or waste materials. SAF can reduce CO2 emissions by up to 80% compared to fossil fuels. SAF can also reduce other pollutants such as NOx, SOx, particulate matter (PM), etc. SAF can be used in existing aircraft engines without major modifications. SAF can also stimulate economic growth and create jobs in rural areas.The prospects for the improvement of air traffic in Europe are good. There are a number of initiatives underway to address the challenges of

Another important initiative is the development of new technologies. New technologies, such as Free Route Airspace (FRA), can help to improve the efficiency of airspace and reduce the environmental impact of air travel.

Over the past years, the continuous implementation of Free Route Airspace (FRA) throughout Europe has been an enabler for improved flight efficiency as it offers airlines a more flexible environment compared to a rigid route structure and therefore more choices and opportunities for airlines to reduce fuel consumption and emissions.

FRA was first implemented in Portugal in 2009 and mandated by EC legislation in 2011.

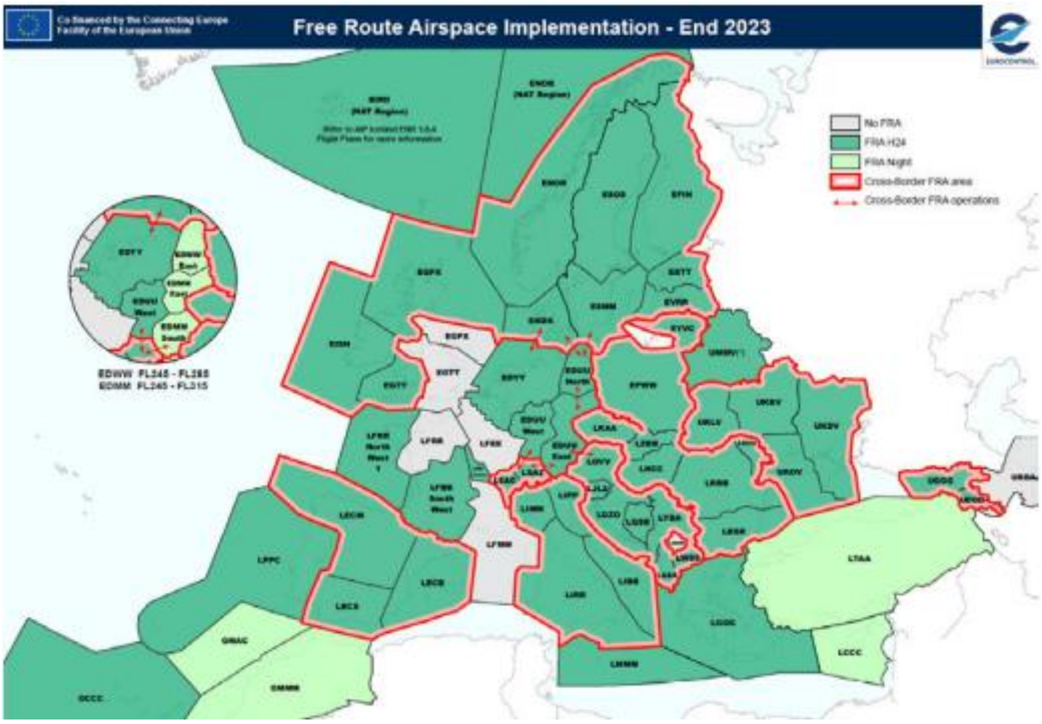

Figure 1.7 – Implementation status of Free Route Airspace (FRA) End 2023

Except for some areas in France and the United Kingdom (grey areas), the FRA will be partially or fully implemented in most regions of Europe (green areas). While local implementation of the FRA has brought notable benefits over the past decade, more attention needs to be paid to cross-border efforts in order to fully utilize the full potential of the network as a whole.

In addition to these initiatives, there is a growing awareness of the need to improve air traffic in Europe. This is being driven by a number of factors, including the increasing cost of fuel, the environmental impact of air travel, and the growing demand for air travel.

As a result of these factors, we can expect to see significant improvements in air traffic in Europe in the coming years. These improvements will benefit everyone involved in air travel, including airlines, passengers, and the environment.

CONCLUSION FOR THE CHAPTER 1

This chapter has provided an overview of the general situation regarding air traffic flows in European airspace. The structure of European airspace consists of various components like flight information regions, control areas, upper control areas etc. It is managed by organizations such as EASA, Eurocontrol, and national authorities. Air traffic flow and capacity management (ATFCM) tools help manage traffic, enhance safety and efficiency. This involves strategic planning, pre-tactical coordination, tactical adjustments, and post-ops analysis. Traffic is recovering after COVID-19 declines, but infrastructure strains pose challenges. The Russia-Ukraine war has also altered some flight paths. Overall, levels are still below 2019.

Capacity and efficiency optimization is an ongoing effort. Free Route Airspace initiatives like that implemented in Ukraine aim to improve flexibility and flight efficiency. Environmental goals are also driving efforts to reduce fuel burn, emissions and noise impact. Technologies and sustainable fuels will play a role along with enhanced airspace design.

In summary, while traffic is rebounding, Europe faces airspace congestion and other systemic issues. However, concerted development programs aligned on safety, efficiency and sustainability objectives provide promise for significant air traffic improvements in coming years.

CHAPTER 2. FORMAL MODELS OF FREE ROUTE AIRSPACE IMPROVEMENT AND THE EUROCONTROL NETWORK STRATEGIC TOOL FUNCTIONALITY

Air traffic volumes are constantly increasing each year, leading to the need for continuous improvement in European air traffic management. It is therefore necessary to increase the capacity and efficiency of the airspace, but keeping in mind the environmental and safety aspects, which should be maintained or improved. The most important way to reduce environmental impact is to reduce aircraft fuel consumption. To achieve this goal as quickly and easily as possible, start with flight routes. If the plane flew directly between two points, it would save a lot of kilometers and therefore tons of fuel. The result, much appreciated today, is the reduction of CO_2 emissions.

The basis is the awareness that the object of air traffic control is the organization of aircraft movements in the airspace, including methods and practices in traffic management and safety. Air traffic control is a cybernetic process based on the continuous exchange of information and interaction between air traffic control units and between them and the controlled aircraft.

2.1 Free Route Airspace Design and Models.

The fundamental concept of Free Route Airspace (FRA) is that in designated airspace, users have the ability to plan their own route freely from a specified entry point to a defined exit point. This includes the option to choose intermediate waypoints, whether published or unpublished, without being constrained by the ATS route network, contingent upon airspace availability. However, flights within this airspace are still under the jurisdiction of air traffic control. [8]

Factors that contribute to Free Route Airspace (FRA) implementation include:

a) Adequate System Support, enhancements made for improved Flight Planning and Air Traffic Flow and Capacity Management (ATFCM).

b) Procedures, enhanced procedures implemented as needed for operations within FRA and its interfaces.

c) Adjustments to Airspace Structures, modifications to accommodate the requirements of FRA.

d) Adjustments to Airspace Management Procedures, changes made to align with the management of FRA.

e) No additional equipment requirements or modifications to flight planning procedures are anticipated for aircraft operators. However, adjustments to flight planning systems may be necessary to ensure the full benefits of FRA are realized.

The idea is to establish a facilitating framework for the coordinated adoption of Free Route Airspace (FRA) in Europe, whenever a State/FAB/ANSP or a group of States/FABs/ANSPs opts for such implementation. The FRA Concept serves as the foundation for a shared comprehension among all Air Traffic Management (ATM) partners participating in the implementation of FRA.

The FRA Concept includes different scenarios for implementing Free Route Airspace (FRA) that will [8]:

a) Achieve the Safety Objectives;

b) Align with current operations;

c) Ensure sustainability through ongoing development;

d) Allow for expansion and connectivity to adjacent airspace;

e) Enable exportability to other regions.

The concept of Free Route Airspace (FRA) is relevant to any region where FRA is implemented within the European airspace network. FRA is an essential component of the overall European Air Traffic Management (ATM) network and is linked either vertically or laterally to neighboring airspace with fixed Air Traffic Service (ATS) routes. While airspace reservations will persist, the implementation of FRA ensures that all airspace users enjoy equal access. The application of the Flexible Use of Airspace (FUA) concept and civil/military coordination is considered to maintain standardized procedures and services, ultimately benefiting all airspace users.

The Free Route Airspace (FRA) is generally categorized as Class C airspace, with specific agreed-upon exceptions, such as above FL460 and within NOTA.

Vertical Limits of FRA

The primary objective of the Free Route Airspace (FRA) concept is to streamline the adoption of FRA in a coordinated manner whenever a State/FAB/ANSP opts for implementation. It is noteworthy that there is no explicit suggestion regarding the minimum Flight Level (FL) for such implementation[19].

The vertical boundaries of FRA are detailed in national Aeronautical Information Service (AIS) publications. Importantly, setting the lower limit of FRA should not adversely affect neighboring areas where FRA has not been introduced or is only partially applied.

However, aiming for a unified airspace structure throughout the European network, the following suggestions are made[8]:

a) T
h
e

b) T
h

Horizontal Limits of FRA

The determination of horizontal limits should be guided by operational necessities rather than strictly adhering to FIR/UIR or ATC unit boundaries. In instances where the configuration of the lateral boundaries of an FIR/UIR or ATC unit may lead to a direct route causing a temporary departure to adjacent airspace, concerted efforts

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should be undertaken to organize the applicability of Free Route Airspace (FRA) based on operational requirements. Corresponding agreements should be established with neighboring ATC units/States. In unavoidable situations of this nature, it is crucial to appropriately publish entry/exit points for FRA horizontally. If FRA is implemented across neighboring FIRs/UIRs, the publication of FRA should transparently indicate this cross-border application.

The defined horizontal entry/exit points for FRA should consider adjacent airspace where FRA is not implemented, ensuring a structured transition between the two operational environments. This transition need not necessarily occur at the edge of the FIR or ATC unit. To uphold the overall connectivity of the European airspace structure, the horizontal entry/exit points for FRA into/out of neighboring non-FRA airspace structures must guarantee connectivity with the fixed route network of Air Traffic Service (ATS).

Free Route Airspace Significant Points

If airspace is referred to as a flow element, then entry into it is either prohibited or mandatory within the specified flight range level. The initial crossing of the lateral or vertical boundary of airspace is designated as the **entry point**, while the subsequent crossing is termed the **exit point**. These points are not obligatory to be published as significant points and can encompass any geographical coordinates along the trajectory. Additionally, entry and exit points are not required to be crossed at the same altitude[13].

The trajectory satisfies the "**departure airspace**" condition when the departure airport is situated within ground level projection of the relevant airspace.

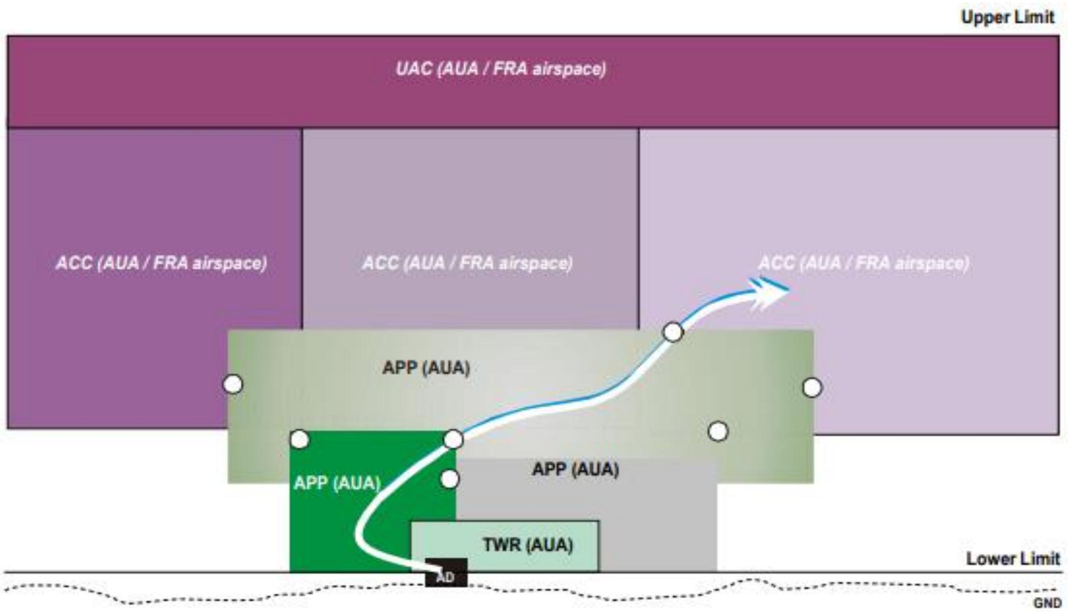

Figure 2.1 – Exemplary trajectory which fulfils a “departure airspace” condition

The trajectory meets the **“arrival airspace”** condition if the arrival airport is situated within the ground level projection of the relevant airspace.

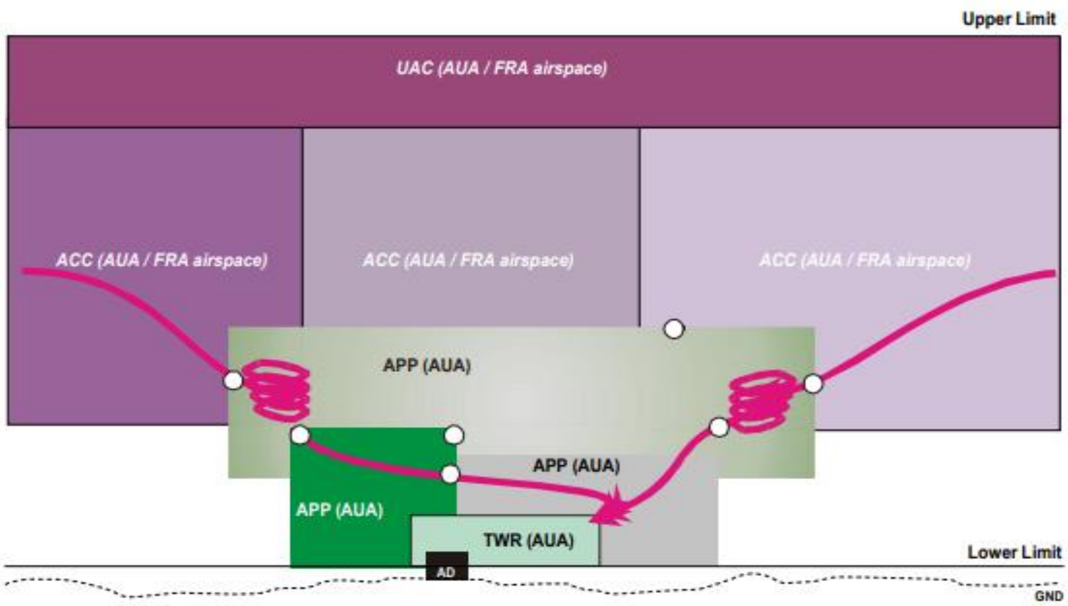

Figure 2.2 – Example of trajectory which responds an “arrival airspace” condition

But the lower vertical boundary of the departure/arrival airspace doesn't have to be at ground level necessarily.

The trajectory called **“overfly airspace”** in the condition met if a portion of the trajectory is located within the confines of the corresponding airspace volume and this airspace does not refer to departure or arrival airspace for particular flight.

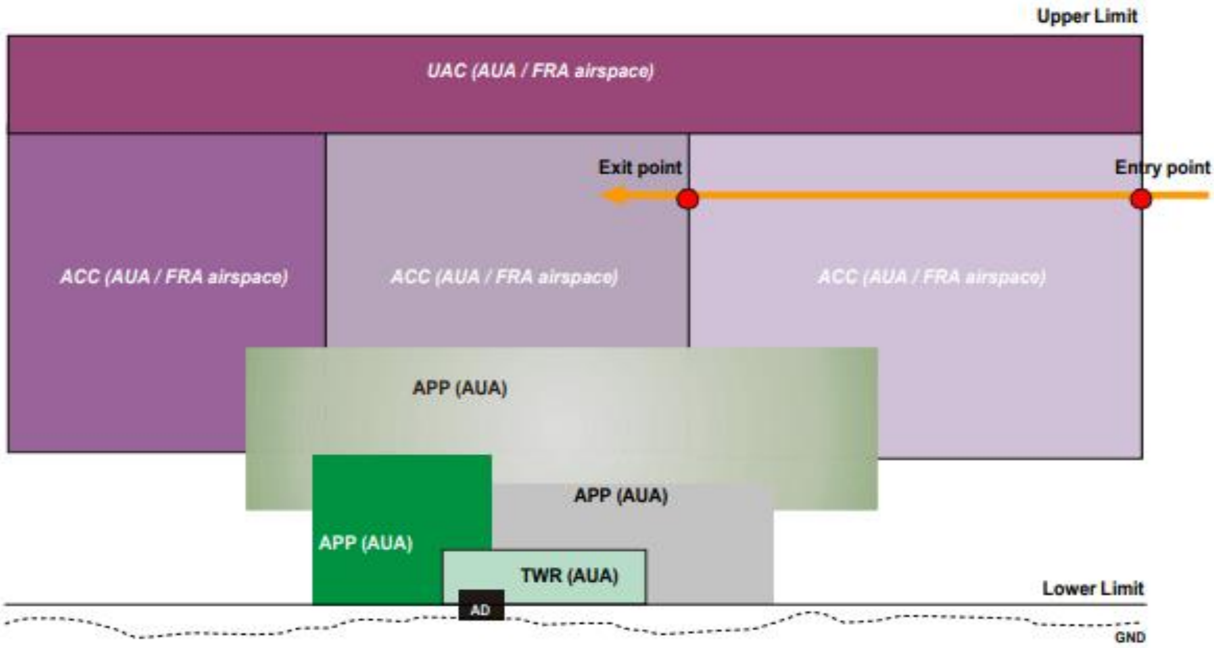

Figure 2.3 – Example of trajectory which responds an “Overfly airspace” condition constant level with lateral entry and exit

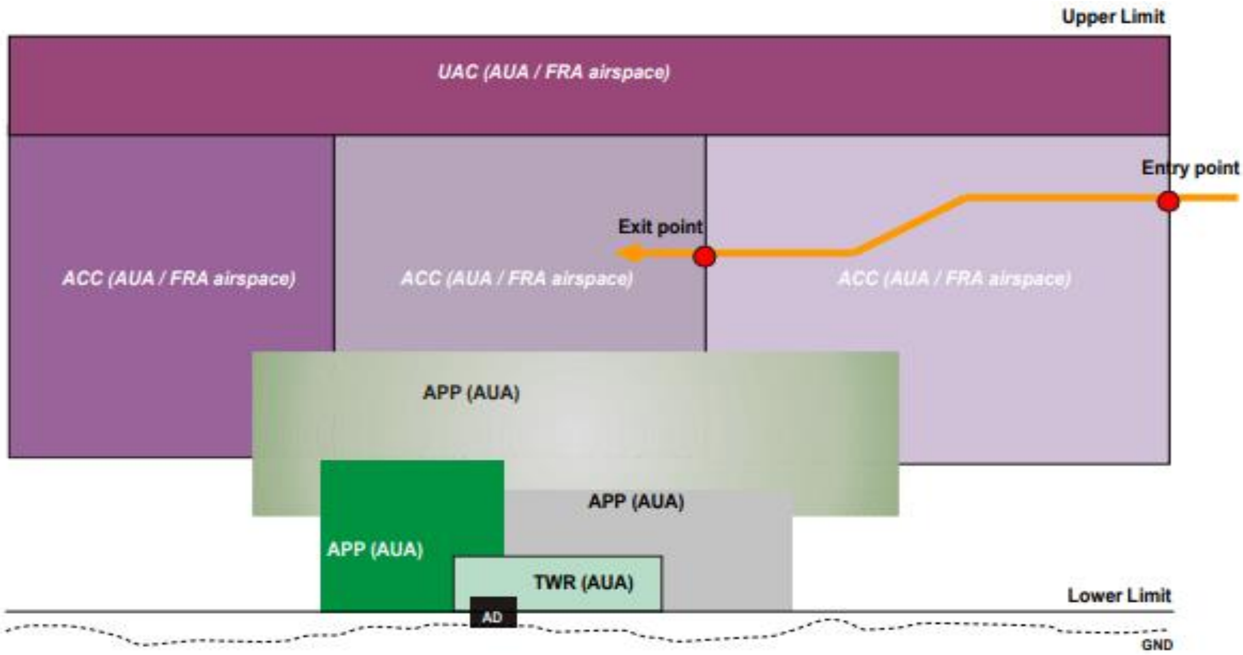

Figure 2.4 – Example of trajectory which responds an “Overfly airspace” condition with intermediate descent with lateral entry and exit

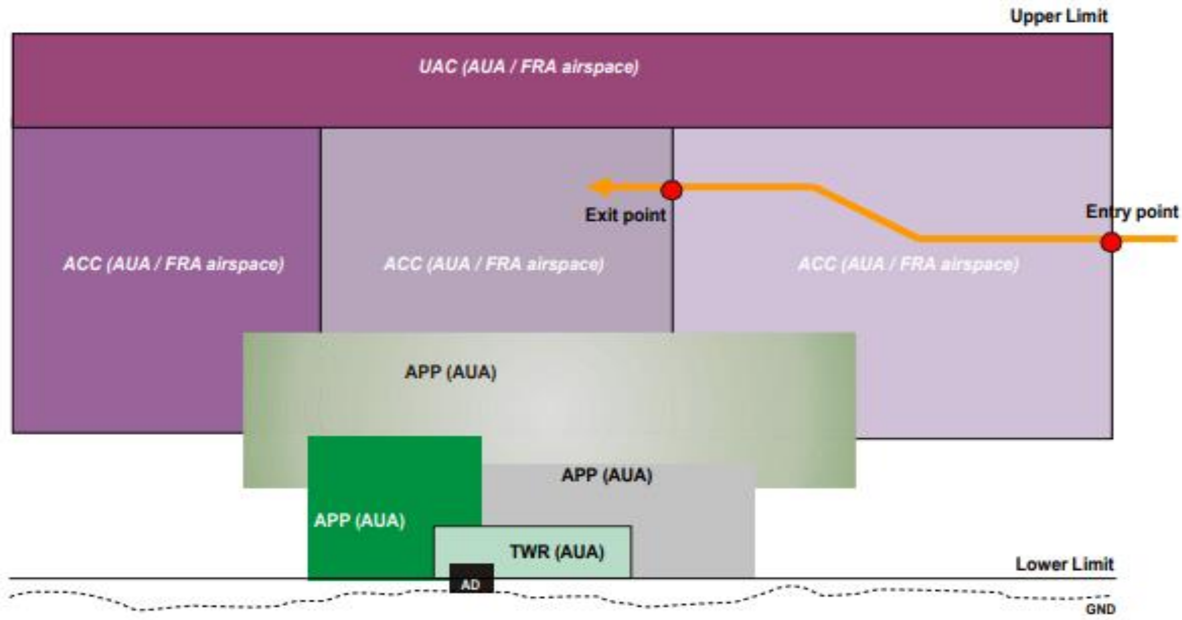

Figure 2.5 – Example of trajectory which responds an “Overfly airspace” condition with intermediate climb with lateral entry and exit

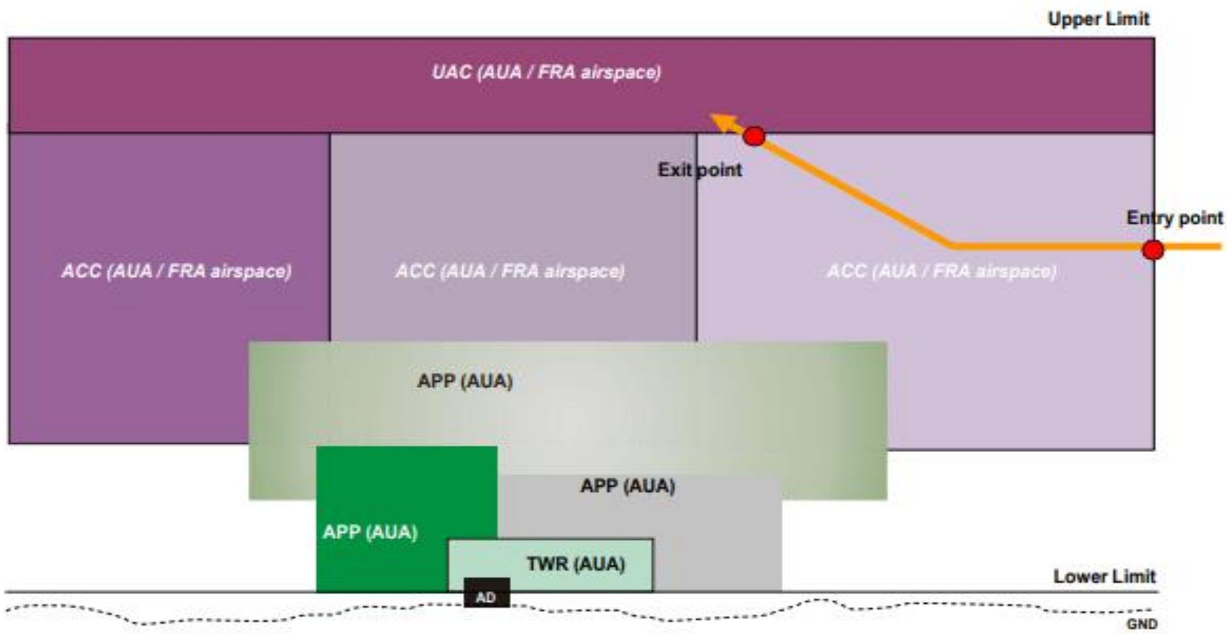

Figure 2.6 – Example of trajectory which responds an “Overfly airspace” condition with lateral entry and vertical exit

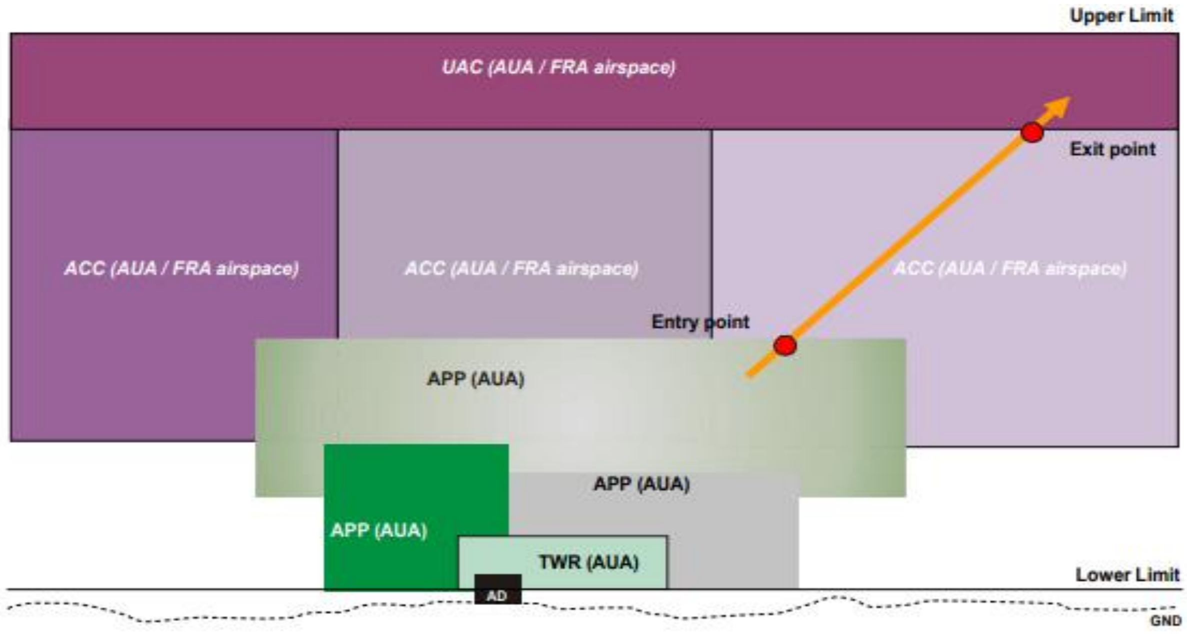

Figure 2.7 – Example of trajectory which responds a "Overfly airspace" condition with vertical entry and vertical exit

The significant points within the Free Route Airspace (FRA) will be documented in national Aeronautical Information Publications (AIPs), explicitly mentioning their association with the FRA and highlighting their relevance in this context.

Given that NAVAIDs can serve as significant points within Free Route Airspace (FRA), it is advisable to contemplate the publication of relevant FRA information for en-route navigation aids as well.

The FRA relevance of the significant points shall be indicated by the following letters and published within brackets [8]:

(E), for "FRA Horizontal Entry Point"

(X), for "FRA Horizontal Exit Point"

(I), for "FRA Intermediate Point"

(A), for "FRA Arrival Connecting Point"

(D), for "FRA Departure Connecting Point"

Letter combinations can be published following the guidelines outlined in this matrix:

E	EA		
X		XD	EXAD
EX	EXA	EXD	EXADI

I	IA	ID	IAD
	A	D	AD

Figure 2.8 – Combinations of letters for Significant Points

Two models of Free Route Airspace (FRA) with shared characteristics can be incorporated into the Centralized Airspace Data Communication (CADC) system, as outlined below [15]:

a) Flights have the option to travel from an FRA Entry point to an FRA Exit point.

b) Flights can follow a route that includes one or multiple FRA Intermediate points.

c) The inclusion of FRA Intermediate points in a flight plan is optional.

d) Flights have the flexibility to utilize either the FRA or the Air Traffic Service (ATS) route network, as long as the ATS route network remains accessible.

Full FRA

The "Full FRA" is the model where free route airspace intermediate points can be used as published point (defined in CADC with their "Significant Point Type" and published by States in AIP's) and unpublished points(defined by geographical coordinates) with DCT limit in FRA set by the CADC to N/A = Unlimited. It is means that out the ATS network the airspace can be crossed on a DCT via any FRA intermediate point.

FRA with Intermediate points (FRA - IP)

FRA – IP it is the model where only published and well defined in CADC FRA intermediate points can be used with DCT limit is installed in CADC to 0 NM. This implies that beyond the Air Traffic Service (ATS) route network, the airspace can only be traversed directly (DCT) from an FRA entry point to an FRA exit point or through specifically permitted FRA intermediate points.

FRA Vertical Connectivity

The concept of "Vertical Connectivity" pertains to the procedures for entering or exiting a free route airspace area by traversing the vertical limit of the FRA. It encompasses both departing and arriving traffic, as well as traffic altering its cruising level, but only if such a change results in entering or exiting the FRA, excluding cruising traffic that stays within the vertical limits of the FRA.

The process of vertical connectivity in IFPS is relating to the two following cases[15]:

a) FRA co-exists with ATS route network;
b) FRA without the ATS route network.

a) Departing and Arriving traffic

Departing and arriving traffic have two potential methods for vertical entry into the FRA area: one through the ATS route network and the corresponding SID.

If the ATS route network is employed for entry into the FRA area, the use of an FRA Entry point is not obligatory.

In the provided illustrations (Figure 2.9), point B functions as an FRA Intermediate point, and point C serves as an FRA Exit point. Similarly, in the subsequent examples (Figure 2.10), point A is designated as an FRA Entry point, while point B operates as an FRA Intermediate point [15].

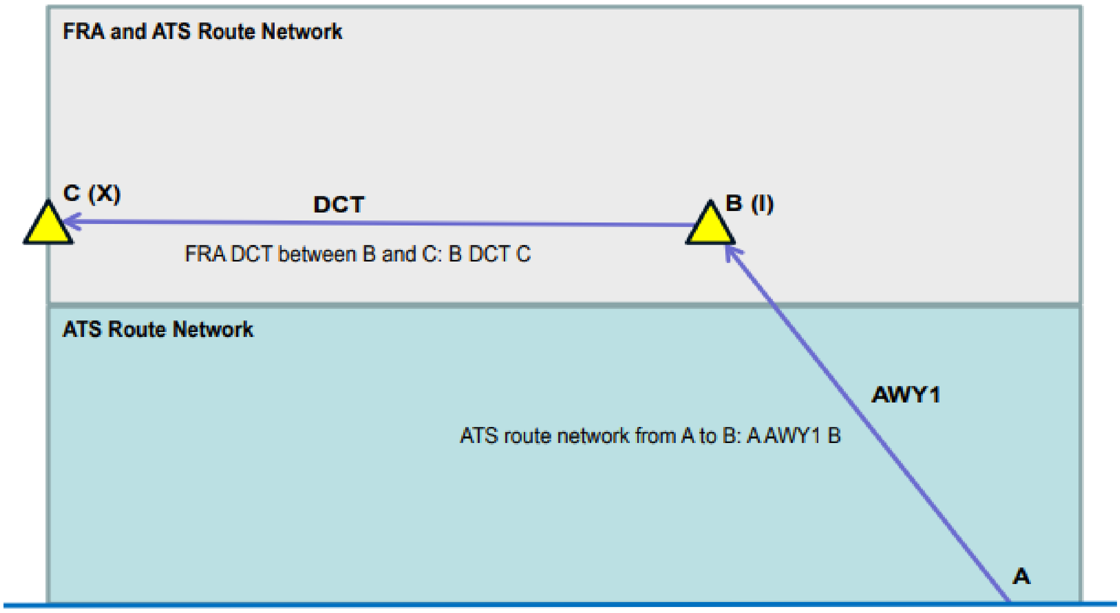

Figure 2.9 – Example trajectory of departing traffic in FRA with ATS route network entering via airway

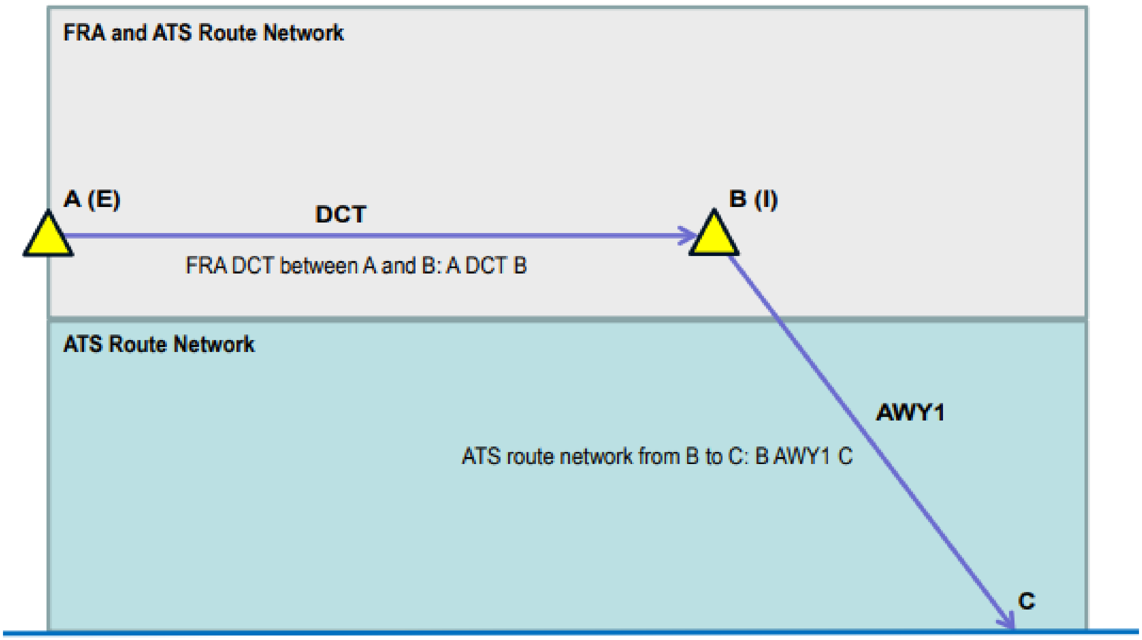

Figure 2.10 – Example trajectory of arriving traffic in FRA with ATS route network exiting via airway

Given that SID and STAR constitute components of the ATS route network, they can be utilized for entry into the FRA area. The feasibility of entry is contingent upon the overlapping minimum level of the FRA area and the maximum level of the SID. In the provided example (Figure 2.11), point A serves as an FRA Departure Connecting point, and point B is an FRA Exit point. In a parallel scenario (Figure 2.12), point A functions as an FRA Entry point, while point B is an FRA Arrival Connecting point [15].

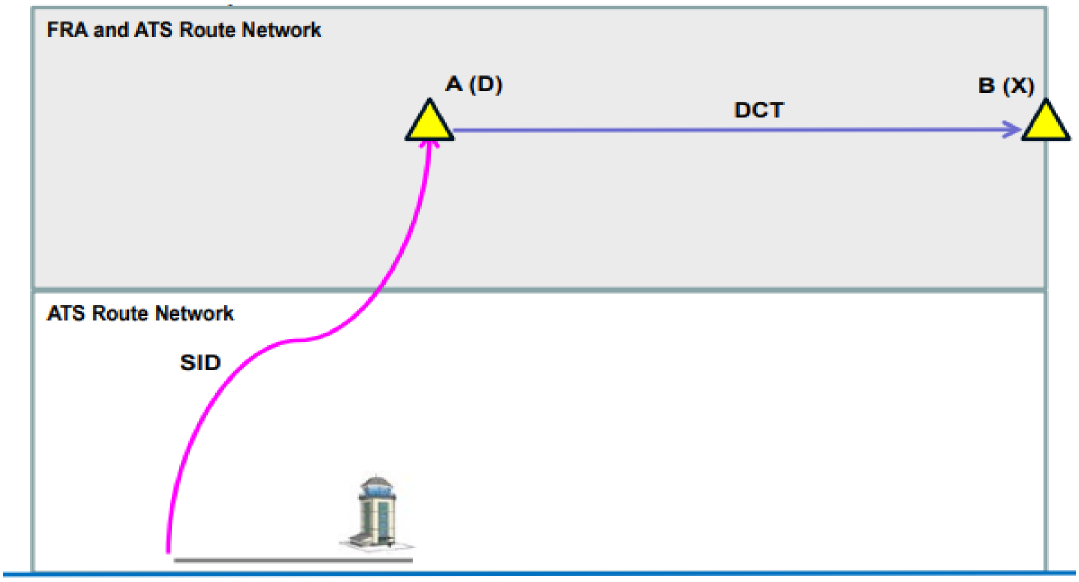

Figure 2.11 – Example trajectory of departing traffic in FRA with ATS route network entering via SID

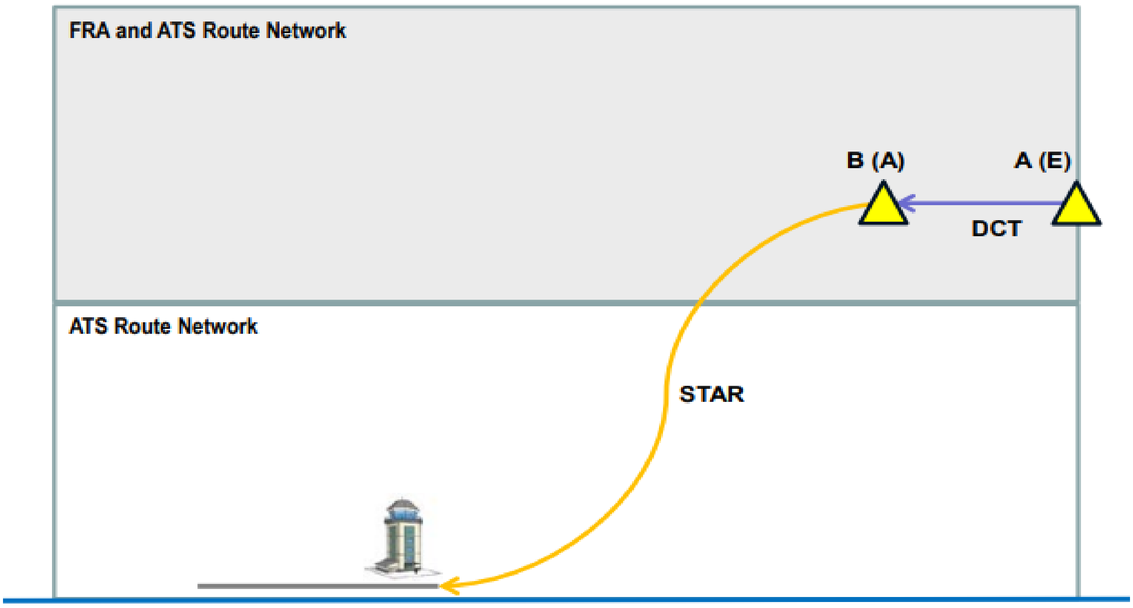

Figure 2.12 – Example trajectory of arriving traffic in FRA with ATS route network existing via STAR

b) Overflying traffic

The principles remain consistent for overflying traffic, whether departing or joining the Free Route Airspace (FRA) after a change in the Requested Flight Level (RFL) [15].

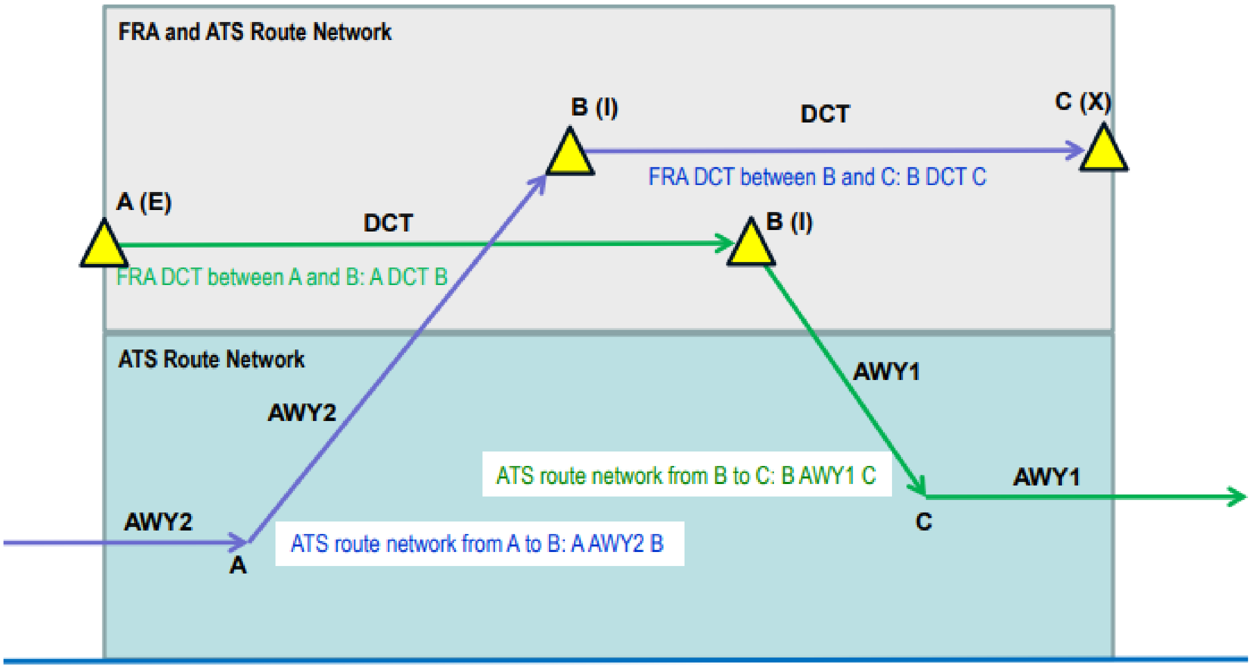

Figure 2.13 – Example trajectory of overflying traffic in FRA with ATS route network

FRA without ATS route network

In case of Full FRA, there are two possible ways of processing based on DCT limits allowed within the AUA below the FRA area for xxxNM or 0NM.

Regarding Full FRA, there are two potential methods of handling the process, which depend on the Direct (DCT) limits permitted within the Area of Uncontrolled Airspace below the FRA area, either within xxx NM or 0 NM.

a) Full FRA: DCT limit xxxNM below the FRA area

Departing or Climbing traffic (Figure 2.14)

In instances where the DCT limit within the AUA below the FRA is, for example, 300 nautical miles , IFPS accepts the option of B direct C even if the level at the initial point (B) falls below the minimum level of the FRA. Point B resides within an AUA where the DCT limit is 300 NM, and if the distance of B DCT C is <300 NM, IFPS approves it. This implies that B DCT C could potentially enter the FRA area from below, provided the allowed AUA DCT limit permits. However, if there is an entry restriction "from below" in the FRA area, then it is necessary to designate point B as an FRA Entry point in the relevant FRA DCT restriction.

The choice to access the Free Route Airspace through a SID is applicable when the FRA minimum level aligns with the SID's maximum level, facilitating airspace connectivity. In cases where there is no level overlap, the entry into the FRA area is accomplished using the ATS route network [15].

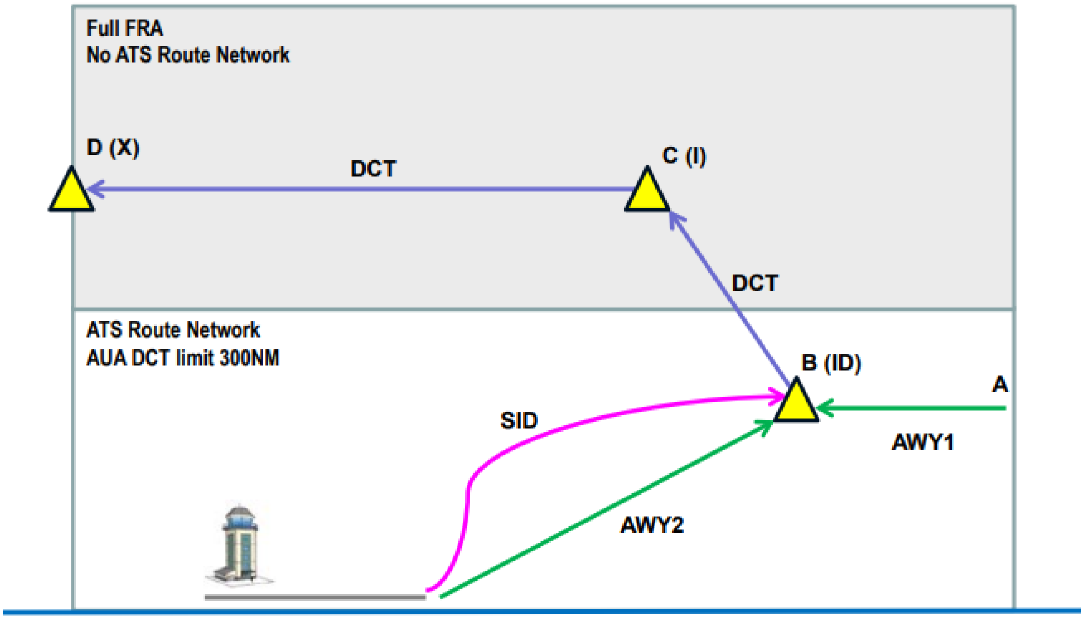

Figure 2.14 – Example trajectory of departing and overflying traffic in FRA without ATS route network with AUA DCT xxx NM

Arriving or Descending traffic (Figure 2.15)

If the DCT limit within the AUA below the FRA area is, for example, 300 nautical miles, IFPS accepts the choice of C direct B even if the level at the final point (B) falls below the FRA minimum level. Point B is situated within an AUA where the DCT limit is 300 NM, and if C DCT B is <300 NM, it is sanctioned by IFPS. This indicates that C DCT B could potentially enter the FRA area from above, provided the allowed AUA DCT limit allows for it. However, if there is an entry restriction "from above" in the

FRA area, then it becomes necessary to designate point B as an FRA Exit point in the relevant FRA DCT restriction.

Additionally, the option to exit the FRA area through a STAR is feasible when the FRA minimum level aligns with the STAR's maximum level, facilitating airspace connectivity. In cases where there is no level overlap, the exit from the FRA area is accomplished using the Air Traffic Service (ATS) route network [15].

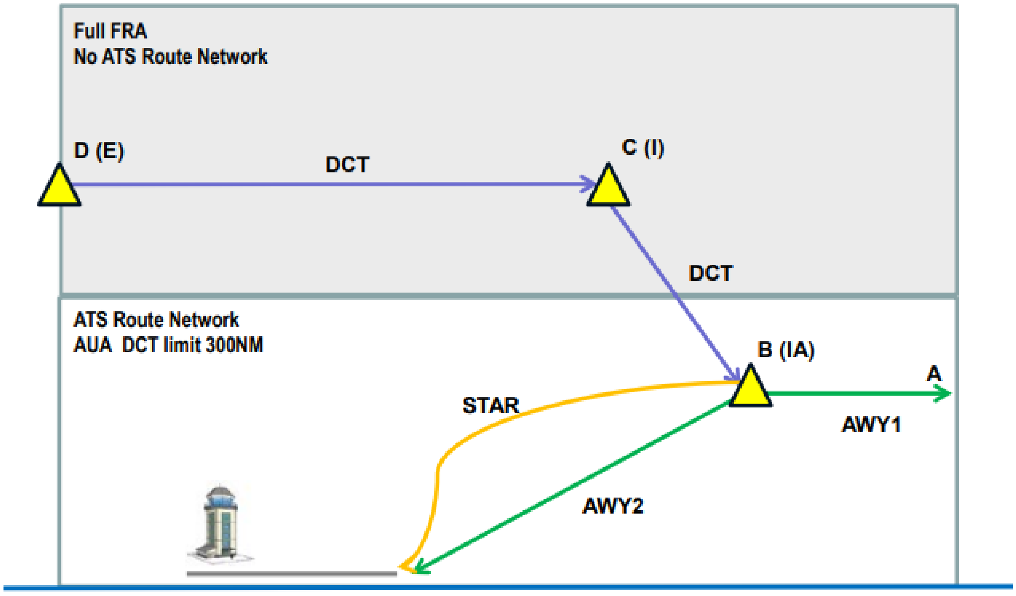

Figure 2.15 – Example trajectory of arriving and overflying traffic in FRA without ATS route network with AUA DCT xxx NM

b) Full FRA and FRA - IP: DCT limits 0NM below the FRA area.

<u>Departing or Climbing traffic (Figure 2.16)</u>

The initial point of the DCT trajectory entering the FRA area must be specified as an FRA Intermediate point in the State AIP but defined within the CADC system as the "system FRA Entry point." This point should traverse the level band between FLxxx and FLyyy. IFPS accepts options A DCT B or A DCT C, even if the level at point A is below the FRA minimum level. This acceptance overrides the DCT limit below FLyyy within the AUA, which is set at 0 nautical miles.

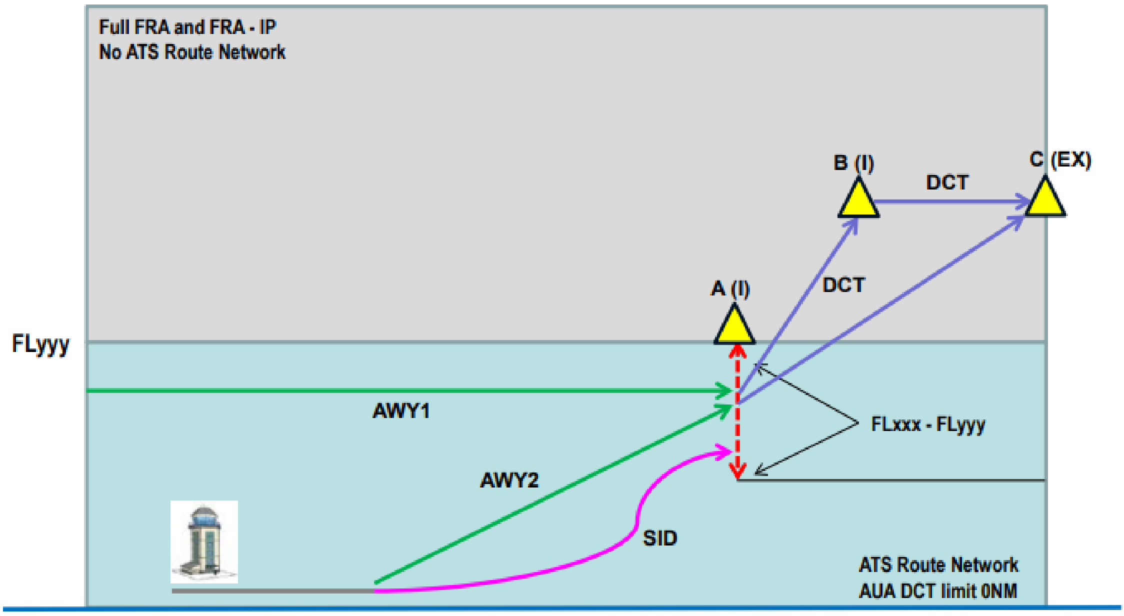

Figure 2.16 – Example of trajectory of departing and overflying traffic in FRA without ATS route network with AUA DCT 0NM

Arriving or Descending traffic (Figure 2.17)

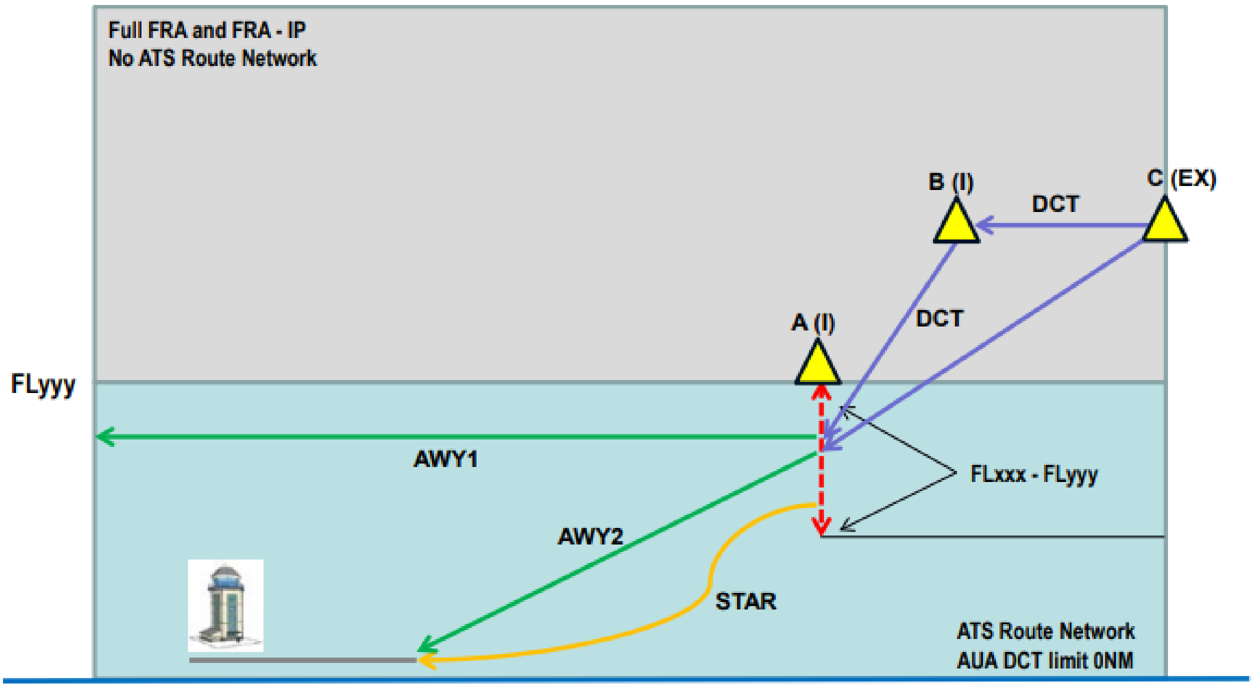

Figure 2.17 – Example trajectory of arriving and overflying traffic in FRA without ATS route network with AUA DCT 0NM

The final point of the DCT trajectory exiting the FRA area must be specified as an FRA Intermediate point in the State AIP but defined within the CADC system as the "system FRA Exit point." This point should traverse the level band between FLxxx and FLyyy. IFPS accepts options B DCT A or C DCT A, even if the level at point A is below the FRA minimum level. This acceptance supersedes the DCT limit below FLyyy within the AUA, which is set at 0 nautical miles [15].

Cross-border Free Route Airspace concept

The introduction of cross-border FRA is another milestone towards the improvement of flight and Air Traffic Management (ATM) systems efficiency. The implementation and expansion of cross-border FRA may have a positive impact on flight efficiency improvement due to the reduction of distance and consequently the flight time, fuel waste, CO2 emission and operating costs. It can also mitigate the problem of the European Airspace capacity gradually reaching its maximum level. Thus, there is still a lot of places for further optimization of air traffic flow in European Airspace.

The cross-border FRA is an expanded version of the regular FRA. Under this type of FRA, the obligation to exit/enter the previous/next country's FRA only through a published exit/entry point ceases to apply. Instead, users have the freedom to exit/enter the airspace of another country at any point of their choice, determined by geographic coordinates or bearing and distance. In the transboundary FRA, points (E) and (X) cease to exist and are replaced by points (I), which in the FRA are not mandatory for overflight.

General concept of transboundary FRA compared to traditional FRA is presented in Figure 2.18.

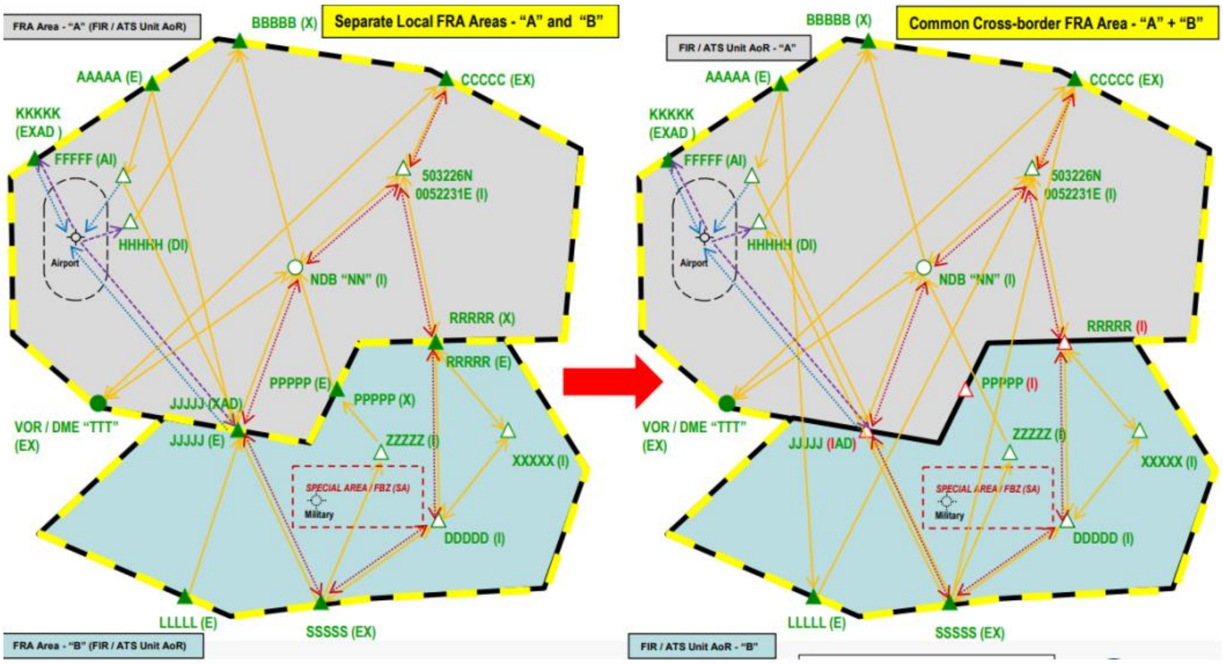

Figure 2.18 – Main difference between classic FRA and cross-border FRA

The cross-border FRA is currently operative in the airspaces over the following countries [11]:

- SAXFRA (Austria/Slovenia);
- SEENFRA (Romania/Hungary/Bulgaria);
- SEAFRA (Belgrade/Sarajevo/Zagreb);
- NEFRA (Estonia/Latvia/Finland/Sweden/Denmark/Norway).

The cross-border FRA is another step towards the increase of airspace capacity and flight efficiency.

As mentioned above, the main benefit is the straightening of flight routes and the resulting reduction in total distance flown. Another change with respect to airways is that airspace information is provided, airway availability information is replaced with airspace availability information.

While the goal is to implement FRA on an ongoing basis, limited implementation during certain periods of time could facilitate earlier implementation. Procedures should be established for the transition between FRA and ATS fixed route operations.

To enhance the effectiveness of Free Route Airspace (FRA) and guarantee the secure and efficient transition of flights, it is essential to exert every effort to facilitate any necessary adjustments to the established Air Traffic Service (ATS) route network in neighboring airspace where FRA is not applicable. In cases where a fixed ATS route network continues to operate beneath the FRA, this underlying network should be systematically improved and coordinated at the network level to accommodate the requirements of free route operations in the airspace above [8].

2.2 Implementation of the FRA in Europe

Airspace users are obligated to adhere to standard ATFCM procedures, whether operating within or outside FRA. The widespread adoption of FRA on a large scale or the integration of free route operations in adjacent ATC units will result in a diverse range of flight paths. To provide the latest ATFCM information at both network and local levels, real-time updates regarding sector configurations and airspace reservations are essential in response to the dynamic airspace situation[16].

The design of sectors must adapt to this shift and may require increased flexibility to accommodate fluctuations in traffic demand.

The sectors within Free Route Airspace should have the following characteristics:

a) They should not be restricted by boundaries of Flight Information Regions, Upper Information Regions, or State borders.

b) They should have the capability to undergo reconfiguration based on demand. In regions where there are substantial variations in the orientation of traffic flow, a systematic approach involving a library of pre-known sector designs, recognized by both internal and external systems, is likely. Any modifications to sector definitions must be communicated to the Network Manager Operations Centre (NMOC) and should be seamless and evident to neighboring units.

The alignment of sectors should be optimized to minimize the number of flights with brief transit times. In instances where achieving such alignment is impractical, traffic falling under this category should be excluded from the Network Manager traffic counts. Appropriate regulations should be established to govern these conditions.

The design of sectors should aim to reduce brief transits and prevent the re-entry of flights into sectors or Air Traffic Control units. Operationally crafted, cross-border sectors may be essential in cases where Free Route Airspace is implemented in neighboring regions.

The implementation of FRA in Europe is a complex and challenging process that requires close collaboration and coordination among various actors, such as states, air navigation service providers, military authorities, airport operators, industry partners, and the Network Manager. The benefits of FRA are expected to outweigh the costs and challenges, as FRA can contribute to improving flight efficiency, safety, capacity, and sustainability, as well as supporting the achievement of the SES vision and goals. FRA is also a key enabler for future airspace design and ATM operational concepts, such as dynamic airspace configuration, flexible use of airspace, higher airspace operations, and advanced flexible trajectories. FRA is therefore not only a current reality, but also a

2.3 Implementation of the FRA in Ukraine

The implementation of FRA in Ukraine is a remarkable achievement that demonstrates the commitment and capability of Ukraine to align with the European standards and best practices in air traffic management. FRA is not only a current reality, but also a future opportunity for Ukraine to further improve its airspace performance and integration with the European network. FRA is also a strategic asset for Ukraine to defend its sovereignty and security against external threats and aggression.

Also, realization of FRA in Ukraine has also contributed to enhancing the safety, capacity, and resilience of the Ukrainian air traffic management system, especially during the COVID-19 pandemic and the recent Russian invasion. FRA operations have enabled more flexible and efficient use of airspace resources, more stable and predictable traffic flows, and more effective coordination and cooperation among

f u t u r e o p p o r t u n

stakeholders. FRA operations have also facilitated the adaptation and recovery of air traffic in Ukraine amid the changing and challenging operational environment.

The FRAU project is grounded in a safety case, with its supporting requirements aimed at maximizing airspace utilization. This consideration encompasses factors such as air traffic flows, compatibility with the European Air Traffic Service route network, and overall added value. The justification for these requirements extends to optimizing both technical and human resources through cost and benefit analyses. The project also seeks to facilitate seamless analysis and flexible transfer of air traffic control responsibility between units, ensuring compatibility among airspace configurations. Additionally, it aims to optimize existing flight information regions, adhering to conditions specified in regional agreements within the International Civil Aviation Organization.

Advancements in the operational facets of the Free Route Airspace Utilization (FRAU) should adhere to the following principles [10]:

a) FRAU developments

b) The requirements of military users should be taken into account during the development of FRAU.

c) The European airspace design concept, along with general principles and technical specifications related to airspace design, should be considered in alignment with the European Route Network Improvement Plan Part 1.

d) EUROCONTROL's general practices and concepts employed for implementing FRA initiatives will be utilized for optimizing the structures of airspace design.

The main task of the FRAU is to develop optimal trajectories within defined significant entry/exit points from/to FRAU and intermediate significant points, determination of the ATS sector for further development of operational scenarios for FRAU using an operationally driven approach.

The FRAU design working plan is divided into 2 steps [10]:

Step 1: FRAU implementation within individual FRA areas.

<u>Scenario 1.a</u>

- FRAU within individual FRA areas, which are published in AIP UKRAINE ENR 1.3.7;
- Horizontal limits: within individual FRA areas;
- Vertical limits: FL275 - FL660;
- Operating hours: Night time 20.00 - 05.00 (21.00 - 04.00) UTC.

Implementation: implemented from 05 March 2015.

<u>Scenario 1.b</u>

- FRAU within individual FRA areas, which are published in AIP UKRAINE ENR 1.3.7;
- Horizontal limits: within individual FRA areas;
- Vertical limits: FL275 - FL660;
- Operating hours: H24

Implementation: 2019.

Step 2: FRAU implementation within Ukrainian UIR.

<u>Scenario 2.a</u>

> FRAU within Ukrainian UIR;

• Horizontal limits: Within Ukrainian UIR;

• Vertical limits: FL275 - FL660;

> Operating hours: H24.

I

m <u>Scenario 2.b</u>

p
- FRAU within Ukrainian FIRs and UIR;

l
- Horizontal limits: Within Ukrainian FIRs and UIR;

e
- Vertical limits: Controlled ATS airspace class "C", excluding TMA

m and CTR;

e

n

t

- Operating hours: H24.

Implementation: 2023.

In an effort to achieve maximum benefits, as well as to maximize the capacity and efficiency of the ATM system in the region and, consequently, maintain a high level of safety, FRAU is the implementation blueprint that is currently available for flight planning and direct routes between defined points within the established airspace structure.

The design of Free Route Airspace considers the diverse needs of multiple airspace user groups, which are determined based on national priorities. An important goal of FRA airspace design, therefore, is to balance providing equal access to airspace for all users while still accommodating their specific and occasionally conflicting requirements. This balancing act must be achieved within the constraints of limited airspace capacity. Overall, FRA aims to enable flexible airspace usage that meets the needs of both civil and military airspace users to the greatest extent possible.

FRAU lower vertical limit - FL 275, is chosen in accordance with the next criteria [3]:

a) Complexity of the airspace and amount of air traffic;

b) Terminal airspace;

c) Military activity;

d) FUA procedures;

e) Airspace classification;

f) Airspace reservation and restriction (TRA, TSA, D, R, P and other special areas);

g) Adjacent regions impact;

h) RNAV 5;

i) Aligning the airspace to ensure consistency within the European Air Traffic Service (ATS) route network;

FRAU implementation will require acting SID/STAR redesign for the purpose of their integration to existing ATS routes and operations within FRAU. It may be necessary to redesign airspace and modify the Air Traffic Service (ATS) route network to enable seamless flight transfers and optimize capacity advantages within Free Route Airspace Utilization (FRAU).

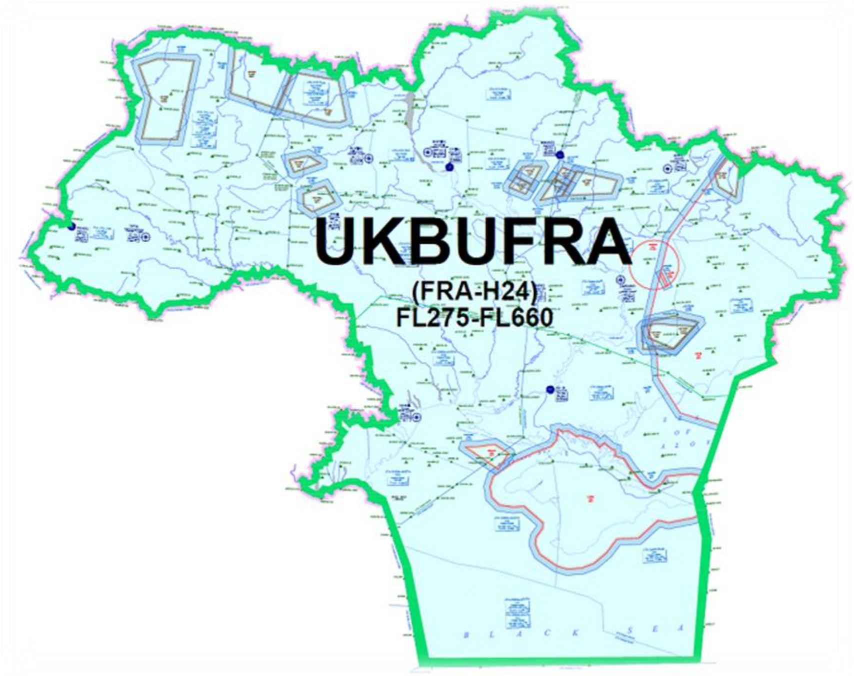

Figure 2.19 – FRA areas

An operationally driven approach enables the organization of optimal DCT routes within the airspace, leading to the identification of sector families. This process considers the airspace's complexity and air traffic demand, relying on a set of potential scenarios for Free Route Airspace Utilization (FRAU). These scenarios are grouped according to economic, social, military, institutional, and other conditions that need to be taken into consideration.

This method follows the outlined steps:

a) The design of the sector will need to be rearranged to facilitate the flow of air traffic in both the FRAU fixed route network and the ATS network, which is under the FRAU, and to be more flexible as traffic demand changes. In this case, the design of ATS sectors should be based on areas of high complexity;

b) In some cases, it may be necessary to review the terminal airspace design (SID/STAR) and, depending on the complexity of the airspace, it may be necessary to explore extensions to ensure adequate traffic separation;

c) If an adequate SID/STAR is not available for some airports, flight planning should be facilitated using the DCT;

d) Sustain the level of combat effectiveness required by the Armed Forces of Ukraine;

e) Must be considered for all possible FRAU scenarios.

2.4 The Eurocontrol Network Strategic Tool

NEST (Network Strategic Tool) is a stand-alone desktop application used by the Network Manager (EUROCONTROL) and ANSPs (Air Navigation Service Providers) for airspace structure design and development, for capacity planning and post operations analysis, for strategic traffic flow organization, for scenario preparation for fast and real-time simulations and for ad-hoc studies at the local and network level[14].

The application has a user-friendly interface and a powerful modelling engine that can perform various analysis and optimization functions. NEST can work with different levels of data, from years to minutes, and can handle complex and realistic operational situations. Users can download these datasets from the DDR (Demand Data Repository) web site.

NEST is scenario-based program. Users have the flexibility to modify the initial dataset or reference scenario, allowing for the modeling of a myriad of distinct operational planning alternatives [14].

The demand for air traffic can be established by utilizing historical data or adjusting it in accordance with the chosen traffic projections. 4D trajectories have the capability to represent real flight paths or can be generated based on customized route networks, considering either the shortest or most cost-effective routes, with cost-effectiveness accounting for route charges. Modifications can be made to 3D airspaces, sector capacities, configurations, route networks, restrictions, and flight level constraints. The consequences of alterations to airspace on sector capacities can be assessed using integrated workload calculations.

The surveillance of traffic volumes for regulatory purposes can be enhanced by fine-tuning the monitored flows. The quantity of controllers accessible can be modified to simulate situations such as compromised operations with diminished capacity. NEST has the capability to optimize opening schedules based on available resources and can identify bottlenecks along with their underlying causes. Subsequently, proposed solutions can be put forward and assessed. Additionally, NEST can simulate free route operations within each region and evaluate potential advantages.

NEST is planner-oriented, any two scenarios can be loaded simultaneously allowing them to be compared on any criteria[14]. Users can see how different parameters affect the results instantly, which allows them to explore and evaluate more options.

2.5 NEST functionality for FRA applications

NEST can create future traffic scenarios based on the traffic growth forecasts from STATFOR. It also has the capability to restrict traffic growth in accordance with airport capacities and curfews. NEST is equipped to calculate 4D flight trajectories within a specified route network, considering aircraft performance data, route restrictions, flight level constraints, SID and STAR, and military area opening times. Traffic distribution can be optimized based on the shortest or most cost-effective routes, considering route charges. NEST can propose an optimal operational opening schedule considering controller availability, sector configurations, and sector capacities. The model can strike a balance between working time and overloads, employing a customizable optimization strategy. NEST can automatically determine the timeframe and capacity required to alleviate identified overloads. The model can be fine-tuned to replicate operational behaviors. Furthermore, NEST is capable of estimating ATFM delays for any scenario throughout the day, accounting for network effects.

Also, graphs can be generated to illustrate and compare airspace loads, entry rates, occupancy counts, conflicts, traffic mix, complexity, saturation, overload, delays etc.

Comprehensive metrics, encompassing factors such as route extension for flight efficiency (on a spherical Earth model), fuel consumption, capacity baselines, ATFM delay, route charges, CO_2 emissions, and NOx emissions, can be individually assessed or amalgamated to generate composite indicators [14].The program can analyze large amounts of data from multiple years, which gives them a strategic perspective to identify trends and conduct detailed analysis.

Users can modify any data using either the built-in editors or the powerful data import feature. All modifications are saved in the current scenario and shown in the data modification history. Users can undo, redo, and save the changes to a small scenario file. Scenario files store all the changes made to the 28 days of environment and traffic data that belong to an AIRAC cycle data set.

The application of the Eurocontrol NEST software helps in[15]:

- Optimization of Routes, identify and select relevant points in a way that optimizes routes for airspace users. Consider factors such as direct routing, fuel efficiency, and overall flight path optimization;

- Strategic Location, choose FRA relevant points strategically to facilitate the smooth flow of air traffic. These points should align with major air routes, waypoints, and air navigation infrastructure to support efficient route planning;

- Continuous Review and Update, FRA relevant points should be subject to continuous review and update based on changes in air traffic patterns, airspace demand, and technological advancements. Regularly assess the effectiveness of existing points and be prepared to make adjustments;

- Integration with Air Traffic Flow and Capacity Management (ATFCM), ensure that FRA relevant points are integrated into broader Air Traffic Flow Management systems. This coordination helps manage traffic flows, optimize airspace capacity, and prevent congestion;

- Safety Considerations, prioritize safety in the assignment of FRA relevant points. Consider factors such as airspace congestion, potential conflicts, and safety margins when determining the location and spacing of points.

Item Selection

Segments and navigation points from the current network can be selected on the map using a left mouse click (LMC). Only segments and navigation points from the "current network" can be selected on the map[14].

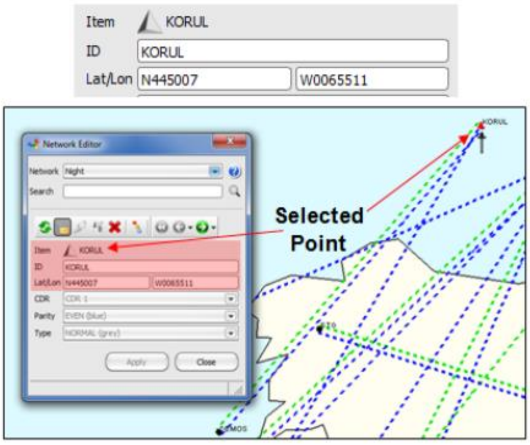

Figure 2.20 – Selected navigation point

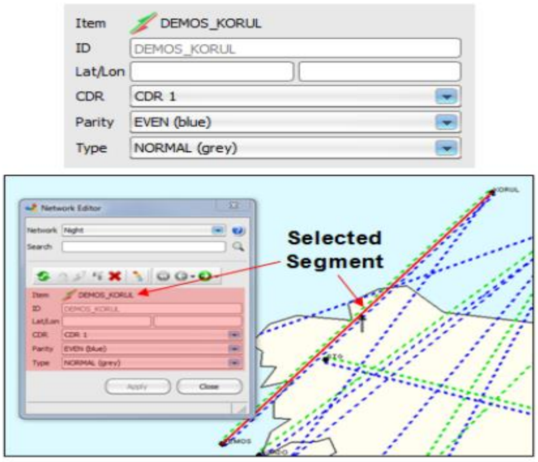

Figure 2.21 – Selected Segment

Segments and navigation points from the current network can be selected on the map using a left mouse click (LMC). Only segments and navigation points from the "current network" can be selected on the map[14].

Edit Displayed Airspace

The Airspace Editor allows creating and editing air blocks and elementary Sectors and can only edit the airspaces that are displayed on the map.

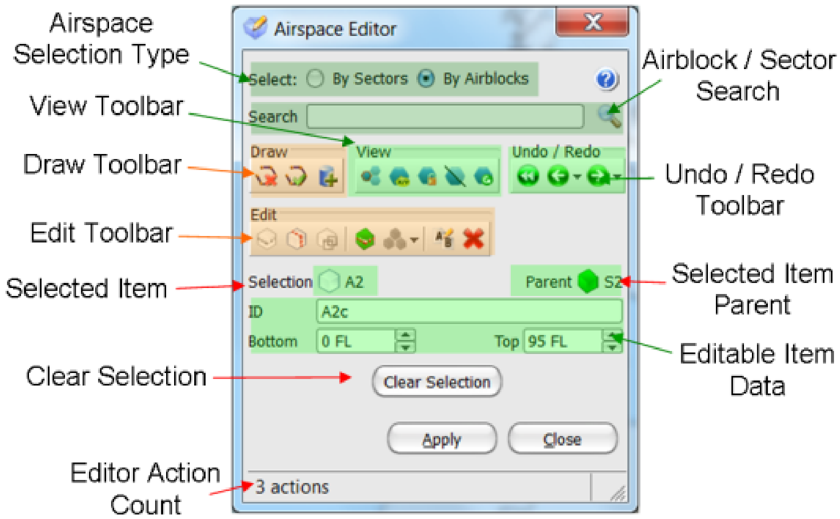

Figure 2.22 – Airspace Editor

There are one or more selected and unselected airspaces. In both 3D view and 2D edit modes, the limits of selected airspaces are shown by a translucent red line. An airspace selection click may target many airspaces, some of which may be concealed from view, especially in 2D edit mode. In this instance, the user can manually designate the airspaces to be picked by viewing the list of airblocks that is provided. It is possible to pick or unselect multiple airspaces simultaneously.

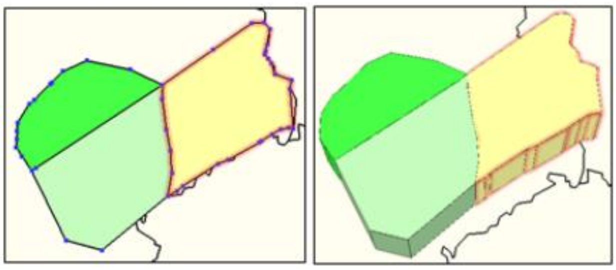

Figure 2.23 – Airspace selection in 2D Edit and 3D View mode

The map can be switched between the Edit and View modes using.

In *View mode* the map is in 3D, only airspaces can be selected, selected airblocks can have their upper and lower boundaries modified on the map and the camera position is unlocked, all map movements are possible including zooming, panning, tilting etc[14].

In *Edit mode* the map is in 2D with all airblock boundary points displayed as selectable items, the camera position is locked; by default no panning is allowed (please refer to general map options), both airspaces and vertices can be selected / unselected, selected boundary vertices of selected airspaces can be re-positioned on the map or deleted, new intermediary vertices can be inserted between existing boundary vertices of the selected airblock(s), new airblocks can be created from scratch[14].

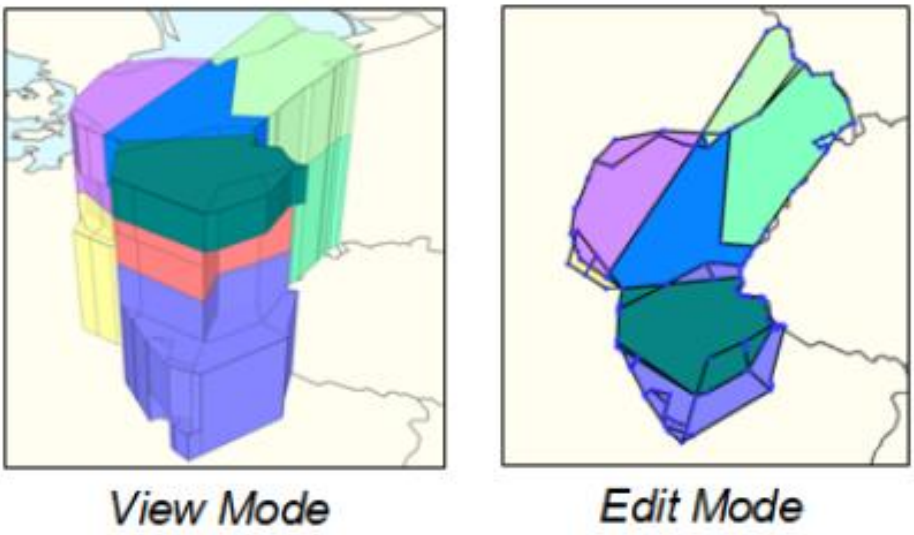

Figure 2.24 – 3D View Mode and 2D Edit Mode

Also, it is possible to create new vertices. The airblock describes the 2D polygon on the ground and the sector is defined using the new airblock from FL0 to FL095 by default. A snap-to-vertex feature automatically re-positions new vertices directly onto existing nearby vertices, thereby avoiding holes between neighboring airblocks[14]. Additional vertices may be inserted into the boundaries of an existing airblock . The vertices can be automatically inserted into all airblocks sharing a given boundary using grouped mode, thereby automating changes to neighboring airblocks. Airblock boundary vertices can only be moved once an airblock is selected. Also, a vertex can also be deleted. The list of selected airblocks determines which airblocks are impacted when a vertex is removed.

The airspace editor allows splitting an elementary sector at the split altitude in order to add two new upper and lower elementary sectors to the environment. The airspace editor will remain in split mode as long as the upper and lower sectors remain selected. Indeed the airspace editor automatically switches to split mode whenever two sectors sharing a DFL are selected.

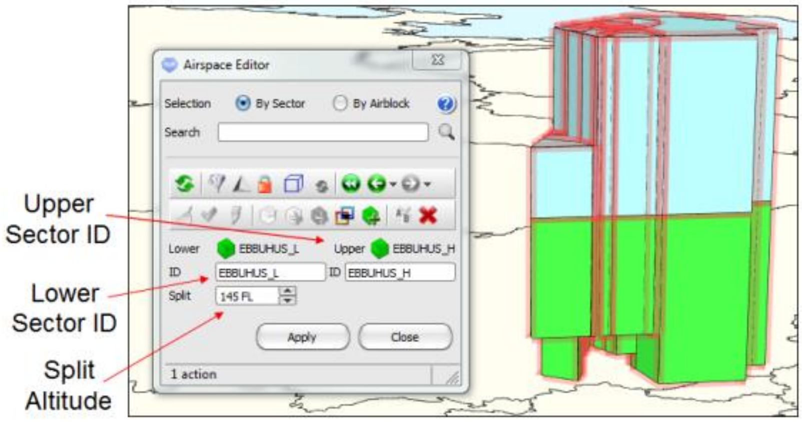

Figure 2.25 – Airspace Editor Interface in split sector mode

Simulate Trajectory

The trajectory simulation interface allows simulating new trajectories for a selection of flights by assigning them on the constrained route network and calculating a new flight profile. These simulated trajectories are then combined with the selected base trajectories to form a new simulated trajectory slot for all flights.

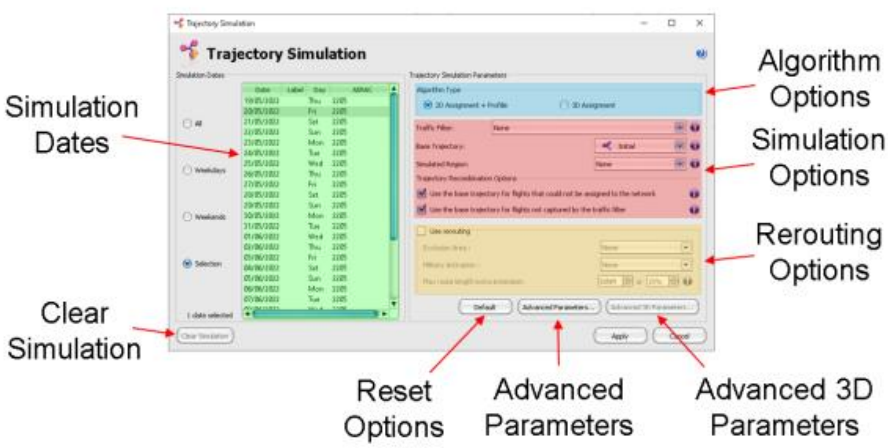

Figure 2.26 – Trajectory Simulations

The button “Clear Simulations” clears all previous trajectory simulation data and removes the "simulated" trajectory from the scenario. The trajectory simulation is run on all selected dates in the simulation date list.

There are two Algorithm Options *2D Assignment + Profile*(runs the trajectory simulation as a two-step process using the legacy Assignment and Profile algorithms) and *3D Assignment*(runs the trajectory simulation as a single-step process using an improved 3D Assignment algorithm which handles all network constraints simultaneously)

The Simulation Options includes the traffic filter(used to capture the list of flights for the trajectory simulation), base trajectory(to evaluate the list of captured flights when a traffic filter is used, to provide a reference trajectory when the regional simulation is used, to provide the default trajectories that are combined with the simulated ones to form a complete list of trajectories (i.e. one per flight) for the "simulated" trajectory slot), simulated region(the trajectory simulation will occur only inside the specified Region) and trajectory recombination options which includes "usage of the base trajectory for flights that could not be assigned to the network" and "usage the base trajectory for flights not captured by the traffic filter".

Simulated flight trajectories correspond to trajectories generated using internal assignment and profiling algorithms. These algorithms use the activated route networks and associated rules and restrictions as well as the aircraft performance characteristics. The simulated trajectory data is managed so that a re-simulation will be recommended if any of the simulation input data changes. Flights are assigned on the shortest available route by default.

The trajectory simulation process entails harmonizing a set of demand and network constraints. Occasionally, a small percentage of flights encounter challenges in meeting network constraints, including segment availability, permitted turn angles, segment penalization, etc., within the prescribed route length extension. These flights are called non-assigned or missing flights. The simulation results window displayed at the end of the trajectory simulation process indicates the number of non-assigned flights.

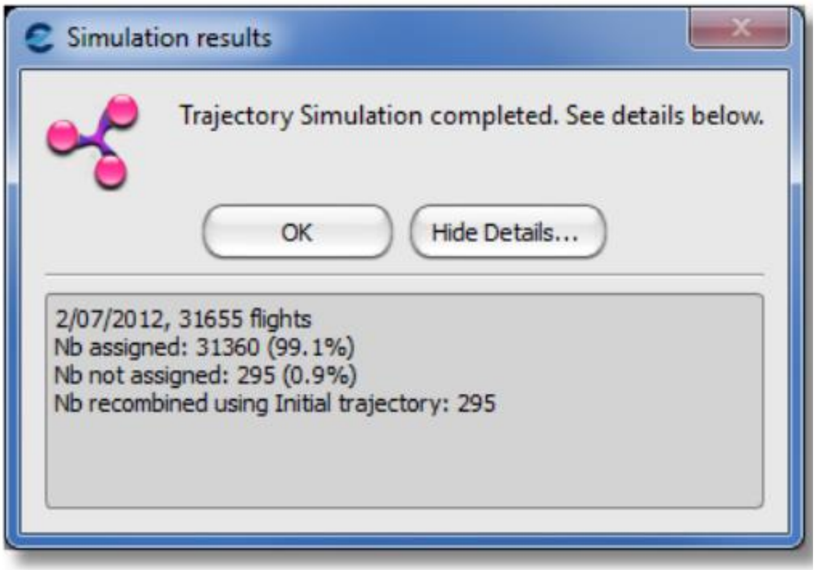

Figure 2.27 – Simulation Result

CONCLUSION FOR THE CHAPTER

This chapter has explored formal models and concepts related to Free Route Airspace (FRA) implementation. The main FRA principle is flexible routing between defined entry and exit points, with optional intermediate waypoints, without fixed airways. Benefits include reduced flight distances and emissions.

Models like "full FRA" and "FRA with Intermediate Points" provide frameworks for applying the concept. Rules govern vertical connectivity with adjacent airspace. Cross-border FRA further expands flexibility across borders.

Airspace design, flight planning processes, ATC systems and military coordination all need adaptation for FRA operations. A phased approach focuses on high-complexity areas first.

An "operationally driven approach" structures flows and identifies sector boundaries based on demand. Stepwise expansion from core areas to full FIR/UIR coverage is envisioned for Ukraine.

FRA relies on various formal models to systematically transform airspace architecture. Methodical phase-in combining technical upgrades, procedure updates, traffic analysis and regional agreements enables successful implementation. The concepts and frameworks covered lay the foundation to optimize routes throughout Ukraine's airspace.

NEST is scenario-based and allows users to model an unlimited number of operational planning options. It can create future traffic scenarios, compute flight trajectories, suggest optimal operational opening schemes, estimate ATFM delays, and generate various graphs and indicators. Users can easily modify data and save changes in scenario files. NEST is a valuable tool for optimizing routes, choosing strategic locations, continuous review and updating, integration with ATFCM, and prioritizing safety in airspace planning.

CHAPTER 3. TRIAL SIMULATIONS OF NEW FREE ROUTE AIRSPACE RELEVANT POINTS USING NEST SOFRWARE

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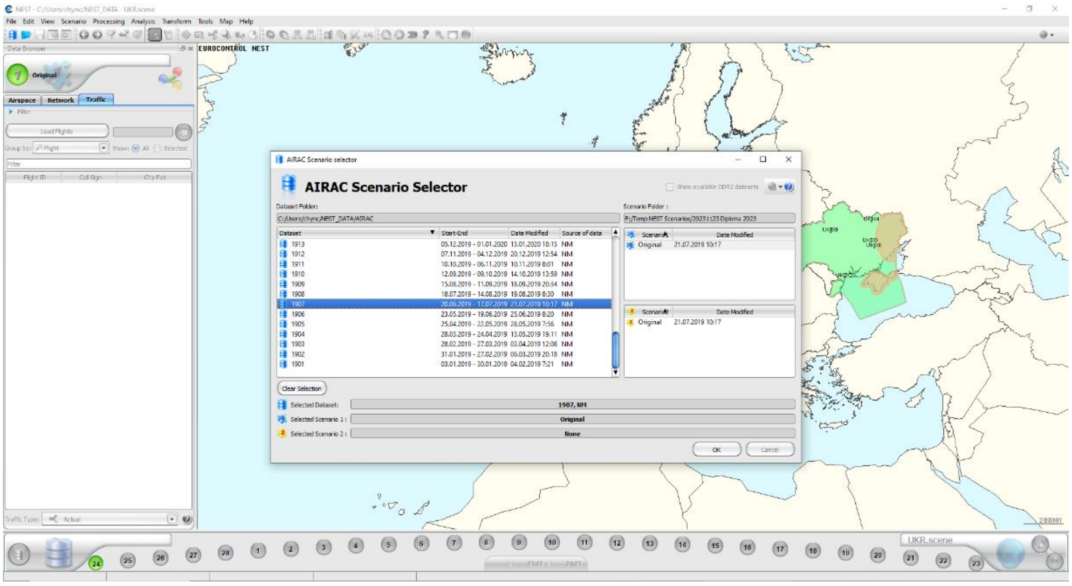
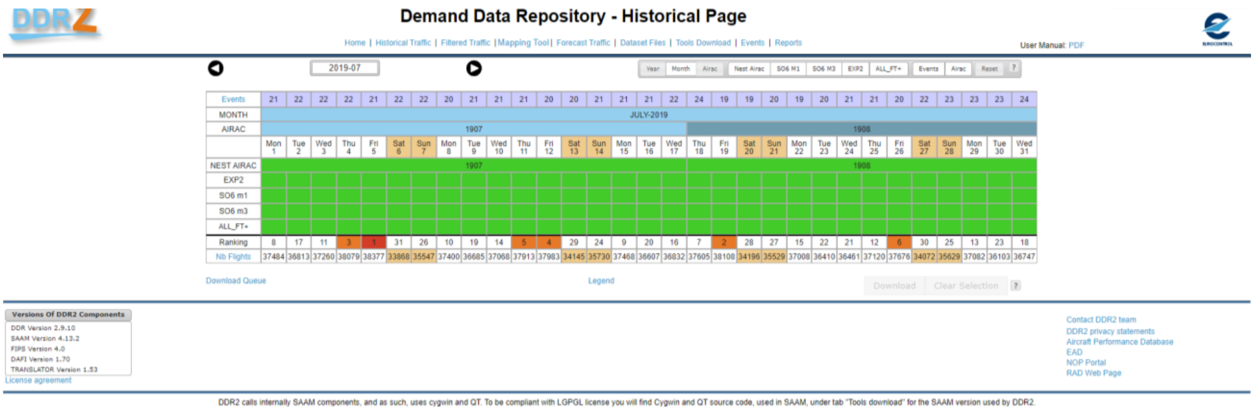
Simulation Environment Description





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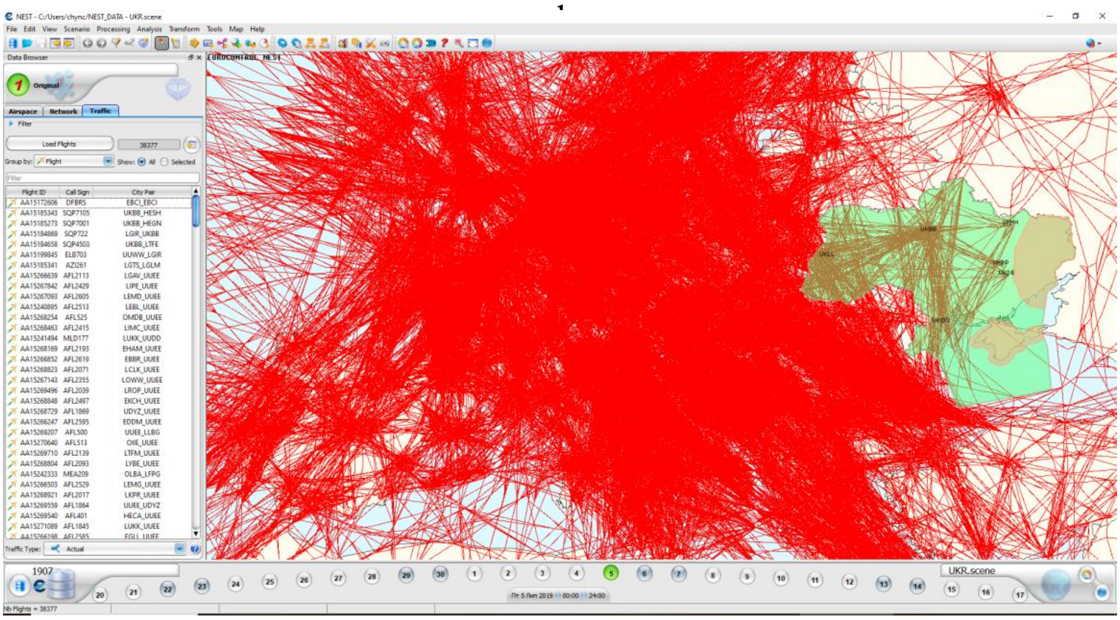
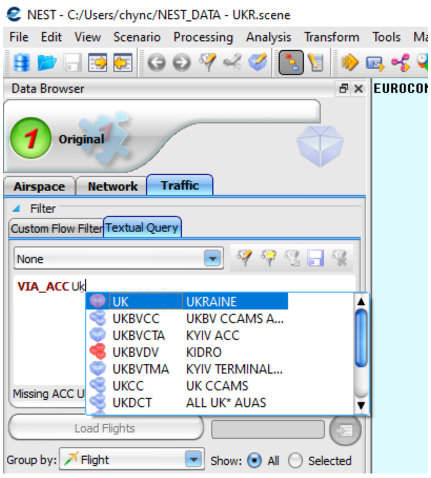
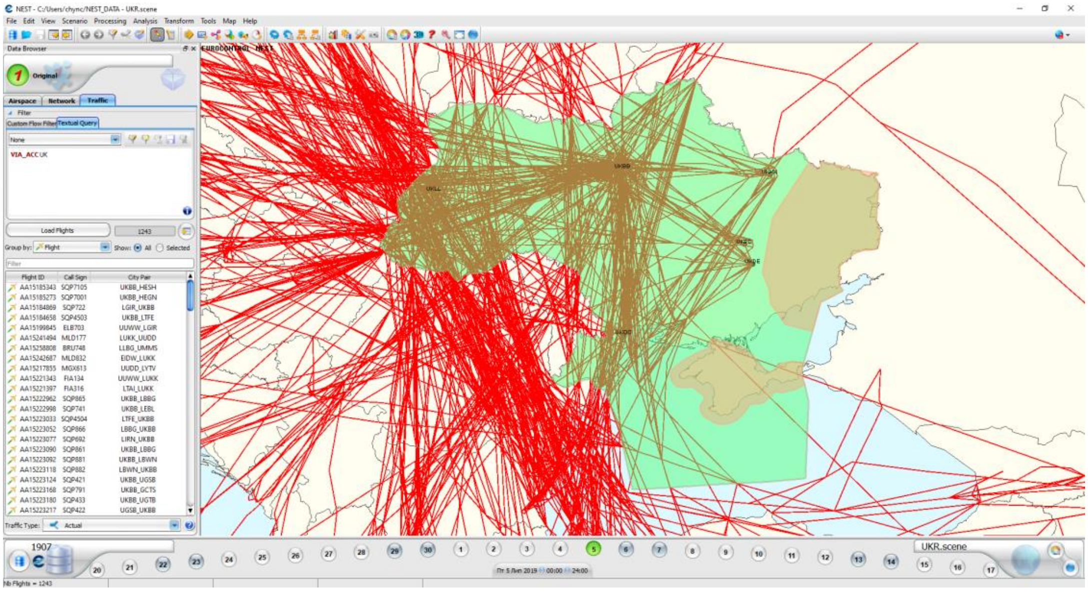
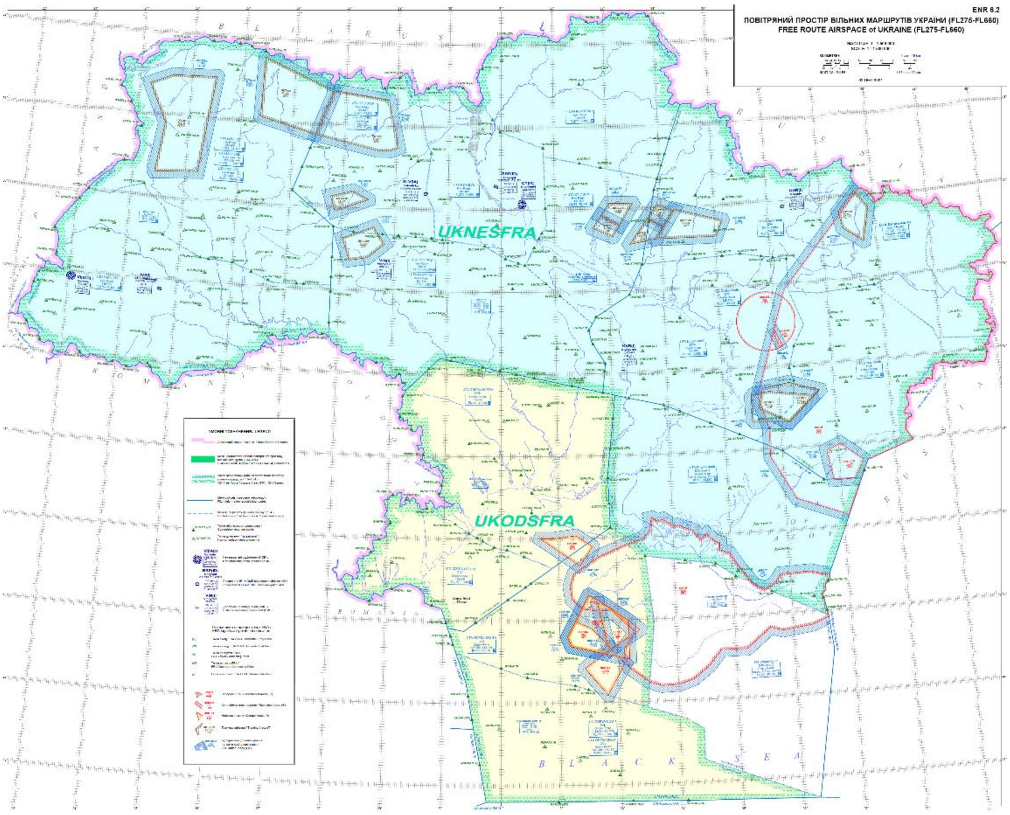




– The filter for modeling air traffic flows at interfaces with other countries



3.2 Simulation Process for defining new FRA points in adjacent interfaces



– FRAU interfaces with neighboring countries

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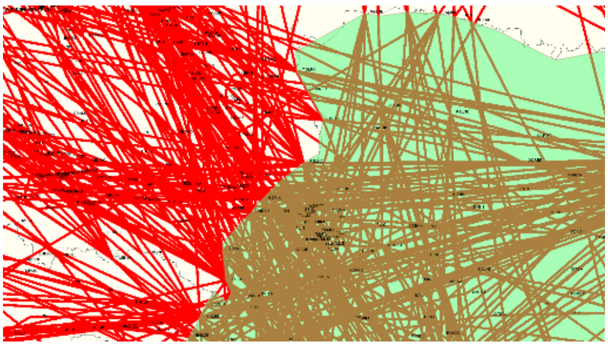
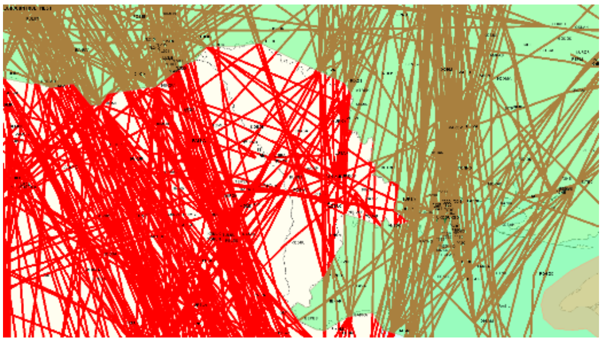
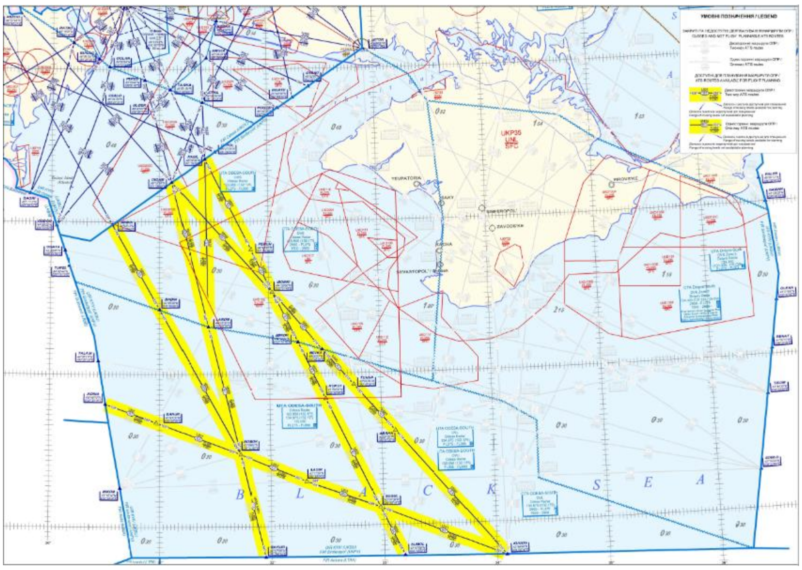




.8. – Interface with Moldova



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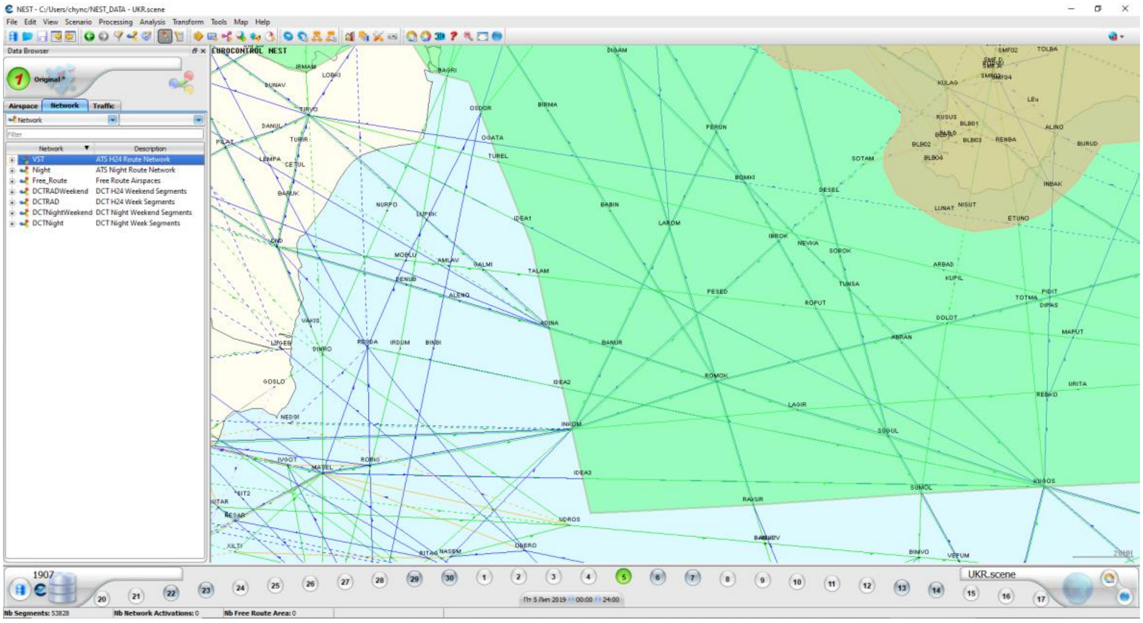
.9 – FRAU interfaces with Romania, Turkey, and Bulgaria



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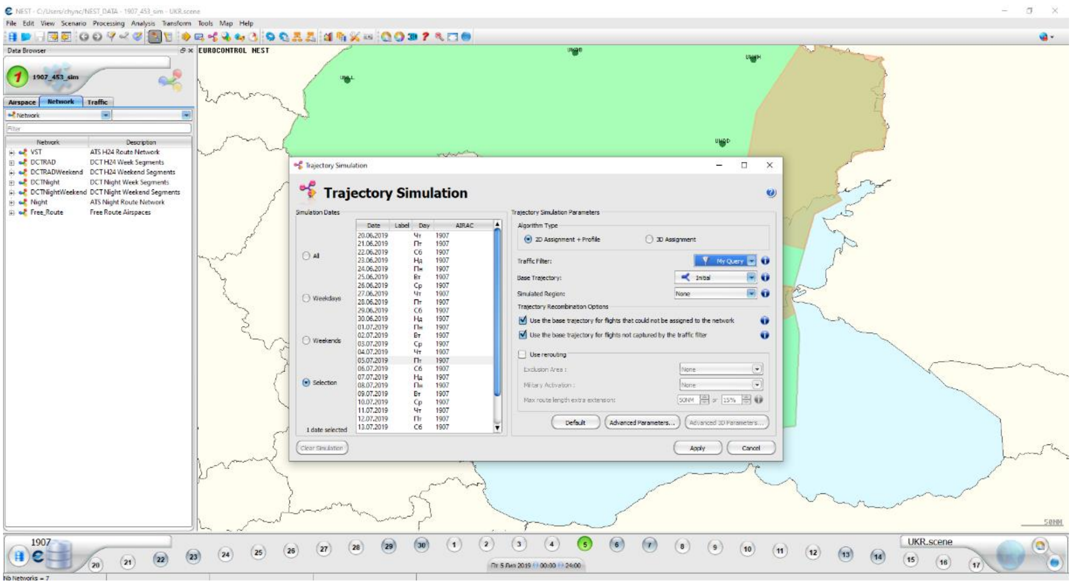
ATS H24 Route Network
ATS Night Route Network
Free Route Airspaces
UKR.scene



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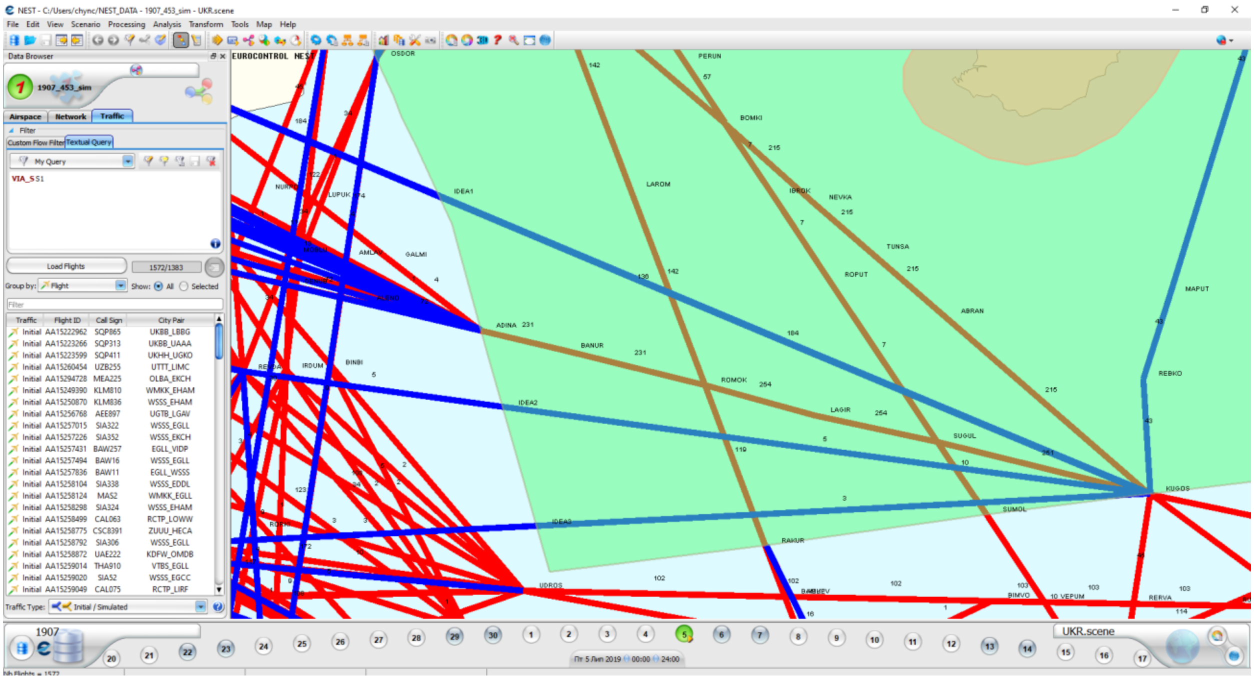


CONCLUSION FOR THE CHAPTER 3

In this chapter has demonstrated a simulation-based methodology for analyzing air traffic flows and defining new free route airspace points in Ukraine's airspace interfaces with neighboring countries.

The air traffic on July 5, 2019, was modeled using the NEST simulation environment, focusing specifically on flows to/from and transiting Ukraine. The results visualized the distribution of flights and enabled a quantitative analysis.

Based on studying the interfaces with Romania, Turkey, and Bulgaria which have potential for more traffic, three additional FRA points were proposed: IDEA1, IDEA2, and IDEA3. Further modeling tested these points and showed significant new traffic volumes: 184, 5, and 3 extra aircraft per day respectively.

Therefore the simulation approach was effective for hypothesizing and evaluating improvements to the airspace structure. The proposed FRA points demonstrate potential benefits for traffic flows and should be further coordinated with aviation stakeholders towards implementation.

Overall this methodology of simulation, analysis and proposing changes can serve as a general framework to optimize interfaces between airspaces and better accommodate growth in air traffic. It may be applied to different areas in future research, or it might include other criteria like environmental effect, efficiency, and safety.

CHAPTER 4. EFFICIENCY OF THE AVIATION SYSTEM

4.1 Statistical analysis. Correlation-regression analysis. Forecasting the efficiency of transportation.

– Predictive data

Years	x	Statistics (Number of flights)
2017	17	36,7
2018	18	37,8
2019	19	38,9
2020	20	16,9
2021	21	20,1
2022	22	27,7
2023	23	34,4

x.

$$y = b_0 + b_1 x,$$

Calculation of regression coefficients according to the formulas:

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

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

where

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

$-1 \le r \le 1$

n – amount of data.

The value of the correlation coefficient shows how the variables x and y are related (inverse (as the value of r is negative) weak (as the value of r is closer to 0 than to -1) relationship). That is, over time, the number of transported drones decreases.

A statistical analysis of transportation was made and, with the help of correlation-regression analysis, a forecast of transportation until 2028 was made (Table 4.2) using MS Excel.

Table 4.2 – Calculation of correlation and regression coefficients

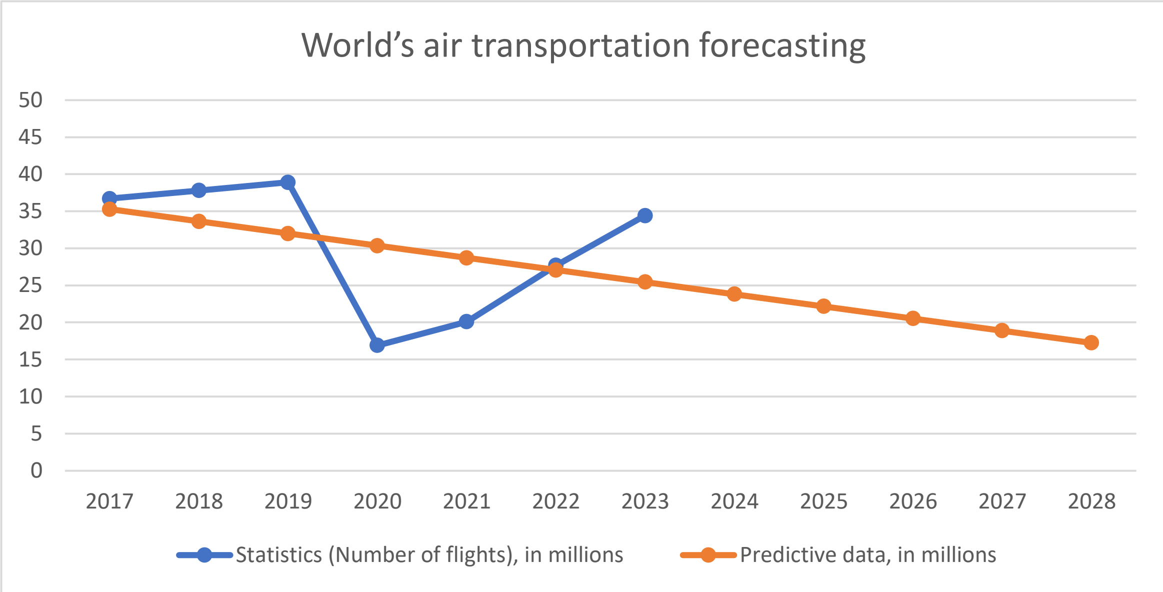
Transportation forecasting		
Years	**X**	**Statistics (Number of flights)**
2017	17	36,7
2018	18	37,8
2019	19	38,9
2020	20	16,9

2021	21	20,1
2022	22	27,7
2023	23	34,4
Correlation coefficient	**r**	**-0,396620992**
Regression coefficients	**b0**	63,143
	b1	–1,6393
regression equation (transportation model)	**y=b0+b1x=y = 63,143–1,6393x**	

world's air transportation. We received a transportation model for demand forecasting: y=b0+b1x=y = 63,143–1,6393x

Table 3 – Forecasted traffic data

Years	**x-conditional time unit**	**Predictive data, in millions**	**Statistics (Number of flights), in millions**
2017	17	35,2749	36,7
2018	18	33,6356	37,8
2019	19	31,9963	38,9
2020	20	30,357	16,9
2021	21	28,7177	20,1
2022	22	27,0784	27,7
2023	23	25,4391	34,4
2024	24	23,7998	
2025	25	22,1605	
2026	26	20,5212	
2027	27	18,8819	
2028	28	17,2426	



4.1 – World's air transportation forecasting

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4 **4.2 Evaluation of implementation effectiveness of implementing of new FRA points by the Expert Judgment Method.**

4 After conducting a survey of a group of experts, the results are processed. The initial information for processing is numerical data expressing the preferences of experts and the meaningful justification of these preferences. The purpose of the processing is to obtain generalized data and new information contained in a hidden form in expert assessments. Based on the processing results, a solution to the problem is formed. The presence of both numerical data and meaningful statements of experts leads to the need to use qualitative and quantitative methods of processing the results of group expert evaluation. The specific weight of these methods significantly depends on the class of problems solved by expert evaluation.

Depending on the goals of the expert assessment and the selected measurement method, the following main tasks arise when processing the survey results:

f a) construction of a generalized assessment of objects based on individual assessments of experts;

f b) construction of a generalized assessment based on a pairwise

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comparison of objects by each expert;

c) determination of relative importance of objects;

d) determining the consistency of experts' opinions;

e) determination of dependencies between rankings;

f) assessment of the reliability of processing results.

The rational use of information received from experts is possible provided that it is transformed into a form convenient for further analysis aimed at the preparation of PR. The form of presentation of expert data depends on the accepted criterion, the choice of which, in turn, is significantly influenced by the specifics of the investigated problem. So, the most important thing for us is to formalize this information in such a way as to help the LPR to choose one (or several) of the many actions that are most acceptable in relation to some criterion. If the expert is able to compare and evaluate possible options for actions, assigning a certain number to each of them, we will consider that he has a certain system of advantages. Depending on the scale on which these preferences can be set, expert evaluations contain a larger or smaller amount of information and have a different ability to mathematical formalization.

In cases where, as a result of the comparison, the studied objects can be placed in a certain sequence, taking into account any significant factor (factors), ordinal scales are used, which allow establishing equality or dominance. The use of ordinal scales allows us to distinguish objects even in those cases when the factor (criterion) is not specified in an explicit form, that is, when we do not know the sign of comparison, but we can partially or completely order the objects based on the system of preferences that the expert has (experts).

When solving many practical problems, it often turns out that the factors that determine the final results cannot be directly measured. The arrangement of these factors in order of increasing (or decreasing) importance is called ranking. The ranking allows you to choose the most significant factor from the studied set of factors. In this case, a ranking scale is obtained - a scale that contains elements arranged in order of importance.

When ranking, the expert must arrange the objects (parameters) in the order that seems most rational to him, and assign to each of them the numbers of the natural series - ranks. At the same time, rank 1 is given to the most acceptable alternative, and rank N is the least preferred. Therefore, the ordinal scale obtained as a result of ranking must satisfy the condition of equality of the number of ranks N of the number of objects n being ranked.

When evaluating research objects, experts often disagree on the problem to be solved. In this connection, there is a need to quantify the degree of agreement of experts - the consistency of the opinions of experts. Obtaining a quantitative measure of agreement allows for a more reasonable interpretation of the reasons for the difference of opinion. Using pairwise comparison methods, it is possible to find the rank correlation between the evaluations of each pair of experts.

Let's consider the algorithms for applying the method of expert evaluations and determining the weighting coefficients.

Algorithm No. 1 application of the method of expert evaluations

evelopment of a questionnaire for an expert and conducting an expert survey,

he structure of the matrix of individual preferences Anxn=(aii) (i=1,n)

Determination of the system of individual preferences of the j-th expert:

$$R_j = R_1 \square R_2 \square {}_3 \square \ldots, \; j=1$$

he structure of the matrix of group preferences: Anxm=(aii) (i=1,n,j=1,n)

Defining the system of group preferences according to the average value of the ranks of the group parameters:

$$R_{ãð} = R_1 \square R_2 \square {}_3 \square R_4 \square R_5 \square \ldots$$

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

Determination of the degree of agreement of the group of experts:

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

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

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

If ν < 33% - the experts' opinions are agreed, if ν > 33% - the experts' opinions are not agreed, it is necessary to repeat the expert survey or usethe Kendall concordance coefficient to determine the agreement of the experts' opinions on all parameters (procedures):

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

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

where t_j - the number of identical ranks in the j-th line, which waspresented by the j-th expert

- variance (total):

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

- average sum of ranks for each parameter:

$$\overline{R} = \frac{1}{n}\sum_{i=1}^{m} R_{ij}$$

If W = 0.6..0.7 - the agreement of experts' opinions is high, if W < 0.6 - itis necessary to repeat the expert survey.

etermination of the statistical significance of the concordance coefficient W according to the criterion χ^2

$$\chi_{\phi}^{2} = \frac{S}{\frac{1}{2}m(n+1) - \frac{1}{12(n-1)}\sum_{j=1}^{m} R} > \chi_{t}^{2}$$

inding the Spearman rank correlation coefficient to determine theconsistency of the j-th expert and the group of experts:

$$r_{s_{1}} = 1 - \frac{6\sum_{I=1}^{n}(x_{I} - y_{I})^{2}}{n(n^{2}-1)}$$

tatistical significance of Spearman's rank correlation coefficientaccording to Student's test

$$t_{\phi} = r_{s}\sqrt{\frac{n-2}{1-r_{s}^{2}}} > t_{st}$$

btaining a model of the significance of the studied parametersaccording to the agreed system of group preferences of experts:

$$R_{ăð} = R_{1} \square\ R_{2} \square\ _{3}\square\ R_{4} \square\ R_{5} \square\ \ldots$$

Algorithm No. 2 determination of weighting factors

1. Definition of the system of group preferences of experts

$$R_{\tilde{a}\eth} = R_i \; ⊠ \; R_{i+j} \dots$$

2. Determination of weighting factors:

$$\omega_i = \frac{C_i}{\sum_{i=1}^{n} C_j},$$

where, $C_i = 1 - \dfrac{R_{ij} - 1}{n}$ - the estimate obtained under the assumption of the hypothesis of a linear relationship between the rank and the relative value of the parameter;

R_{ij} - rank *i*-th of parameter;

j-th expert ($R_{i\,гр}$ – Ranks of expertgroups).

$$\sum_{i=1}^{m} w_i = 1,$$

Evaluation of the decision support system based on criteria is considered:

Experts (22 experts) assessed the significance of the system.

Average (opinion of a group of experts):

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

Root mean square deviation:

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

Coefficient of variation:

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

The calculations are presented in table 4.4.

Table 4.4 – Determining the effectiveness of implementing of new FRA points

Experts	Criterias			
	Safety	Regularity	Efficiency	Economy
	w_1	w_2	w_3	w_4
1	1	4	2	3
2	1	3	2	3
3	2	4	3	2
4	2	3	1	3
5	1	3	1	2
6	1	4	2	4
7	4	3	2	3
8	4	3	2	3
9	4	3	1	3
10	3	1	3	2
11	1	4	1	2
12	2	4	3	2
13	1	2	3	2
14	3	1	3	1
15	4	2	3	2
16	1	4	1	4
17	3	2	3	4

18	2	4	2	3
19	1	3	4	2
20	1	3	3	3
21	1	3	4	2
22	1	3	3	3
R_{rp}	2	3	2,363636364	2,636363636
D_i	1,428571	0,857142857	0,909090909	0,623376623
δi	1,195229	0,9258201	0,953462589	0,789542034
V_i, %	59,7613	30,86066999	40,33880185	29,94814612
c	0,75	0,5	0,6590909	0,590909091
w	0,3	0,2	0,263636364	0,236363636

Correlation coefficients are less than 33%, that is, the opinion of experts is agreed. The importance of the criteria is presented in Figure 4.2.

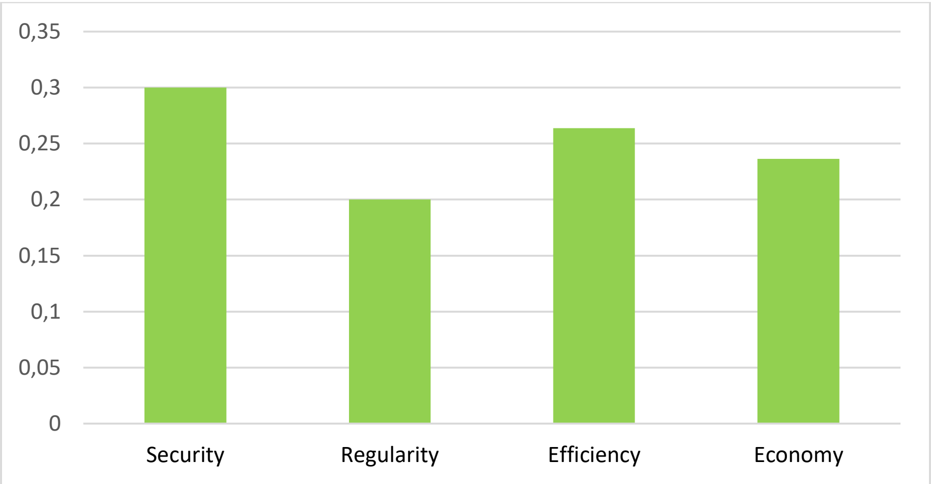

Figure 4.2 – System efficiency according to the criteria.

CONCLUSION TO THE CHAPTER 4

This special section consists of two sub-sections. The first part of the special

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The second section the determining the effectiveness of implementing of new FRA points based on the Expert Judgment Method. The article analyses the step-by-step application of this method along with the formulas used at each stage. The calculation of the specific case is presented in the second part of the section, where a table with calculations is provided. In addition, the table contains data on the opinions of 22 experts and their assessment of the effectiveness of the system for assessing the risk of losing echeloning standards. After that, we determined the opinion of the group of experts to determine the following indicators: variance, standard deviation, and coefficient of variation. Finally, we determined the weighting factor and created a graph showing the criterion that, according to experts, is the most effective in the system.c

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CHAPTER 5. LABOR PRECAUTION AND ENVIRONMENT SAFETY

5.1 Rules for working with computers

[16]

Keep the room constantly ventilated: Fresh air and regular cleaning can work wonders. And fresh, cool air helps you to get up and get in the mood for productive work. Fresh air has also been scientifically proven to help overcome drowsiness and moodiness.

Clean your monitor: It is not recommended to leave fingerprints or stains on your monitor. You should also wipe off dust and dirt from your computer using microfibre and special sprays or wipes. The monitor should be placed 70-80 cm from your face and below eye level.

Frequent blinking: Do not forget to blink when you're working at a computer for a long time. Blink every 5 seconds if you feel your eyes are overstretched. This massages your eyes and helps moisturise the cornea.

Focusing your eyes: To "sharpen" your eyes, go to a window and focus your gaze first on near objects, then look into the distance. These exercises will help your eyes rest and recover.

:

. When working with a PC, it is prohibited to[16]:

- disassemble or repair the system unit (laptop case), monitor, keyboard, computer mouse, etc;
- insert foreign objects into the ventilation openings of a PC, laptop or monitor;
- place metal objects, containers with water (vases, flower pots, glasses) on the PC system unit and peripheral devices, as water ingress into the device may cause a fire or electric shock.

The duration of continuous work at a PC should not exceed 2 hours. After that, take a 15-minute break. If you experience visual discomfort or other unpleasant sensations, take a short break. To reduce nervous and emotional stress, visual analyser fatigue, improve cerebral circulation, overcome the adverse effects of physical inactivity, and prevent fatigue, it is advisable to perform a set of exercises during several breaks.

5.2 Safety requirements in an emergency situation

Emergency and dangerous situations during PC operation may occur in the following cases: short circuit, overload of the system unit power supply, overheating, fire, chair breakdown, etc.

In the event of an accident or a situation that may lead to an accident, immediately disconnect the PC from the power supply and report the incident to your supervisor. Do not allow unauthorised persons to enter the hazardous area.

Keep the environment in the work area and equipment in the same condition as they were at the time of the accident (unless it threatens the life and health of other employees and leads to more serious consequences). Inform the work supervisor (other responsible person of the enterprise) about the incident and follow his/her instructions. Take measures to prevent similar incidents in the future.

In the event of a fire (signs of burning), inform the supervisor and, if necessary, call the emergency service by calling 101 or 112 (name the address and location of the fire, the presence of people, give your name) and take all possible measures to evacuate people, extinguish (localise) the fire with available fire extinguishing equipment. Remember to extinguish live electrical devices only after they have been disconnected from the power supply. Extinguish with carbon dioxide or powder fire extinguishers, and in some cases with dry sand.

CONCLUSION TO THE CHAPTER 5

Working at a computer if you do not follow safety rules can have a negative impact on your health - cause diseases of the spine, eyes, blood vessels, etc.

There are clear recommendations on how to organize a workplace to minimize the harmful effects of the computer - proper posture, adequate lighting, ventilation, screen cleanliness, etc.

It is important to take regular breaks from work, perform physical exercises for the eyes and body, and change the type of activity to reduce stress and prevent fatigue.

There are clear restrictions on the duration of continuous computer work - no more than 2 hours in a row.

Safety rules have been defined in case of emergencies while working with a PC: immediately switch off the power, notify a responsible person, keep outsiders out of the danger zone, etc.

Thus, compliance with the established labour protection requirements will minimise the risks to the health of employees when working at a computer.

GENERAL CONCLUSION

In the course of implementation this work has explored techniques for optimized flight planning through enhanced design of Free Route Airspace structures. Efficient airspace is critical as demand grows, and improved route flexibility unlocks benefits.

First, the European air traffic situation was analyzed. Though flows are rebounding post-pandemic, infrastructure strains pose challenges. However single sky initiatives like Free Route Airspace aim to transform efficiency. FRA principles enable flexible routing, conditional only on fixed entry/exit points.

Models help formalize Free Route Airspace systems. Options include full FRA with unpublished intermediate waypoints or restricting to published points only. Vertical connectivity considers interfaces between FRA and fixed route networks. Cross-border FRA expands flexibility across state boundaries. Adapting flight planning, ATC systems, airspace configurations and military coordination are implementation factors.

Advanced software assists analysis. The Eurocontrol NEST tool models complex scenarios for traffic forecasting, what-if evaluations, and optimization. Its assignment algorithms and custom editors empower strategic evaluations.

So, air traffic on particular day, 05.07.2019 was modeled using the NEST simulation environment. Based on studying the interfaces with Romania, Turkey, and Bulgaria which have potential for more traffic, three additional FRA points were proposed: IDEA1, IDEA2, and IDEA3. Further modeling tested these points and showed significant new traffic volumes: 184, 5, and 3 extra aircraft per day respectively.

Therefore the simulation approach was effective for hypothesizing and evaluating improvements to the airspace structure. The proposed FRA points demonstrate potential benefits for traffic flows and should be further coordinated with aviation stakeholders towards implementation.

Overall this methodology of simulation, analysis and proposing changes can serve as a general framework to optimize interfaces between airspaces and better accommodate growth in air traffic. It may be applied to different areas in future research, or it might include other criteria like environmental effect, efficiency, and safety.

Both theoretical foundations and practical tools are delivered for airspace planning. The framework developed serves Ukraine’s FRA evolution while benefiting international aviation.

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