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UTILIZATION OF FLEXIBLE AIRSPACE STRUCTURE IN FLIGHT EFFICIENCY OPTIMIZATION

ABSTRACT

With increasing air traffic demand in the Pan-European airspace there is a need for optimizing the use of the airspace structure (civilian and military) in a manner that would satisfy the requirements of civil and military users. In the area of Europe with the highest levels of air traffic (Core area) 32% of the volume of airspace above FL 195 is shared by both civil and military users. Until the introduction of the concept of flexible use of airspace, flexible airspace structures were 24 hours per day unavailable for commercial air transport. Flexible use of airspace concept provides a substantial level of dynamic airspace management by the usage of conditional routes. This paper analyses underutilization of resources, flexible airspace structures in the Pan-European airspace, especially in the south-eastern part of the traffic flows (East South Axis), reducing the efficiency of flight operations, as result of delegating the flexible structures to military users. Based on previous analysis, utilization model for flexible use of airspace is developed (scenarios) with defined airspace structure. The model is based on the temporal, vertical, and modular airspace sectorisation parameters in order to optimize flight efficiency. The presented model brings significant improvement in flight efficiency (in terms of reduced flight distance) for air carriers that planned to fly through the selected flexible airspace structure (LI_RST-49).

KEY WORDS

flight efficiency, flexible airspace structure, utilization model, System for traffic Assignment and Analysis at a Macroscopic level (SAAM)

1. INTRODUCTION

According to the EUROCONTROL Performance Review Commission between 1999 and 2009 air traffic increased by 18%, effective capacity increased by 48%, while average ATFM delay per flight decreased by 79%. In the period between 2004 and 2009 there was increase in air traffic by 7.7%, increase of effective capacity by only 6.7% and increase of average ATFM delay per flight by 6.7%. The traffic demand in 2010 had an average of 26 329 flights per day. In the year 2010 there was a decrease of effective capacity by 9.3% across the European network in comparison with the year 2009 [1, 2].

The length of the route network in Europe is 3.46% higher than the hypothetical optimal route network length - the shortest distance between all entry/exit points of terminal airspace in Europe in 2009. The average flight distance extension in 2009 was 25.7 NM/flight. The part of the flight on route (en-route) influenced by the specific routing regime results in the extension of flight distance by 17.4 NM/flight, while the design of terminal airspace influences the extension of the flight distance by 8.3 NM/flight. In terms of airspace design efficiency, if all the aircraft used the route network without any restrictions, and if the conditional routes (CDR) were always available for usage there would be a total reduction in average flight distance by 0.5 NM/flight on the network level. If this value was interpolated into a balance, the total flight distance reduction would amount to 4.4 million NM per year, while the daily flight distance using the routes

with no restrictions would be reduced by 12,000 NM [3, 4].

In the European airspace there are more than 150 commercial air carriers with a fleet of 4,650 aircraft. In 2010 air traffic in Europe increased by 0.9% to 9.49 million flights per year compared to 2009, when a great economic crisis significantly affected the commercial air traffic.

According to EUROCONTROL in 2009 in Europe there were 11,621 military aircraft, while civilian users had a fleet of 4,650 aircraft.

On the average, in one year, in the European core area the flexible airspace structures are allocated to civil users 74% of the time while 26% of the time is allocated for military operations [5]. In EUROCONTROL study, the following activities are specified:

- in traffic most loaded part of European airspace 32% of airspace volume above flight level FL195 is used as a so-called flexible airspace structure;
- approximately 96% of general air traffic (GAT) operates between 04:00 and 22:00 UTC (yield over a period of 18 hours);
- flexible airspace structure is available for civil users 199 days, while the military activities are carried out 246 days a year;
- flexible airspace structure is reserved, on the average, seven hours and used only three hours a day by military users;
- civil users can use flexible airspace structure for 11 hours a day in those 246 days reserved by military users.

2. FLEXIBLE AIRSPACE STRUCTURE INFLUENCE ON FLIGHT EFFICIENCY

Airspace structure presents airspace designed to secure safe and optimal operation of aircraft. The basis of FUA (Flexible Use of Airspace) concept is that airspace should not be regarded as entirely civil or military airspace but as a continuum. The use of airspace should be based on a daily basis, where any necessary temporary segregation of airspace is done according to the actual operational requirements in real time. Flexible airspace structures are those structures that are temporarily allocated and/or used [6].

There is a number of different interpretations and definitions of flight efficiency, where every participant in air traffic has their own perception of effectiveness of flight. The most common definition used in scientific research is the following: flight efficiency presents the difference between the distance of the actual flight path and the possible distance of the direct flight path, which connects the entry and exit points for the selected airport, and is presented as additional mileage, additional travel time, additional fuel consumption and further increase of the cost of airline operators.

Flight efficiency consists of a horizontal (flight distance) and vertical component (difference in the altitude of flight). Horizontal component performance indicators of flight efficiency relate to the difference between the actual distance of flight and great circle distance, assuming that each flight is the only aircraft in the system, and that it is not subject of any restrictions [7, 8].

Since this research deals with the impact of flexible airspace structure on the flight efficiency, a detailed analysis of the use of flexible airspace structure in Europe was conducted. The use of flexible airspace structure has been analysed through the availability of planning and utilization of conditional routes (CDR). Conditional routes are being implemented through the flexible airspace structure (TSA / TRA). The use of conditional routes CDR 2 and CDR 1/2 in 2010 compared to 2007 increased by 36.84%. Between 2007 and 2010 flight efficiency achieved by using conditional routes CDR 2 and 1/2 increased to 43.62%.

3. FLEXIBLE AIRSPACE STRUCTURE UTILISATION MODEL

Factors that influence the definition of the flexible airspace structures utilisation model are: the organization and design of airspace (civil and military), civil user's requirements, and requirements of military users. All these factors can branch out into specific sub-factors.

For the identification of flexible airspace structure that is affecting the civil operators it is important to analyse the delays in air traffic. In Europe, 90% of ATFM delays along the route are generated by the 17 en-route air traffic control centres (in Europe there are 67 ACCs) which control 37% of all flight hours in Europe. EUROCONTROL in its report emphasizes that the area of south-east flow (South East Axis) with 16.7% of all ATFM delays in Europe is one of the main areas where the application of new methods and concepts can significantly reduce ATFM delay per flight [1].

When observing the characteristics of traffic demand of civil airspace users for this research, the vertical distribution of traffic in Europe is very important. Flight levels from FL 320 to FL 380 are the ones that are used most in the ECAC area.

National interests require from the military air force to be capable, efficient, and to be able to cope with unpredictable scenarios. The distance from the base to the military airspace structures (TSA / TRA) should be reachable to all military aircraft (which operate in a given airspace structure) with a maximum amount of fuel. Also, the amount of fuel used for certain missions should include, apart from the quantity of fuel required for transit between military bases and airspace structure, additional fuel required for the performance

Table 1 - Military airspace requirements

	Event	No A/C	Min Horizontal (NM)	Min Vertical (ft)	How often	Duration (min)
Country A	Aircraft handling and missile evasive manoeuvring	1	15 x 15	15,000	Daily, up to 6x	20
	Aircraft handling	1	30 x 15	15,000	Daily, up to 6x	20
	Formation	2 do 4	30 x 30	10,000	Several times a week	30
	Interception	2	30 x 60	30,000	Daily, up to 6x	60
	Supersonic *	2	60 x 90	30,000	Weekly	20
	Basic fighting manoeuvre	2	30 x 30	30,000	Daily, up to 6x	60
	Air combat manoeuvre	3	30 x 30	30,000	Daily, up to 6x	60

* flexible airspace structure lower limit starts at altitude of 10,000ft ASL, and 36,000ft above terrain

of selected military missions within the selected structure of airspace. The meteorological conditions play a major role in air traffic, especially in the military part of air traffic, where a large number of operations are conducted in visual meteorological conditions (VMC) [9, 10].

Sufficient airspace to be used for military operations is considered to be an area that can accept a certain number of aircraft (depending on the military mission) at any time for the purpose of training, weapons testing, development of strategic and tactical capabilities. It should be noted that sufficient volume of airspace used for military missions in one country is not necessarily sufficient in another country. In Table 1 there is a description of minimum requirements for the volume of airspace in relation to specific military missions. Due to the sensitivity of data, the country's name is not presented. All data

provided in this table are credible and trusted by military experts in international organizations (NATO and EUROCONTROL).

Based on the above described factors that influence the use of flexible airspace structure, a model was developed for using the abovementioned structures that will improve flight efficiency and reduce negative impact of civil air traffic on the environment (Figure 1).

In the first step of the model development it is necessary to collect and analyse the information about the airspace user requirements. Civil airspace users requirements (traffic demand) affects the definition of traffic flows in Europe.

In the second step there is a definition and analysis of traffic flow of civil and military user requirements. Analysing the military airspace user requirements the conclusion was made that it is most important to meet

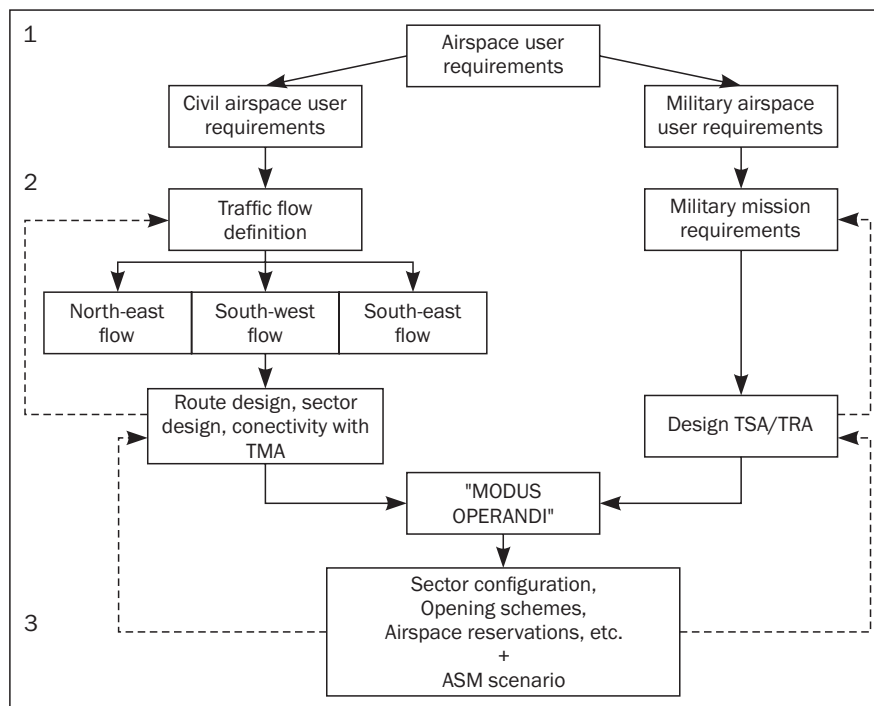


Figure 1 - Model for flexible airspace structure utilisation

the following requirements: that a flexible airspace structure is close enough in relation to the military base, the volume of flexible airspace structure is sufficient for the military mission, and to ensure the required period of time for usage of the flexible airspace structure.

In the third step based on the requirements of civil and military users, en-route network design, definition of ATC sectors and design of flexible airspace structure is performed. When designing ATS routes, air traffic control sectors and flexible airspace structure following factors should be taken into account: the predefined flexible routing options and/or optimized flight trajectories and optimum sectorisation of airspace that would be able to dynamically adjust according to air traffic flows. It should be noted that the organization and method of operation of ATM network (“modus operandi”) which includes sector opening scheme, sector configuration, Conditional Route (CDR) availability, reservation of flexible airspace structures and routing scenarios, primarily affects the requirements of civil and military users. In addition to the above-mentioned factors affecting the organization and func-

tioning of the ATM network, this model incorporated so-called scenarios of flexible airspace structures utilization (ASM scenarios).

The ultimate objective of these scenarios, which will be described in more detail in the next chapter, is the development of flexible airspace structure that will allow different airspace users to fly on selected routes and flight paths with efficient airspace organization and safe operations.

4. AIRSPACE MANAGEMENT SCENARIOS VALIDATION

The validation of the ASM scenarios was performed using SAAM simulation program (System for Traffic Assignment and Analysis at a Macroscopic level) that is used for modelling and analysis of the airspace and en-route network, aiming to improve the organization of traffic flows, en-route network, and airspace structure [11].

On the basis of interviews with airspace design and airspace management experts in the South-east traffic

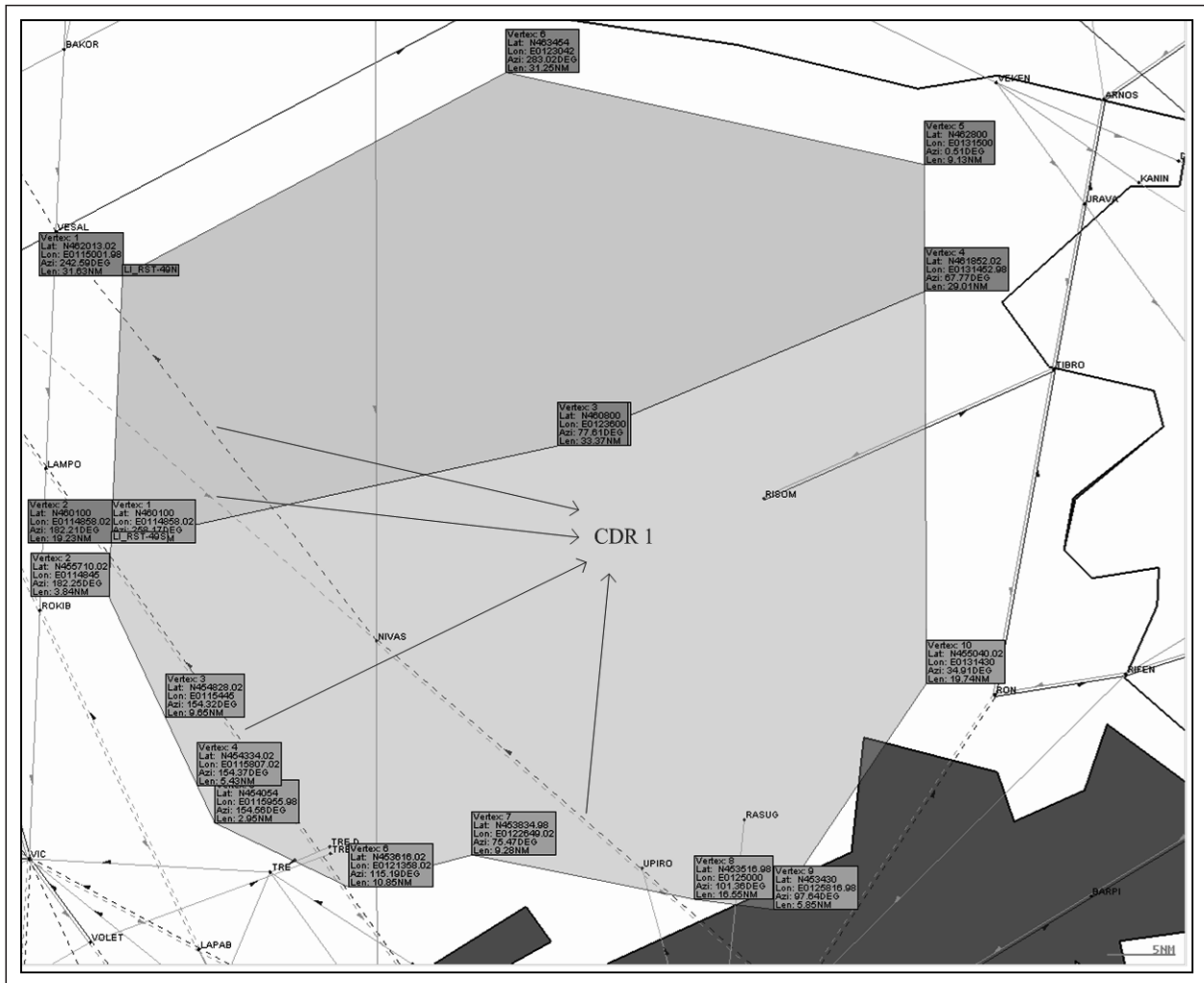


Figure 2 - Flexible Airspace Structure Zita (LI_RST-49)

Table 2 - Traffic sample and activation periods

August 2010					
Year: 2010, AIRAC: 337					
Day	Mon	Tue	Wed	Thu	Fri
Date	23	24	25	26	27
Ranking	8	11	7	2	1
Flight No	30 623	30 121	30 861	31 338	31 855
Activation Period	0900 - 1100 (FL 290-FL340), 1200 -1400 (FL290-FL370)	0700 - 0800 0900 - 1000 1130 - 1400 1830 - 2000 (FL290-FL370)	0	1530 - 1630 (FL290-FL370)	0800 - 1000 (FL290-FL370)

flow, flexible airspace structure Zita (AMC manageable area LI_RST-49) was identified and found suitable for this research (Figure 2). The data on Zita activation time periods were obtained by the Italian Airspace Management Cell of Air Navigation Services (Enav) and Italian military forces.

The traffic sample which is used in the simulation is Model 1, and it contains data with details of flight plans that are corrected by the Central Flow Management Unit (CFMU). In addition to selecting the traffic sample it is important to select the route network that corresponds to the time period of the selected traffic sample (Table 2).

The methodology that evaluates the impact of AMC Manageable area LI_RST-49 on flight efficiency is divided into six steps:

- Step one: Create *reference scenario* with current LI_RST-49 airspace design where there is *no military activity* in LI_RST-49 area,
- Step two: Create *current scenario* with current LI_RST-49 airspace design with *military activity* in the LI_RST-49 area,
- Step three: Create *solution scenarios with advanced military use of LI_RST-49*, when there are military activities in the LI_RST-49 area:
 - vertical,
 - time-related.
- Step four: Create *solution scenarios with re-designed LI_RST-49* when there are military activities in the LI_RST-49 area:
 - Airspace re-design:
 - LI_RST-49
 - Lateral,
- Step five: Create *solution scenarios with different modularity and modus operandi for LI_RST-49*.

Reference scenario represents the best possible situation for civil air traffic flying through the LI_RST-49 airspace, because the Assignment process in SAAM does not include the activation of the LI_RST-49, thus allowing civil air traffic to cross the LI_RST-49 airspace volume without imposing any restrictions and rerouting of the flights.

The number of aircraft that flew through the airspace volume LI_RST-49 in the selected time period ranged between 200 and 230 aircraft per day. This number of aircraft that flew through the LI_RST-49 airspace will be used as traffic sample for the actual and modified scenarios. Since on 25th of August 2010 (Wednesday) there was no military activity in LI_RST-49 airspace, for that day the simulation was not performed. Also for 28th of August 2010 and 29th of August 2010 the simulation was not performed because military air forces in Europe do not operate during weekends. Analysing the Reference scenario it can be seen that the majority of aircraft flying through LI_RST-49 are flying on flight levels from FL320 to FL360. On the basis of these findings the vertical shift of activated volume of airspace LI_RST-49 has been proposed.

Table 3 - Total number of A/C and flight distance of A/C that cross LI_RST-49

Date	Number of A/C through LI_RST-49	Flight distance (NM)
23/08/2010	211	302,799.2
24/08/2010	221	336,638.8
26/08/2010	228	333,687.2
27/08/2010	203	269,978.8

Table 3 presents the total distance of all flights that fly through LI_RST-49 airspace. The data from Table 3 will be used for the comparison with the actual distance of flights that fly through LI_RST-49 airspace, thus indicating the impact of flexible airspace structure LI_RST-49 activation on the flight efficiency.

The traffic demand that is used in the Current scenario is the same traffic demand as in the Reference scenario. The share of regulated flights in the total number of flights refers to the number of flights that had to fly through LI_RST-49 in the period when a certain volume of airspace LI_RST-49 was activated (Table 4).

The objective of the comparison of Reference (no military activity) and Current scenario (military operations) is to identify the impact of flexible airspace structure LI_RST-49 on flight efficiency of civil opera-

Table 4 - Total number of A/C and flight distance of A/C that fly through LI_RST-49 in Current scenario

Date	Original flights		Regulated (rerouted)		Total flight distance (Dist 1+Dist 2) (NM)
	A/C No	Distance 1 (NM)	A/C No	Distance 2 (NM)	
23/08/2010	184	272,052.7	27	30,860.7	302,913.4
24/08/2010	154	248,249.8	67	88,731.4	336,981.2
26/08/2010	219	320,701.7	9	13,037.3	333,739.0
27/08/2010	188	253,782.8	15	16,272.7	270,055.5

Table 5 - Comparative analysis of Reference and Current scenario

Date	Activation periods and limits	Total distance (Original + Rerouted) (NM)	Reference distance (NM)	Distance difference (NM)
23/08/2010	0900 - 1100 (FL290-FL340), 1200 -1400 (FL290-FL370)	302,913.4	302,799.2	114.2
24/08/2010	0700 - 0800 0900 - 1000 1130 - 1400 1830 - 2000 (FL290-FL370)	336,981.2	336,638.8	342.4
26/08/2010	1530 - 1630 (FL290-FL370)	333,739.0	333,687.2	51.8
27/08/2010	0800 - 1000 (FL290-FL370)	270,055.5	269,978.8	76.7
Total		1,243,689.1	1,243,104.0	585.1

tors. A comparative analysis of Reference and Current scenario presents the values of selected parameter that describes flight efficiency (Table 5). The development of solution scenarios aims to reduce the values of the parameters obtained by comparative analysis of Reference and Current scenarios.

Apart from additional flight distance (flight efficiency measure) caused by the activation of flexible airspace structure LI_RST-49, there are other indicators that express flight efficiency. Activation of LI_RST-49 in the selected time period contributed to additional fuel burn by 6.43 tons and additional 20.33 tons of CO₂ emission.

Vertical modification scenario represents the modification of vertical limits of activated volume of

airspace LI_RST-49. The methodology used for vertical modification scenario is based on lowering the volume of airspace LI_RST-49 for three flight levels. The activated volume of airspace used by military users in this scenario will remain the same as the upper and lower limits of the volume move at the same time.

Moving the vertical boundary of activated airspace volume is achieved by lowering the volume of airspace LI_RST-49 for three-level flights, at 1,000 feet increments of actual activated limit volume LI_RST-49 (FL290 - FL370) in order to analyse the impact of lowering the volume of activated vertical border LI_RST-49, with respect to the vertical distribution of traffic in LI_RST-49 (Figure 3).

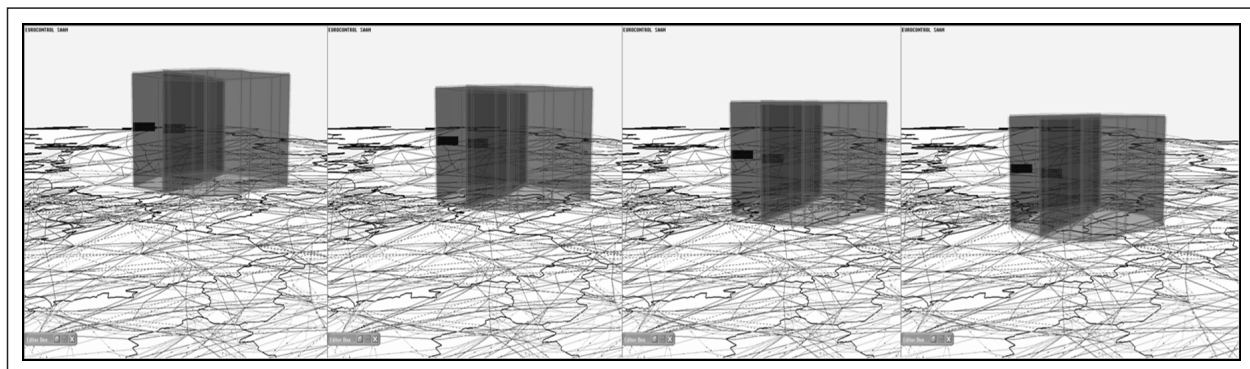


Figure 3 - Vertical shift of activated volume of airspace

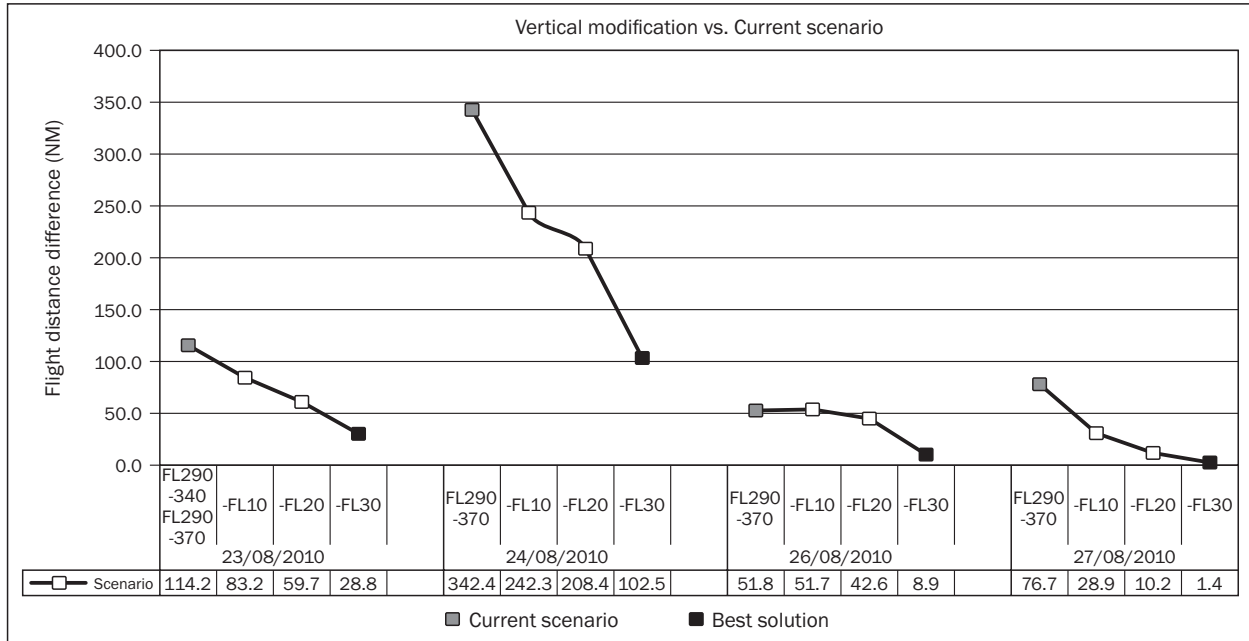


Figure 4 - Comparative analysis of vertical modification and Current scenario

Figure 4 describes the comparative analysis of the flight distance differences between the results obtained by modifying the vertical limits of activated volume LI_RST-49 and the Current scenario. In Figure 4 the x-axis represents flight distance difference while y-axis represents different scenarios and values of additional flight distance. Using vertical modification scenarios of activated volume LI_RST-49 on a weekly basis the total increase in flight efficiency of the flights using the best solutions (V4-R49 scenario) would amount to 75.8%. The best solution for every simulated day would be to lower the LI_RST-49 airspace volume by three flight levels (-FL30).

Modification of activation period scenarios are based on the moving time period of activation of volume of airspace LI_RST-49 45 minutes before and 45 minutes after the estimated time period of activation, in so-called time windows for a period of 15 minutes.

Figure 5 presents the comparative analysis of the flight distance difference between the results obtained by modification of activation period scenarios (shift of activation periods by time windows of 15 minutes) and the Current scenario. Using modification of activation period scenarios on a weekly basis an overall increase of the flight efficiency using the best solution for every simulated day would be 29.98%.

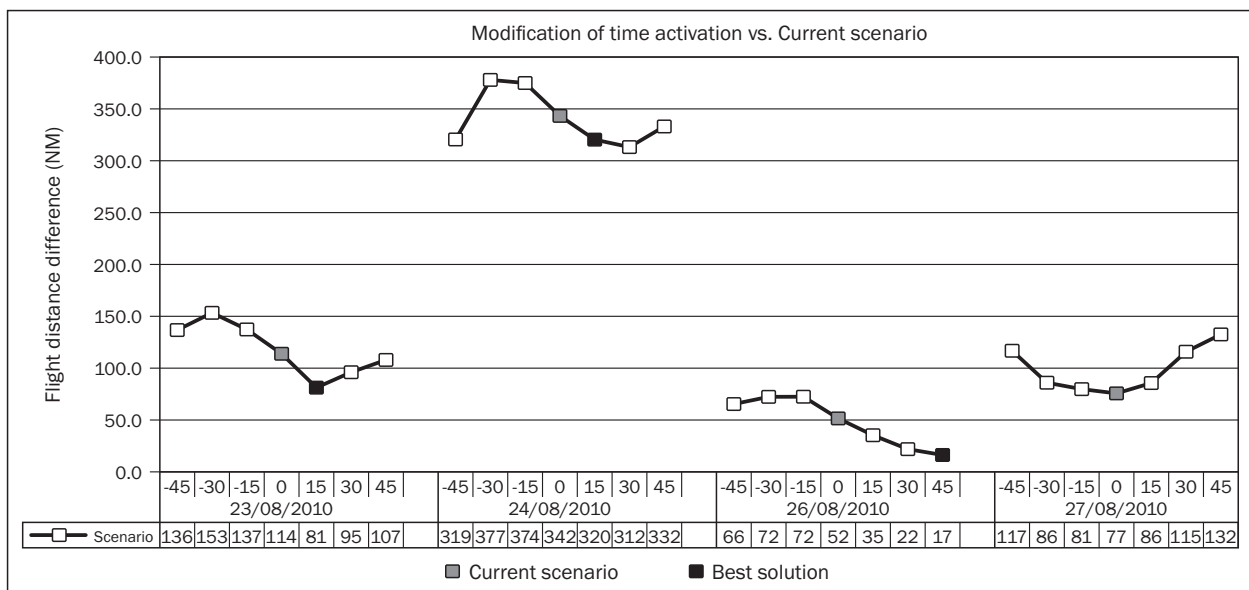


Figure 5 - Comparative analysis of Modification of activation period scenarios and Current scenario

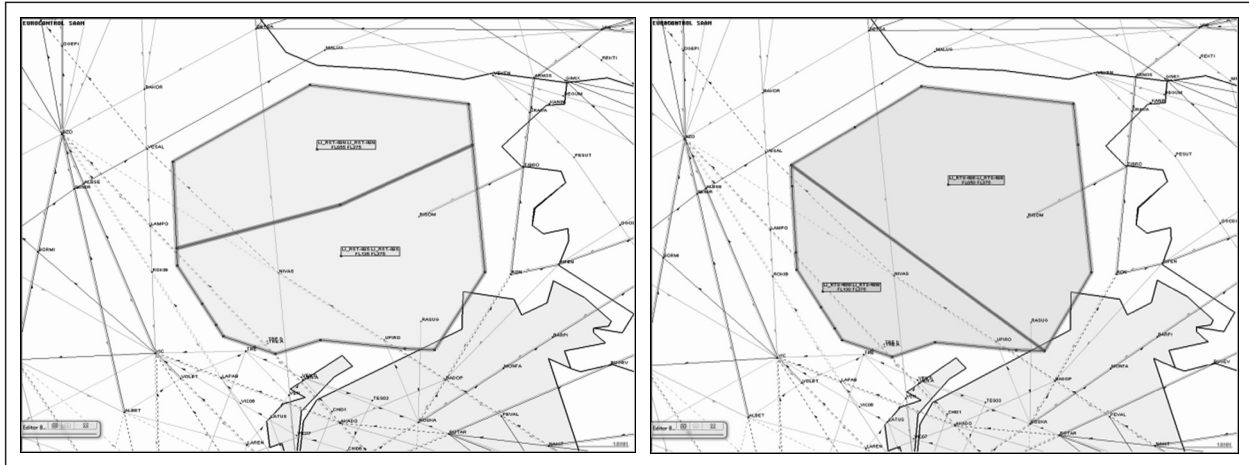


Figure 6 - Current and redesign of LI_RST-49

In order to achieve the *redesign of flexible airspace structure* LI_RST-49 it is necessary to analyse the use of the existing airspace sectorisation of the LI_RST-49. Airspace volume LI_RST-49 is divided into two sectors (Figure 6):

- LI_RST-49N (North) - Vertical limits: FL050 - FL370,
- LI_RST-49S (South) - Vertical limits: FL130 - FL370.

Since the majority of en-route segments are located in the western part of the LI_RST-49 airspace, which means that civil users mainly use the western part of the LI_RST-49 volume, it is necessary to analyse the usability of route segments for a selected period of time, in order to define a new design of airspace LI_RST-49.

Since 2/3 of all civil flights pass through LI_RST-49 using en route segments: BADOP-NIVAS, NIVAS-BADOP, NIVAS-VESAL, BZO-NIVAS, it is preferable to design this part of airspace as a separate sector, e.g. sector LI_RST-49W (western sector). On the basis of the analysis of the usability of route segments in airspace LI_RST-49 there is new proposed design of LI_RST-49 airspace (Figure 6).

New design of LI_RST-49 airspace as opposed to the current design, which consists of the northern (LI_

RST-49N) and southern sectors (LI_RST-49S) consists of a new western (LI_RST-49W) and eastern sector (LI_RST-49E). The vertical boundaries of the new design of LI_RST-49 are as follows:

- LI_RST-49E (East) - Vertical limits: FL050 - FL370,
- LI_RST-49W (SW) - Vertical limits: FL130 - FL370.

With the application of redesign scenarios the ratio of regulated flights between the eastern and western sectors amounts to 1:3 to 1:5, whereas the existing design ratio is 1:1.3.

Modularity scenario is based on the assumptions of the redesign scenario. The main difference between the redesign and modularity scenario are the vertical limits of the module of the Western sector.

Analysing the results obtained from the redesign scenario LI_RST-49, as most of civil air traffic fly through the western part of the LI_RST-49 airspace (most conditional routes located in the western part), this sector of airspace represents the part of airspace where the use of modular design could bring a significant increase in the flight efficiency of civil users (Figure 7).

Lowering the western sector upper vertical boundary by two flight levels (M4_R49) on the 24th of August

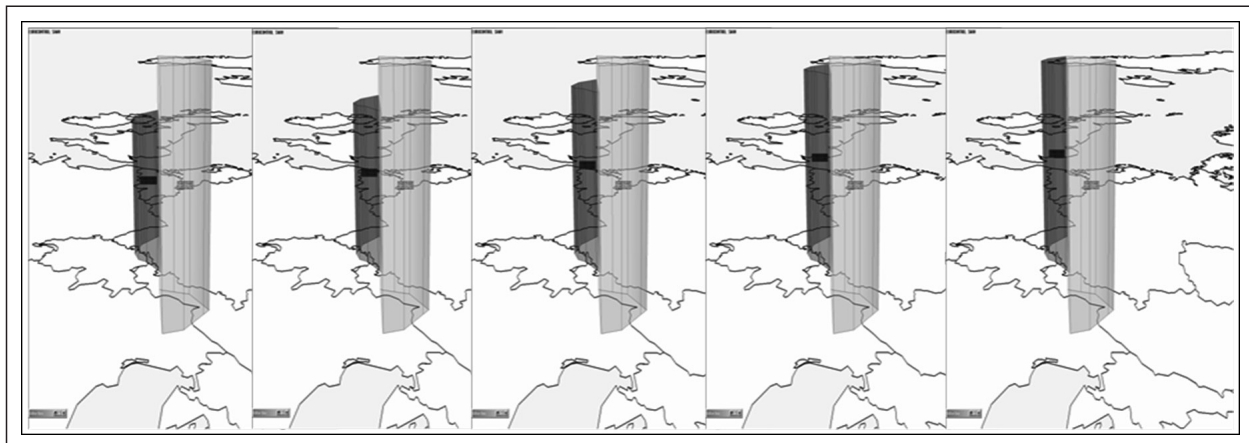


Figure 7 - Modularity scenario

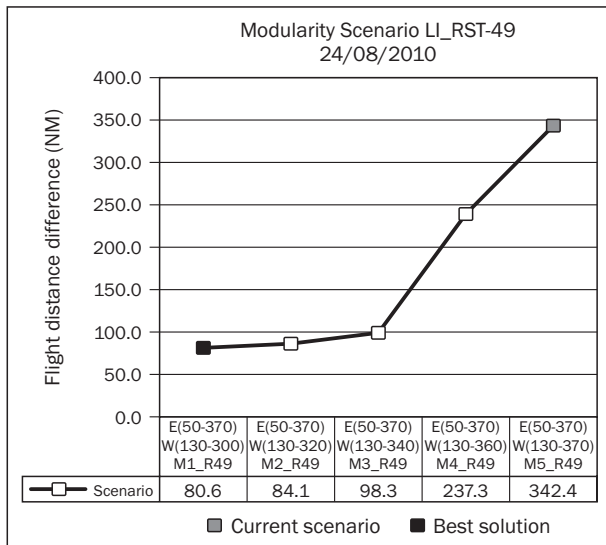


Figure 8 - Comparative analysis of Modularity scenario and Current scenario

2010 there would have been an increase in the flight efficiency by 30%, and with additional lowering of the upper limit by five flight levels the flight efficiency would increase by 76% (Figure 8).

5. CONCLUSION

Since the full potential of airspace utilization is constrained by imposed restriction and diverse airspace structure, it is necessary to introduce new concepts and methods that will lead to a reduction in airspace structures diversity, existing restrictions, and consequently lead to greater flight efficiency of civil users, as well as military operators, reduce delays and increase capacity of air traffic control system in Europe.

The implementation of flexible airspace structure utilization model should represent a collaborative process that in the first step should define the criteria for establishment of the model and objectives to be achieved by using the model. Defining the criteria, rules, and objectives for the use of flexible airspace structure should be made at the national level in accordance with the requirements of flexible use of airspace, specific functional airspace block (FAB) and network manager requirements.

Planning the flexible airspace structures utilization model and operational use of the same one, should take into account the required volume of flexible airspace structure, period of use, amount of traffic demand, and the geographical distribution of the airspace structure. The implementation of the flexible airspace structure utilization model should follow the process of validation using the verified simulation tools. This model (different scenarios) is applicable to all flexible airspace structures depending on the factors mentioned above.

Based on the simulations performed within this paper and significant flight efficiency improvements (between 30% and 76%), this model should be taken into account when planning the utilization of new or existing flexible airspace structure. Based on these results air carriers should increase their active participation in the route network development and increase pressure towards service providers in order to improve their flight efficiency and attributed costs.

The limitation of the simulations performed is that the impact of different scenarios on the sector capacities of the neighbouring sectors and all the other sectors influenced on a particular flow was not analysed. Based on the research presented in this paper the next step in the evaluation of the impact of flexible airspace structures utilization model would be the analysis of the influence of different scenarios on air traffic control sector capacities.

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SAŽETAK

UPOTREBA FLEKSIBILNE STRUKTURE ZRAČNOG PROSTORA U OPTIMIZACIJI UČINKOVITOSTI LETA

S povećanjem prometne potražnje u Pan-europskom zračnom prostoru dolazi do potrebe za optimiziranjem upotrebe struktura zračnog prostora (civilnih i vojnih) na način koji bi zadovoljio zahtjeve civilnih i vojnih korisnika. U području Europe s najvećom razinom zračnog prometa, 32% volumena zračnog prostora iznad razine leta FL 195 podijeljeno je između civilnih i vojnih korisnika. Do uvođenja koncepta fleksibilne upotrebe zračnog prostora, fleksibilne strukture zračnog prostora bile su 24 sata dnevno nedostupne za komercijalni zračni promet. Koncept fleksibilne upotrebe zračnog prostora pruža značajniju razinu dinamičkog upravljanja zračnim prostorom, uz korištenje uvjetnih ruta. U radu se analizira neiskorištenost resursa, fleksibilnih struktura zračnog prostora u Pan-europskom zračnom prostoru, osobito u jugoistočnom dijelu Europe (Jugoistočni prometni tok) u kojem postoji smanjena učinkovitost leta, kao rezultat delegiranja fleksibilnih struktura vojnim korisnicima. Na temelju prethodnih istraživanja, razvijeni su modeli (scenariji) za fleksibilnu upotrebu zračnog prostora u definiranom zračnom prostoru na temelju vremenskih, vertikalnih i modularnih parametara sektorizacije zračnog prostora, a sve u cilju optimiziranja učinkovitosti leta. Predstavljen model don-

osi značajno unapređenje učinkovitosti leta (u smislu smanjene duljine leta) za komercijalne zračne prijevoznike, koji planiraju letjeti kroz odabranu strukturu fleksibilnog zračnog prostora (LI_RST-49).

KLJUČNE RIJEČI

učinkovitost leta, fleksibilna struktura zračnog prostora, model upotrebe, System for traffic Assignment and Analysis at a Macroscopic level (SAAM)

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