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THE COMPARISON OF THE EN-ROUTE HORIZONTAL FLIGHT TRAJECTORY COMPONENTS

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Abstract. EUROCONTROL aims at improving the design and use of the European routes. Inefficiencies in the design of airspace and use of the air route network are considered to be a major causal factor of flight inefficiencies in Europe. 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. Airspace fragmentation following National Borders makes flight routes inefficient due to non requested air routes, flight time, excessive fuel burn, CO 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.The focus of the paper is to show the differences between planned flights and actual trajectories in terms of flight distance, duration and fuel burn. In connection with this, an overview of these indicators in Europe and the USA was made.

Keywords: air traffic management, airspace, air routes, flight trajectory, actual trajectory, direct trajectory.

Introduction

Flights are operated along air routes (airways) using ground based navigational aids structured in a fixed route network (Krzyżanowski 2013).

The air route network influences airspace and flight performance efficiency depending on a number of factors resulting from the boundaries of a particular sector. Some of the factors are ATS oriented, the others are defined by international settlements, such as:

- State boundaries or bilateral agreements for provision of ATS;
- International agreements for provision of ATS over international waters;
- Location of areas of special use – danger, prohibited, temporary segregated;
- Geographical characteristics of the area, type of service that is to be provided, radio and radar coverage;
- Direction of main traffic flow, flight trajectory characteristics, in-sector flight time, conflict point distribution, etc. (Babic, Krstic 2000).

In order to analyse the existing situation from the point of view of en-route horizontal flight components efficiency, several factors have to be taken into account. The most important factors are considered to be: (1) The structure of the airspace and flight routes layout; (2) the problems arrising from the fact of existence of the military airspace.

All the components mentioned above and others are reflected in the Air Traffic Management System (ATM).

This is a complex system composed of a large number of elements (in this case, ATC sectors), which are strongly related to each other (Amor 2006).

The purpose of the ATM System is to ensure a "safe, orderly and expeditious flow of traffic" (Kondroška, Stankūnas 2012a). *Safety* normally is maintained by separating aircraft flying different routes. *Orderliness* is guaranteed by organizing traffic with similar plans into streamlike flows. The problem of the *expeditious flow* can only be solved by making sure that the constraints (e.g., delays) on the efficient operation of each aircraft imposed by the first two requirements affect efficiency as little as possible.

That may explain the fact that ATM is not always the causal reason for an imbalance between capacity and demand (which may also be caused by other participants, weather, military, noise and environmental constraints, etc.).

Airspace is divided into a number of sectors, each of them is assigned to a team of controllers. *Air Traffic Control (ATC) sector* is the basic capacity reference and the most essential operational component of the ATC (Valdés *et al.* 2012). Controllers of a given ATC sector have to control aircraft flying fixed or free routes in order to avoid conflicts between the aircraft when their flight trajectories intersect and to exchange information with the adjacent sector of air traffic control dealing with the traffic in concern (Dugail 2002).

Sector capacity is a maximum number of flights that may enter and leave the sector per hour averaged over a sustainable period of time (Majumdar *et al.* 2004). The sector capacity depends not only on ATC sector configuration, aircraft performance, ATC workload, weather conditions, but as well on flight routes (trajectories). The capacity of each airspace sector with specific route configuration comprises the capacity of the overall ATM system (Gianazza 2007, 2009).

The ATM in different countries and regions vary in their efficiency (Kondroška, Stankūnas 2012b). National ATS planning is still of great importance, and the coordination of airspace and route network development is still carried out for the cross-border connections of nationally planned routes (known as *a fixed route network*).

The comparison of ATM system in the US and Europe

Nowadays the US and European systems are operated using similar technology and operational concepts, and nevertheless one huge difference becomes evident. The US system is operated by the one single service provider employing the same tools and equipment, communication processes, rules and procedures.

In Europe, en route flight efficiency is affected by fragmentation of airspace.

Quite a number of adjacent ANSPs use different Flight Data Processing (FDP) systems which contribute to additional ATCOs workload when dealing with traffic flying different types of routes (climbing to en-route stage, transit, descending from en-route).

In 2010, the European ATM system controlled 9.5 mln, in the US 15.9 mln flights (U.S./Europe Comparison of… 2010).

According to the forecast for the year 2020, the traffic should increase to 17 million flights per year (Mihetec *et al.* 2011). The present ATM system is not capable of fulfilling users demands. That is the reason why the airspace and fixed route network should be reorganised so as to satisfy both airspace operators needs and maintaining required safety levels (Idris *et al.* 2009).

In general, it can be stated that the European ATM system is the sum total of a large number of individual ANSPs whereas the US system functions according to a single ANSP. Thus there are 20 Air Route Traffic Control Centers (ARTCC) in the US CONUS compared to 63 Area Control Centers (ACCs) in Europe (US/Europe 2014).

Horizontal en route flight efficiency

The optimum profile is both the horizontal or the vertical path flown by the aircraft which is the best suitable to the particular type of the aircraft and for the route that has to be covered. The focus of this section is on the horizontal component of the en route phase. This particular analysis compares two types of flight trajectories: the length of the en route flight part of routes according to the last version filed in the flight plan and changed by the radar, which is called "actual distance", and hypothetical direct distances. After the comparison, the problem of "inefficiency" may be discussed, i.e. the difference between the length of the analysed trajectories according to filed flight plan and the actual distance.

According to Chesneau *et al.* (2002), deviations from the "optimum" trajectory generate additional flight time, fuel burn and emissions with a corresponding impact on airspace users' costs and the environment.

"En route" according to the definition is a portion of the flight path between a 40 nm radius around the departure airport and a 100 nm radius around the arrival airport. In this analysis En route part of the flight is calculated with TMA route part extraction of 30 nm around origin and destination airports.

En-route flight efficiency indicators assess actual flight trajectories or filed planned flights against flights in optimal or ideal flight conditions. From an operator's perspective, the ideal flight trajectory would be a User Preferred Trajectory that would have a horiozontal (distance) and a vertical (altitude) components.

Figure 1 demonstrates the fact that horizontal en route flight efficiency depends on the difference between flight planned and actual distance (Kettunen *et al.* 2005). Actual Route (A) is the filed planned route changed by radar. The Great Circle (H) shows the distance between the origin and destination TMA (extraction of 30 nm around departure and destination airports). Currently, the European ATS route network is only 3.6% longer than the Great Circle for intra-European flights (Flight Efficiency Plan 2008). Direct course (D) reflects the distance between TMA exit and entry points (according to CFMU M3). The direct route follows the great circle (the shortest path between two points on the surface of a sphere is given by the arc of the great circle passing through the two points), considering that it is the best approximation, as it is the shortest distance between two points on the Earth's surface.

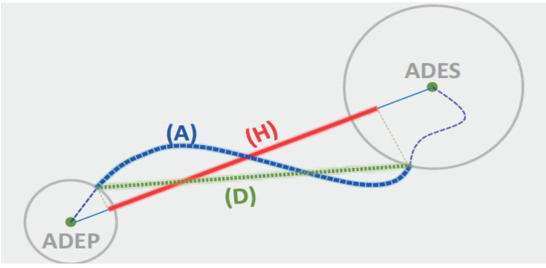

Fig. 1. The comparison of en-route distances
Source: Chesneau *et al.* 2002

En route flight efficiency (flight planned and actual trajectories) can be affected by a several number of factors including:

- Route network design;
- Route availability (military, congested areas);
- Route utilisation (route selection by airspace users);
- Airspace user preferences (time, fuel, route charges);
- ATC measures (tactical routings);
- Weather (wind optimum routes).

Figure 2 below shows the evolution and comparison of horizontal en route flight efficiency (in actual and flight planned routes), made from the year 2011 till 2013 in the US and in Europe. "Inefficiency" of 5% means that there was 50 nm of extra distance for 1000 nm.

In the USA "inefficiency" is evidently less common when comparing planned and actual flight trajectories. The difference reveals that en-route radar flights are more direct than the flight planned ones in both systems. In Europe the difference is 1.9%, in the USA 0.8% (data 2010), in Europe the difference is 0.7%, in the US 1.9% (data 2013). This can be explained by the fact that "more direct tracks are provided by the US ATC on a tactical basis when traffic and airspace availability permits" (U.S./Europe Comparison of... 2010) and because of lesser airspace fragmentation.

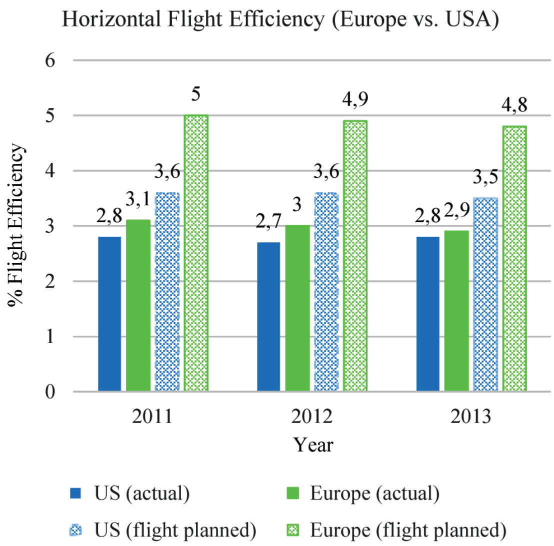

Fig. 2. U.S./Europe horizontal flight efficiency (actual and flight plan) (2011–2013)
Source: FAA-ATO

The restrictions imposed on the utilisation of the European ATS route network contribute with approximately 0.4% to the airspace utilisation inefficiency. The European ATS route network was improved over the past years and the routes implemented are currently only 3.6% longer than the Great Circle. An initial assessment of the European ATS route network design, availability and utilisation indicates that flight efficiency could be further improved by enhancing both route availability and utilisation (Flight Efficiency Plan 2008).

Comparison of flight trajectories

The analysis was carried out using the data from the European upper airspace. The traffic data normally come from Control Flow Management Unit (CFMU). There are two sets of traffic data available, model 1 and model 3. Model 1 (or M1) is the last filed flight plan data, as filed by the airlines with vertical profile and time calculated by CFMU. Model 3 (or M3) is flight planned route as changed by ATC. The flight route is still performed following navigation aids. Such type of routes is also referred as "actual" trajectories.

The data were taken from beginning with the 11 Apr 2014 to 27 Mar 2015. Recordings were done for 12 days throughout the year: each month a day when the flights were most intensive was analysed.

In upper airspace aircraft have to fly according to filed flight plans but if traffic and airspace permits shortcuts may happen, or the aircraft are provided with radar vectoring in case of conflicting traffic, active military areas, adverse weather conditions, etc. The outcome is the fact the new "actual" route differs from the planned one.

The scope of this study was for en-route horizontal flight components within the European Civil Aviation Council (ECAC) area, i.e. domestic and Inter-European flights. Intercontinental flights were not included.

Route efficiency

The flight efficiency indicators are intended to measure how closely the actual, or eventually the planned, 4D path flown by an aircraft approaches the optimum 4D trajectory for route flown.

Route efficiency (only of horizontal component in this case) is influenced by various parameters:

- ATC route structure (special use airspace, etc.);
- Separation of traffic;
- Special authorisation for shortcuts, or deviation allowed to the IFR traffic;
- Weather conditions that cause deviation from flight planned route.

It is calculated as a percentage of the direct route for each flight (Eqn (1)):

$$\% \text{ Route Efficiency} = \frac{\text{Actual Ground Distance flown} - \text{Direct Route}}{\text{Direct Route}}. \quad (1)$$

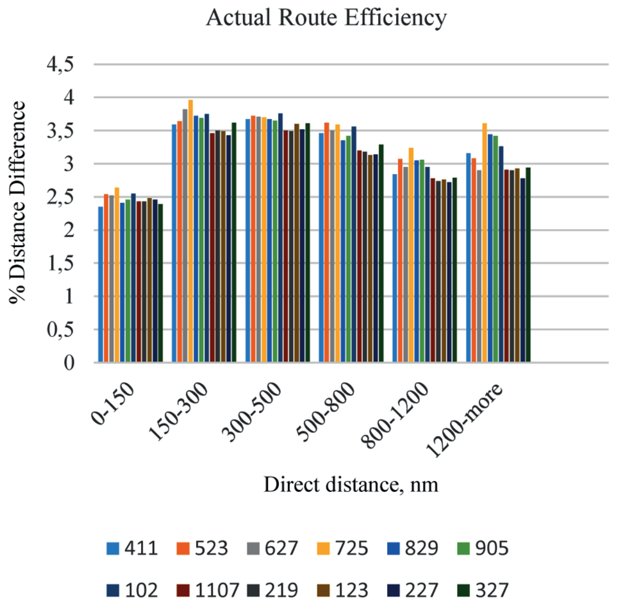

Fig. 3. Actual route efficiency

For the 12 days recorded, the route efficiency is equal to 2.47% at an average for 0–150 nm interval, 3.64% for 150–300 nm interval, 3.63% for 300–500 nm interval, 3.37% for 500–800 nm interval, 2.99% for 800–1200 nm interval, 3.11% for more than 1200 nm interval.

For the 12 recorded most intensive days of the year the Route Efficiency is equal to 3.08% at an average (Fig. 4).

The Route Efficiency is at a maximum for flights between 150–300 nm and reaches 3.34% for flight in the 150–300 nm interval. Such increase could be explained by the reduction of military airspace impact, lower ATC constraints.

Duration difference

The Duration indicator is equivalent to the Route Efficiency expressed as time delay. Actual Flight Duration and Direct

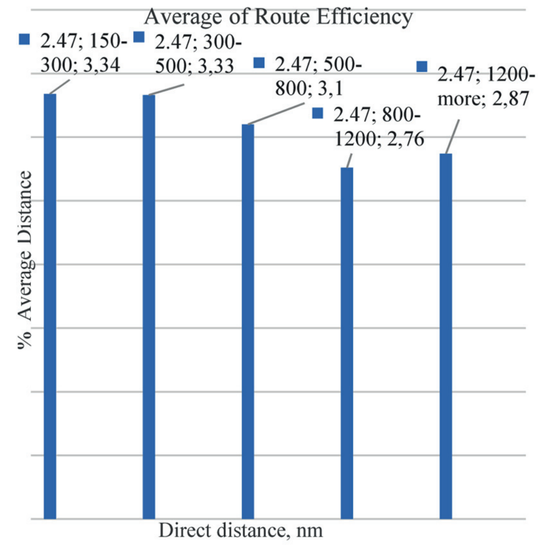

Fig. 4. Average of route efficiency in a range of 0–1200 and more nm

Flight Duration begin at Off-Block time and end at On-Block time. The indicator represents the difference in duration between real and reference profiles and is expressed in percentage points. The Eqn (2) is shown below:

$$\%\text{Duration Difference} = \frac{\text{Actual Flight Duration} - \text{Direct Duration}}{\text{Direct Duration}}. \quad (2)$$

The duration takes into account both horizontal and vertical efficiencies.

The average duration for the 12 most intensive days of every month of the year recorded is a function of the direct distance. The analysis shows that the average is 0.50% (Fig. 5). The Average distance difference is the maximum between 150–300 nm and reaches 0.55%.

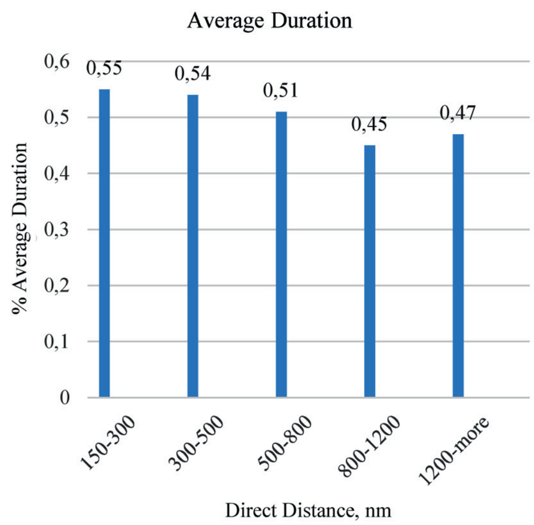

Fig. 5. Average duration in a range of 150–1200 and more nm

Total Fuel Burn

Total Fuel Burn indicator represents the amount of fuel burnt when comparing the real and reference profiles. The indicator is calculated using the same ground tracks as used in calculating the Route Efficiency indicator together with the vertical flight data and simulated optimal vertical profile. The formula is presented above. The type of aircraft plays a role of its own in calculations of this indicator. And because of the fact that there are no available data for each aircraft type it is too complicated to make new and precise calculations at the moment.

The Total Fuel Burn indicator could be presented as percentage relative to the direct trajectory provided the above mentioned data were available.

Conclusions

While technologies, concepts and procedures have helped to further optimise flight paths, increase capacity and efficiency over the past years, it still remains a challenge to maintain the same level of efficiency over the next 20 years. Only an ATM system fully equipped with the latest technologies and operational procedures can efficiently handle the situation.

Within the scope of this study was en-route horizontal flight components within the European Civil Aviation Council (ECAC) area, i.e. domestic and Inter-European flights.

The data were taken from 11 Apr 2014 to 27 Mar 2015. Recordings were done for 12 days throughout the year: each month a day when the flights were the most intensive was analysed.

Corresponding the linear trend observed for the 12 recorded most intensive days of the year the Route Efficiency is an average of 3.08%. The Route Efficiency is at a maximum for the 150–300 nm interval and reaches 3.34%. Such increase could be explained by the reduction of military airspace impact.

The average duration for the 12 most intensive days recorded is a function of the direct distance. The analysis shows that the average is 0.50%. The Average distance difference is the maximum for the 150–300 nm interval and reaches 0.55%.

A modified airspace and air route network would allow air traffic to perform at more efficient level by shortening flight distances, duration, reducing fuel burn, emission impact.

The future challenges in terms of traffic growth and flight efficiency are high. There is an evident need for greater support at a political level and commitment of all the countries towards implementation Single Sky Concept which would significantly benefit both flight efficiency and network capacity.

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HORIZONTALIŲ MARŠRUTINIŲ SKRYDŽIŲ TRAJEKTORIJOS KOMPONENTŲ PALYGINIMAS

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Santrauka

EUROCONTROL siekia pagerinti Europos maršrutų planus ir jų naudojimą. Neefektyvus oro erdvės planų ir oro maršrutinio tinklo naudojimas laikomas viena pagrindinių Europos skrydžių neefektyvumo priežasčių. Europos oro eismo valdymo (angl. ATM) sistema sudaryta iš daugelio atskirų oro navigacijos paslaugų teikėjų (angl. ANSP), o JAV sistema valdoma vieno oro navigacijos paslaugų teikėjo. Oro erdvės susiskirstymas pagal valstybių ribas daro skrydžio maršrutus neefektyvius dėl nepareikalautų oro maršrutų, skrydžio laiko, per didelio kuro sunaudojimo, CO ir NOx išsiskyrimo. Štai kodėl reikėtų pertvarkyti oro erdvę ir fiksuotų maršrutų tinklą, norint patenkinti oro erdvės operatorių poreikius ir išlaikyti reikalingą saugumo lygį. Šio straipsnio tikslas – parodyti skirtumus tarp suplanuotų skrydžių ir realių trajektorijų, įvertinant skrydžio atstumą, trukmę ir kuro sunaudojimą. Be to, buvo padaryta šių rodiklių apžvalga Europos ir JAV mastu.

Reikšminiai žodžiai**:** oro eismo valdymas, oro erdvė, oro maršrutai, skrydžio trajektorija, reali trajektorija, tiesioginė skrydžio trajektorija.