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FLIGHT TRAJECTORIES COMPARISON IN THE BALTIC FAB

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Abstract. Aviation is one of the types of transport which has a crucial role in the modern world and develops with unprecedent speed. As the number of flights tends to increase, the Air Traffic Management (ATM) system has to ensure the safety of these flights and effectiveness of them. The design and use of the European routes and use of the air route network are considered to be a major causal factor of flight inefficiencies in the continent. The present ATM system needs to be reorganised to satisfy airspace operator needs and maintain safety levels, because of the recent and future predicted traffic growth and not always satisfactory indicators of the efficiency of the ATM system.

The airspace is currently fragmented along national borders that is why the efficiency of flights is not assured i.e. to perform flights along optimal trajectories avoiding delays, excessive fuel burn and emissions. One of the conditions for ATM system to be more effective is connection of the airspace blocks, into Functional Airspace Blocks (FAB), within which more efficient flight could be conducted based on more direct routes connecting entry and exit points of the FAB.

According to the analysis on European and US ATM systems, where the European ATM system is the sum total of a large number of separate Air Navigation Service Providers (ANSP) whereas the US system is operated by a single ANSP, it was analysed and stated that the less fragmentation there is, the more efficient flights are.

The focus of this paper is to show the differences between fixed routes and direct trajectories (Great Circle) in the Baltic FAB in terms of flight distance, fuel burn and emission.

Keywords: Baltic FAB, flight trajectory, fixed route, free route, direct route, inefficiency.

Introduction

Nowadays centrally controlled ATM system is step by step being reorganized into a distributed system. Earlier traffic flows were normally structured into airways. Airways originally consisted of routes flying from one navigation beacon to another. It was the easiest way to navigate under Instrument Flight Rules (IFR). Today's navigation equipment no longer requires flying from one beacon to another but the airways are still in place. The reason for this may be that it structures the traffic pattern enabling one air traffic controller to monitor own sector (Hoekstra, van Gent, & Rugrok, 2002). To fly according the Great Circle concept aircraft operators need to use GPS and RNAV equipment.

1. Flight efficiency

Routes need to be optimized, the current five sources of inefficiencies are shown in Figure 1 (Howell, Bennet, Bonn, & Knorr, 2003). It is predicted that FRA could reduce or even completely eliminate this source of inefficiency (route structure).

There are two main reasons explaining the flight inefficiency:

– horizontal inefficiency, where the trajectory flown is longer in kilometers than optimal trajectory;

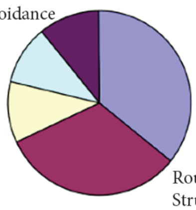

Figure 1. En-route inefficiency sources in the NAS (Pereira, 2015)

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Table 1. Air traffic characteristics of the ATM system in the US and Europe (FAA, 2015)

	Year 2015	Europe	US	US vs. Europe
1	Geographical area (mln km²)	11.5	10.4	≈ –10%
2	Number of civile en-route ANSP	37	1	
3	Nr of ATCO	17370	13138	≈ –24%
4	Total staff	56300	31501	≈ –44%
5	Controlled flights IFR (million)	9.8	15.3	≈ +57%
6	Flight hours controlled (million)	14.8	23.1	≈ +56%
7	Relative density (flight hours per km²)	1.3	2.2	≈ +1.7%
8	Average length of flight (within respective airspace)	575 nm	524 nm	≈ –9%
9	Number of en-route facilities	62	23	–39
10	Source	Eurocontrol	FAA/ATO	

– vertical inefficiency, where the altitude flown at each time is not the optimum altitude.

There are 20 Air Route Traffic Control Centers (ARTCC) in the US CONUS compared to 62 ACCs in Europe (FAA, 2015). Table 1 provides some key air traffic characteristics of the ATM system in the US and Europe.

Airspace fragmentation along National Borders leads to inefficient flight routes due to non-optimal air routes, flight time, excessive fuel burn, CO_2 and NOx emissions (Liutkevičius, 2017). This is one of the reasons why airspace and the fixed route network should be reorganised to satisfy airspace operator needs and maintain required safety levels (Dudoit & Stankūnas, 2015). It is assumed that the optimal route is the shortest route – Great Circle route (Pereira, 2015; EASA.ATPL, 2008). The Great Circle route (Chesneau, Fuller, & Hustache, 2002) is the route which shows the distance between the origin and destination TMA.

A trajectory which has the smallest deviation from the optimum trajectory is sought in order to optimize fuel burn and flight time which affect the cost to airspace users and pollution.

For calculating benefits of free route, most often the direct (Great Circle) route is preferred by pilots, some of such air routes were chosen for analysis.

2. Free Route concept, implementation types and benefits

2.1. Free route concept

Free Route Airspace (FRA) is a specified airspace within which users may freely plan a route between a defined entry point and a defined exit point. Subject to airspace availability, the route can be planned directly from one to the other or via intermediate (published or unpublished) waypoints, without reference to the fixed ATS route network. Within this airspace, flights remain subject to air traffic control (Free Route Airspace, 2018; Krzyżanowski, 2013).

The aim of this paper is to analyze the flight trajectories according to fixed and free route (Great Circle) concepts in the Baltic FAB. For this purpose some of the Lithuanian, Polish and Kaliningrad air routes are chosen to show the difference in trajectory distances when using fixed route and applying free route concepts, that has influence on flight time, fuel burn, emissions, ATC monitoring taskload (Kraus, 2011).

2.2. Free route implementation types

Free route operations need to be (Free Route Airspace, 2018; European Network Operations Plan 2016–2019/20):

– Time limited (e.g. at night) – it is a transitional step in the early implementation of the FRA;
– Structurally or geographically limited (e.g. restricting entry or exit points for certain traffic flows, applicable within CTAs or upper airspace only) – the partial implementation in complex airspaces because of a negative impact on capacity;
– Implemented in a Functional Airspace Block environment – FRA is implemented in the FAB where it is treated as one FIR;
– Within SES airspace – the last stage of FRA use, introduction into Europe (Free Route Airspace, 2018; European Network Operations Plan 2016–2019/20).

2.3. Benefits of Free Route

The implementation of FRA offers a number of efficiency benefits for the operators (Bucuroiu, 2013). There are a lot of challenges and issues of FRA implementation, but summing up, this could be the only way of the most cost-effective changes to the ATS provision in Europe (Free route development in Europe, 2016).

The benefits could be as follows:

– Reduced flight time, because the routes will be shorter;
– Reduced CO2 emissions, because of the reduced flight time;
– Reduced fuel consumption, also because of the reduced flight time and more-optimal flight profiles;

– Low implementation costs for ANSPs;
– Fewer conflicts – because the same number of aircraft are scaterred over all sector;

3. Trajectory distance calculations

There exist several ways to calculate the distance. Orthodromic distance can be calculated using geographical coordinates from point A (φ_1, λ_1) to point B (φ_2, λ_2) summing up the distances according to the formula (1) given below (Eddie & Baciu, 2012; Masiulionis, 2017).

$$d(A,B)=2R\cdot \arcsin \sqrt{sin^2\left(\frac{\varphi^1-\varphi^2}{2}\right)+cos\varphi_1 cos\varphi_2 sin^2\left(\frac{\lambda^1-\lambda^2}{2}\right)}, \quad (1)$$

where:
R – the radius of the Earth;
φ_1, φ_2 – A and B points latitude coordinates;
λ_1, λ_2 – A and B points longitude coordinates.

Applying Euclidian distance (2) calculation formula between two known points, allows to calculate distance between these two points.

$$D = \sqrt{(x_1-x_2)^2+(y_1-y_2)^2}, \quad (2)$$

where:
D – distance;
x_1, x_2 – first point coordinates;
y_1, y_2 – second point coordinates.

4. FAB in FRA implementation

One of the main reasons of flight inefficiencies is the high fragmentation of the specified regions that mostly coincide with the state borders (Figure 2), military area and navigation equipment location (Peleckis, 2018). In order to efficiently develop aviation, the successful development of one country is not enough. Thus, the best results will only be reached by solving the existing problems and intended challenges to the extent of a few countries – up to the extent of the whole region (Kondroška & Stankūnas, 2012).

Comparisons of the ATM systems functioning in different regions of the world show that the less fragmentation there is, the more efficient flights are. One of the main tasks remains, namely, to establish airspace blocks that meet the expectations of the airspace users in terms of distance, flight time, fuel burn, emissions (Kondroška & Stankūnas, 2012; Šakalys, 2015).

Beginning with 2017 Lithuanian Air Navigation Services adopted free route airspace, meanwhile according to Eurocontrol regulations Poland is going to apply this concept in 2019. Both Lithuania and Poland create Baltic Functional Airspace Block (FAB), that is the reason why they both should have the same concept adopted and to standardize their procedures for delivering the most optimal flight trajectories for aircraft flying in their airspace on distance, time, fuel burn, emissions. Furthermore, in case we had ideal political situation with Kaliningrad, better results would be achieved if Baltic FAB cooperated with Kaliningrad FIR (Figure 2) in making routes more optimal for airspace operators (distance, time and fuel-burn) and eco-friendly for environment.

Baltic FAB and Kaliningrad FIR is neighbouring with following FIRs (Table 2).

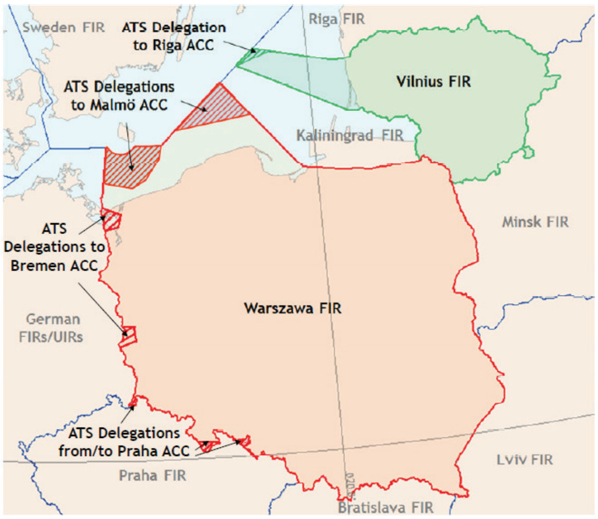

Figure 2. Existing ATC responsibilities in Poland and Lithuania (Baltic FAB concept of operations, 2012).

Table 2. Neighbouring FIRs of Baltic FAB and Kaliningrad FIR

	FIR (Flight Information Region)	Neighbouring FIRs
1	Vilnius (FIR) is neighbouring with 5 other FIRs:	EVRA (Riga) FIR, UMVV (Minsk) FIR, EPWW (Warsaw) FIR, UMKK (Kaliningrad) FIR, ESSA (Sweden) FIR.
2	Warsaw FIR is neighbouring with 9 other FIRs:	EYVL (Vilnius) FIR, UMKK (Kaliningrad) FIR, ESSA (Sweden) FIR, EDWW (Bremen) FIR, EDMM (Muenchen) FIR, LKAA (Praha) FIR, LZBB (Bratislava) FIR, UKLV (Lviv) FIR, UMVV (Minsk) FIR.
3	Kaliningrad FIR is neighbouring with 3 other FIRs:	EYVL (Vilnius) FIR, ESAA (Sweden) FIR, EPWW (Warsaw) FIR.

5. Flight trajectories in the Baltic FAB and Kaliningrad FIR

In this chapter some flight trajectories according to fixed and direct route concept are analyzed. Some routes are analyzed according to distances, fuel burn and emissions. Entry and exit points into/out of airspace are left as in AIP charts, but flight trajectories change due to implementation of free route concept (Figure 3) by Lithuanian Air Navigation and in 2019 by POLAND PANSA and no implementation by Kaliningrad till 2022. Lihuanian, Polish and Kaliningrad entry and exit points were picked from countries national Aeronautical Information Publications (AIP), flight radar live air traffic website and Google Earth programme. Coordinates and distances of these entry and exit points were analyzed and applied with MATLAB programme to calculate the differences between fixed route and direct route lengths in the Baltic FAB and Kaliningrad FIR afterwards the calculations for fuel burn and CO_2 emissions were made.

The status of FRA implementation in 2019 is depicted in the following map.

When comparing internal fixed and direct flight trajectories in the Baltic FAB and Kaliningrad FIR some of them were taken for a deeper analysis. In this analysis 60 air routes were chosen such as to be continuous routes on the same name in one of the FIRs. The fixed and direct routes were analysed according to the traffic flows (Table 3) from North of Lithuania to West of Poland (35 routes) where average distance difference was 19.68 km (10.62 nm), from North of Lithuania to South of Poland (15 routes) where average distance difference was 12.86 km (6.93 nm), from North of Lithuania to East of Poland (3 routes) where average distance difference was 46.52 (25.11 nm) and from East of Lithuania to West of Poland (7 routes) where average distance difference was 6.91 km (3.73 nm).

Air routes according to the fixed routes are compared to the Great Circle routes (calculated according to the entry/exit points coordinates of Baltic FAB). The difference is shown in the table below (Table 3).

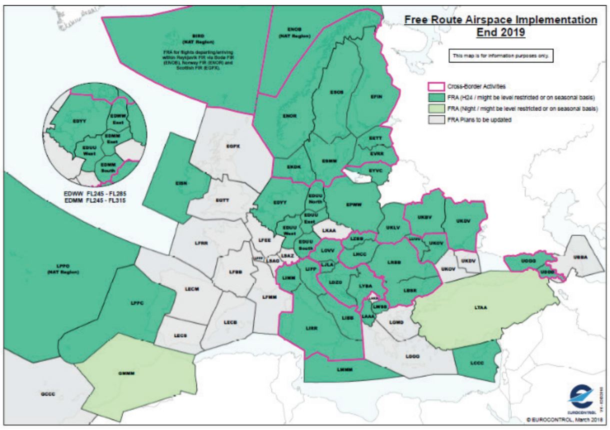

Figure 3. Lithuanian Free Route implementation 2019

Table 3. Average distances of air routes in Baltic FAB

	Air routes	Aver. distance (km)	Aver.GC distance (km)	Aver. difference (km)
1	East-West (7)	728.25	721.34	6.91
2	North-South (15)	742.68	729.82	12.86
3	North-West (35)	542.11	522.43	19.68
4	North-East (3)	378.97	332.45	46.52

According to the above data it is evident that the Great Circle distance is shorter and that when aircraft operators are allowed to fly freely, they can achieve great benefits in distance, flight time, fuel consumption, engine running time, emissions.

Average fuel burn per kilometer (Table 4) can be calculated from assumptions that when flying in cruise level B737-800 uses 3.45 kg/km while A320 consumes 3.13kg/km. That is why rough following calculations can be made.

Table 4. Average fuel consumption

	Air routes	Aver. difference (km)	Aver.fuel consumption (kg/km) B737-800	Aver.fuel consumption (kg/km) A320
1	East-West (7)	6.91	23.83	21.62
2	North-South (15)	12.86	44.36	40.25
3	North-West (35)	19.68	67.93	61.59
4	North –East (3)	46.52	160.49	145.60

According to the aircraft analysis and fleet planning formula (5), the CO_2 emissions for each kilometer can be calculated where B737-800/A320 consumes 3.45kg/km/3.13kg/km (Ngo & Shamoun, 2016), pollution coeficient is 2.580kg/km. Emissions for B737-800 reach 8.901 kg/l, whereas for A320 reach 8.075 kg/km.

CO_2(B737-800) = 3.45 × 2.580 = 8.901 kg/km;

CO_2(A320) = 3.13 × 2.580 =8.075 kg/km.

6. Free Route implementation issues and challenges

In aviation FRA creates a lot of challenges to the airspace users (Enea & Poretta, 2012). And these challenges should be taken into account to gain the best of FRA. Some issues and challenges are (Free Route Airspace, 2018):

- Technology challenge – new equipment is required for aircraft, ANSPs, etc.;
- More challenging conflict detection – at fixed route airspace conflicts occur at specific points (e.g. airway crossings). Since the aircraft will not fly on standard airways that is why conflicting points will not be at fixed locations. Conflicts may become harder to detect because of traffic spread and increased number of possible conflicting points;
- Equipment failures – air traffic controller overload in case of equipment failure;

– Changes to the separation provision methods used by ATC (e.g. direct routes are less an option for solving conflicts since most aircraft are using the most direct route available anyway).

Conclusions

Airspace fragmentation along National Borders makes flight routes inefficient due to non optimal air routes, flight time, excessive fuel burn, CO_2 and NOx emissions. That is the reason why airspace and the fixed route network should be reorganised to satisfy airspace operator needs and maintain required safety levels. Comparisons between the ATM systems functioning in different regions of the world show that the less fragmentation there is, the more efficient flights are. One of the main tasks remains, namely, to establish airspace blocks and direct routes in them that would meet the expectations of the airspace users.

Free route airspace was implemented in Lithuania in 2017 and is about to be deployed in Poland in 2019. As the analysis show free route airspace implementation allows pilots to fly the most convenient way (Great Circle). In case we had ideal political situation with Kaliningrad, better results would be achieved if Baltic FAB cooperated with Kaliningrad FIR in making routes more optimal for airspace operators. As it was shown from calculations that there are great benefits in distance, fuel-burn and emissions.

As the analysis demonstrates direct routes should be implemented and deployed in the BALTIC FAB plus Kaliningrad. Aferwards there should be another step taken for improving airspace explotation, e.g. direct route implementation in SES airspace thus allowing the pilots choose the most direct routes from their origin to destination without being tied up to the FIR boundary entry/exit points and tracks joining these points.

So this analysis showed that Eurocontrol aims are reasonable, efficient and logical, but there is another challenge to be faced, namely, safety guarrantee in traffic distribution in the FAB e.g. complexity.

References

Aircraft analysis and fleet planning. (2005). *Aircraft commerce, issue No.42*. Retrieved from http://www.aircraftcommerce.com/sample_articles/sample_articles/fleet_planning_2_sample.pdf

Baltic FAB concept of operations, version 1. (2012).

Bucuroiu, R. (2013). *Status of free route airspace developments*. Eurocontrol. Retrieved from https://www.eurocontrol.int/sites/default/files/publication/files/brochure-fra-20161209.pdf

Chesneau, S., Fuller, I., & Hustache, C. (2002). *ATM flight efficiency and its impact on the environment*. EUROCONTROL Experimental Centre.

Dudoit, A., & Stankūnas, J. (2015). The comparison of the en-route horizontal flight trajectory components. *Science – Future of Lithuania, 7*(5) 577-582. ISNN 2029-2341. https://doi.org/10.3846/mla.2015.836

EASA.AATPL. (2008). *Ground Training Series – Navigation 1 – General Navigation*. Oxford aviation academy.

Eddie, C. L., & Baciu, G. (2012). *Introduction to wireless localization with iPhone SDK examples (*1st ed.). IEEE. Wiley. ISBN 978-1-118-29851-0.

Enea, G., & Poretta, M. (2012). *A comparison of 4D-trajectory operations envisioned for NextGen and SESAR, some preliminary findings, 5*, 4152-4165.

European Network Operations Plan 2016-2019/20, June 2016.

FAA. (2015). *Comparison of air traffic management-related operational performance: U.S./Europe*.

FRA deployment in Europe. (2016).

Free Route Airspace. (2018). Retrieved from https://www.skybrary.aero/index.php/Free_Route_Airspace_(FRA)

Hoekstra, J. M., van Gent, R. N. H. W., & Ruigrok, R. C. J. (2002). Designing for safety: the „Free Flight" air traffic management concept. *Reliability Engineering* & *System Safety, 75*(2), 215-232. https://doi.org/10.1016/S0951-8320(01)00096-5

Howell, D., Bennett, M., Bonn, J., & Knorr, D. (2003). *Estimating the en-route efficiency benefits pool*. ATM Seminar. Retrieved from http://www.atmseminar.org/seminarContent/seminar5/papers/p_023_MPM.pdf

Kondroška, V., & Stankūnas, J. (2012). Analysis of airspace organization considering air traffic flows. *Transport, 27*(3), 219-228. https://doi.org/10.3846/16484142.2012.719199

Kraus, J. (2011). Free route airpsace (FRA) in Europe. *Free Route Airspace (FRA) Journal, 6(5)*, 129-135. Prague.

Krzyżanowski, M. (2013). Conflict free and efficient flight routes planning in Free Route Airspace. *Prace Naukowe Politechniki Warszawskiej, Transport,* 277-285.

Liutkevičius, D. (2017). *Oro erdvės blokų formavimas Europos regione eigos tyrimas* (Master's thesis). Vilnius. VGTU.

Masiulionis, T. (2017). *Automatizuota orlaivio pilotavimo vertinimo sistema* (daktaro disertacija). Vilnius: „Technika". ISBN 978-609-476-026-6. https://doi.org/10.20334/2017-032-M

Ngo, D., & Shamoun, F. (2016). *Environmental cost of different unit rates*. Sweden.

Peleckis, K. (2018). *The analysis of the limited areas influence to free route airspace* (Master's thesis). Vilnius, VGTU.

Pereira, J. P. (2015). *Free route airspace for route optimization* (Master Thesis). Instituto Superior Tecnico. University of Lisbon Delft University of Technology, October.

Stankūnas, J., & Kondroška, V. (2012). Formation of methodology to model regional airspace with reference to traffic flows. *Aviation, 16*(3), 69-75. https://doi.org/10.3846/16487788.2012.732306

Šakalys, M. (2015). *Oro transporto laisvųjų ir fiksuotųjų skrydžių maršrutų analizė* (Master's thesis). Vilnius. VGTU.

BALTIJOS FUNKCINIO ORO ERDVĖS BLOKO SKRYDŽIŲ TRAJEKTORIJŲ PALYGINIMAS

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Santrauka

Aviacija – viena iš greitai augančių transporto šakų, kuri yra svarbi šiuolaikiniame moderniajame pasaulyje. Kadangi skrydžių nuolatos daugėja, oro eismo valdymo (OEV) sistema turi užtikrinti skrydžių saugą ir efektyvumą. Europos oro maršrutų išdėstymas ir naudojimas laikomi svarbiausiais skrydžių neefektyvumo veiksniais žemyne. Dėl esamo ir numatomo oro eismo augimo ir ne visados patenkinamų OEV sistemos efektyvumo rodiklių esama OEV sistema turi būti reorganizuota, siekiant užtikrinti oro erdvės naudotojų poreikius ir palaikyti reikalingą saugos lygį.

Šiuo metu oro erdvė yra sudalyta pagal kiekvienos šalies valstybines ribas, dėl to skrydžių efektyvumas nėra optimalus, t. y. atliekami skrydžiai nevykdomi pagal optimalias trajektorijas vengiant užlaikymų, mažinant naudojamo kuro sąnaudas ir emisiją. Viena sąlyga, siekiant OEV sistemą padaryti efektyvesnę, – sujungti oro erdvės blokus į funkcinius oro erdvės blokus (FOEB), kuriuose skrydžiai būtų vykdomi tiesesniais maršrutais tarp įskridimo ir išskridimo į FOEB taškų.

Atlikus Europos OEV ir JAV sistemų analizę matyti, kad Europos OEV sistema susideda iš daugybės atskirtų oro navigacijos paslaugų teikėjų, o JAV sistemą valdo vienas oro navigacijos paslaugų teikėjas. Konstatuota, kad ten, kur fragmentacija mažesnė, skrydžių efektyvumas didesnis.

Straipsnio tikslas – parodyti skirtumus tarp fiksuotųjų ir laisvųjų maršrutų Baltijos funkciniame oro erdvės bloke pagal skrydžių atstumo, sunaudojamo kuro ir emisijos faktorius.

Reikšminiai žodžiai: Baltijos FOEB, skrydžio trajektorija, fiksuotieji maršrutai, laisvieji maršrutai, tiesūs maršrutai, neefektyvumas.