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Optimal trajectories planning in an upper airspace

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ABSTRACT

The concept of target function for calculating optimal trajectories and results related to an upper airspace capacity from computer simulations are presented in this paper. The basic model of Free Route Airspace (FRA), role of conflict free and efficient flight route planning as a part of introduction working programme – Step 2, "Trajectory – based Operations" in Single European Sky ATM Research Programme are also presented. Free Route Airspace is defined as specific airspace within which users shall freely plan their routes between an entry point and an exit point without reference to the ATS route network.

KEYWORDS: Optimal trajectories planning, Upper Airspace Capacity, Free Route Airspace

1. Introduction

The existing Airspace Management and Navigation systems in Europe are unlikely to cope with capacity demand. Flights in Europe are operated on air routes or airways essentially anchored on ground based navigational aids structured in a fixed route network. This network is relatively inflexible geographically due to its very nature. Disadvantages of this are less than optimum use of the available capacity and not economical routes from carries point of view. There is, therefore, continued pressure to upgrade the capacity of the European Airspace and Navigation systems to permit more en-route and terminal airspace capacity and to facilitate the flexible use of airspace (civil-military integration). One of possible solution is creation more and more of a new air routes. However this activity can not solve the problem completely because lack of airspace need to create this routes. Better solution is flexible and optimal use of airspace without reference to fixed route structure but with reference to entry and exit points in airspace. That is why Free Route Airspace(FRA) concept have been created in Europe. The subjects of flexible use of airspace, complexity and capacity have been published in the articles as [4,5,6,7,15] and has been researched also by Malarski and Skorupski [10,11,12,13,14]. The main criteria of airspace use assessment have been in those publication are : air traffic intensity, air traffic safety, air traffic controller workload and airspace capacity. Interesting algorithm of conflict free and optimization of route has been also presented by Durand N. and Alliot J.M. [1]. It was based on observation of ants colony behavior and choosing by them particular conflict free routes.

2. Overview of Free Route Airspace Concept

The idea of Free Route Airspace was initially approved by eight European States – Belgium, Nederland, Luxemburg, Germany, Denmark, Norway, Sweden and Maastricht Upper Airspace in 1998. FRA is a concept in which the fixed route network is removed from part of the upper airspace of above European States. Free Routes Airspace (FRA) is defined as:

A specific airspace within which users shall freely plan their routes between an entry point and an exit point without reference to the ATS *(Air Traffic Services)* route network [2].

The main objectives of user prefer routes implementation are:

a. elimination of constrains come from the fixed route network structure;

b. Increased airspace capacity;
c. Enhanced flexibility;
d. Financial and operational benefits to the airspace users;
e. Benefits as above with maintaining safety standards

One of assumption of FRA Concept is sharing the airspace between civil and military users. Using the latest information on airspace availability, supplemented by information on sector capacities, Aircraft Operators will have much more choice for optimum route selection and should benefit from the expected cost savings. Their route choice will be limited only by the need to avoid active segregated airspace (e.g TSA- Temporary Segregated Area, D - Danger Area, P - Prohibited Area or R - Restricted Area).

New FRA sector design will need to be more flexible as traffic demand varies and unrestrained by FIR/UIR or State boundaries. Basic Sector Design Criteria should at least take into account:

- the principle traffic flows and orientation
- minimising short transits through sectors
- minimising sector and centre re-entry
- positions of segregated airspace

FRA Management will differ from that of the Route Network, will no longer be given information on which routes are available, but will need to know which airspace is available. Within the FRA area there will be no limitations on the planning and using of direct (DCT) point to point routes.

With the absence of a fixed route network conflicts are likely to be more random in nature, different in characteristic and less predictable which could result in problems of detection for the Air Traffic Controller. The use of Conflict Detection and Resolution tools is expected to provide significant support to Controllers in the execution of these tasks. The efficiency of these tools, is highly dependent on the availability of an accurate system trajectory for a given flight.

Enhanced or new automatic flight planning systems permitting the computation of a free route may be necessary for airspace users to benefit from the increased flexibility provided by FRA. They should also be able to receive and process real time data concerning updates of airspace availability.

When FRA is implemented, limitations due to national borders will disappear from the perspective of an aircraft operator planning flights. With the elimination of the route network from the FRA, the associated crossing and congestion points will disappear. In their place will be a greater number of "random" crossing points associated with individual flight profiles rather than route alignment. That is why preliminary conflict free trajectory prediction is required before entrance to the airspace.

3. Flight planning area in SESAR Programme

SESAR (Single European Sky ATM Research) aims as technical pillar of the Single European Sky (SES) are eliminating the fragmented approach to European ATM, transform the ATM system, synchronise all stakeholders and combine resources. SESAR programme results will help airlines to run more reliable and punctual services, even in the face of rising demands on air transport capacity, helping their businesses to be sustainable long into the future. Improved air traffic management will lower the environmental impact and infrastructure costs, and will increase safety through better positioning and information sharing. Airspace users and their associations are particularly import and for the validation of SESAR technologies in an operational environment, making sure that the developed innovations fully meet the users' expectations. Key to the SESAR concept is the 'business/mission trajectory' principle in which airspace users, air navigation service providers and airport operators define together, through a collaborative process, the optimal flight path from gate to gate. The 3 SESAR Concept Steps are the phases through the target concept is realized. These Steps are capability-based and not fixed in time.

- Step 1, "Time-based Operations" is the building block for the implementation of the SESAR Concept and is focused on flight efficiency, predictability and the environment. The goal is a synchronised European ATM system where partners are aware of the business and operational situations and collaborate to optimise the network.
- Step 2, "Trajectory-based Operations" is focused on flight efficiency, predictability, environment and capacity, which becomes an important target. The goal is a trajectory-based ATM system where partners optimise "business and mission trajectories" through common 4D trajectory information and users define priorities in the network. "Trajectory based Operations" initiates among other thinks air/ground trajectory exchange to enable tactical planning and conflict free route segments.
- Step 3, "Performance-based Operations" will achieve the high performance required to satisfy the SESAR target concept. The goal is the implementation of a European high‒performance, integrated, network-centric, collaborative and seamless air/ ground ATM system. [3].

4. Flight planning algorithm concept

Optimal flight planning algorithm concept is presented in this chapter. Simulation model of FRA may be represented as cylinder with radius R and has been build for creating and than testing the algorithm. One of assumption is that traffic goes on quantumized levels of height H_i. So, all flight on those levels comply with vertical separation condition (1) automatically.

$$\bigwedge_{t_{kj}} \bigwedge_{j} \bigwedge_{m \neq j} O_{Vjm}\left(t_{kj}\right) \geq SV \tag{1}$$

where:
t_{kj} – k moment of aircraft j position inside the airspace,
$t_{kj} = t_{k-1j} + \Delta t$, $k = 1, 2, \ldots, n$
O_{Vjm} – vertical distance between aircraft j and aircraft m
SV – required vertical separation

Also horizontal separation condition (2) shall be fulfil for all flights in the airspace.

$$\underset{t_{kj}}{\wedge}\ \underset{j}{\wedge}\ \underset{m\neq j}{\wedge} O_{Hjm}\left(t_{kj}\right) > SH \tag{2}$$

where:
t_{kj} – k moment of aircraft j position inside the airspace,
$t_{kj} = t_{k-1j} + \Delta t$, $k = 1, 2, \ldots,$ n
O_{Hjm} – horizontal distance between aircraft j and aircraft m
SH – required horizontal separation

To calculating optimal trajectories for a given flight in simulating airspace the target function (3) has been proposed [8]:

$$Q = [c_1 + a\cdot(L - L_{ek})^2]\cdot[c_2 + b\cdot(H - H_{ek})^2]\cdot[c_3 + d\cdot(V - V_{ek})^2] \tag{3}$$

$$L = \sum_{i=1}^{N}\sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \tag{4}$$

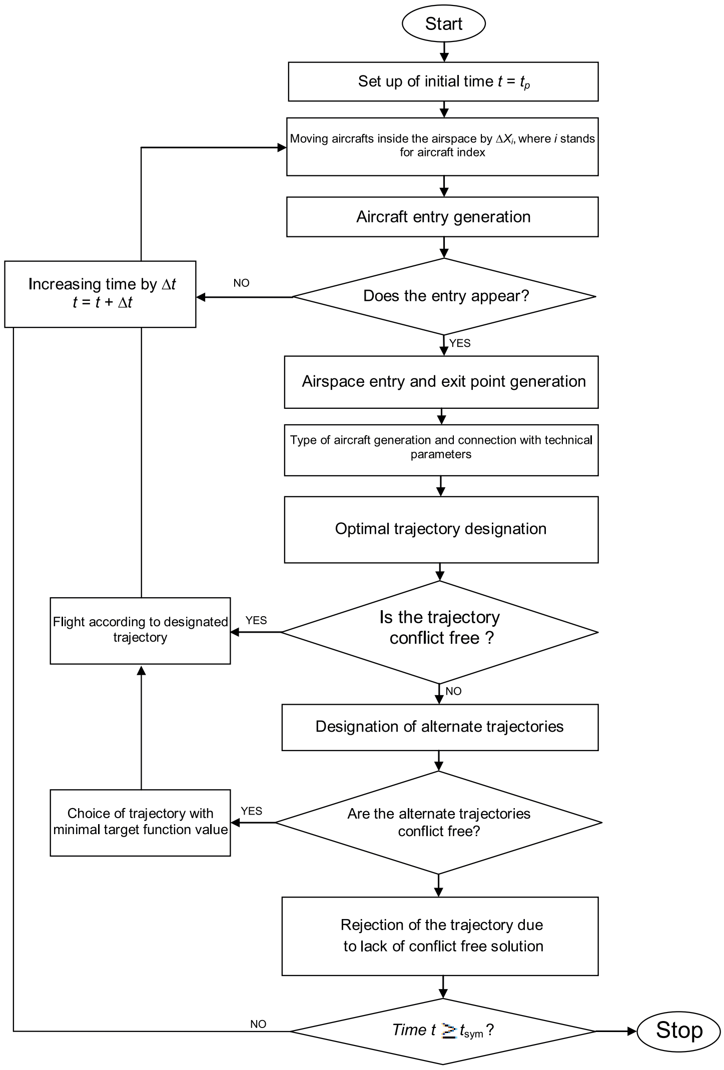
$$L_{\mathrm{ek}} = \sqrt{(x_N - x_0)^2 + (y_N - y_0)^2} \tag{5}$$

where:
$i = 1, 2, \ldots, N$ N – aircraft type index,
c_1, c_2, c_3 – constant,
L – real distance,
L_e – entry and exit point direct distance ,
H – real altitude of aircraft,
H_{ek} – economical altitude of aircraft,
V – real speed of aircraft,
V_{ek} – economical speed of aircraft,
a – distance weighting ratio,
b – altitude weighting ratio,
d – speed weighting ratio,

In optimal case target function (3) is in the form of formula (6) as below:

$$Q_{op.} = c_1 \cdot c_2 \cdot c_3 \tag{6}$$

In case of potential conflict detection before enter the airspace by given aircraft there are 18 solutions applicable to avoid this conflict. The solutions based on changes of main parameters of flight such as bearing, altitude and speed of aircraft and all combinations of them. In the next step the conflict free solution has been chosen from acceptable solutions for which the target function has minimal value. The schema of the algorithm is as below:



The research has been carried out for different aspects:

- value of separation,
- airspace parameters and traffic distribution,
- weighing ratio of: route length changes, altitude and speed of aircraft.

Collective results of the capacity and number of most numerous conflict resolution manoeuvres and simulations is presented in the table as below:

Code of simulation	Cylinder radius [NM]	Safety Buffer [NM]	Parameter *a*	Parameter *b*		Nr of most numerous manoeuvres to avoid the conflict		Max airspace capacity
				$H > H_{eko}$	$H < H_{eko}$	Speed reduction	Change of bearing with speed reduction	
Standard airspace	400	7	0,1	0,75	1,5	31	47	**255**
Free Route Airspace	400	7	0,1	0,75	1,5	53	63	**423**
Standard airspace	400	5	0,1	0,75	1,5	35	71	**340**
Free Route Airspace	400	5	0,1	0,75	1,5	75	69	**525**
Standard airspace	1000	7	0,1	0,75	1,5	54	76	**594**
Free Route Airspace	1000	7	0,1	0,75	1,5	93	63	**890**
Standard airspace	1000	5	0,1	0,75	1,5	76	100	**707**
Free Route Airspace	1000	5	0,1	0,75	1,5	97	88	**1088**
Free Route Airspace	400	7	0,75	0,75	1,5	66	65	**432**
Free Route Airspace	400	5	0,75	0,75	1,5	82	74	**563**
Free Route Airspace	400	7	0,1	0,75	2,25	72	65	**436**
Free Route Airspace	400	5	0,1	0,75	2,25	71	87	**564**
Free Route Airspace	400	7	0,1	0,75	1,5	60	54	**429**
Free Route Airspace	400	5	0,1	0,75	1,5	102	71	**535**

Second results of research is the information on most favorable maneuvers to avoid the conflict from the group of 18 solutions.

5. Conclusion

Main benefit come from implementation of optimal solution it means conflict free and efficient trajectories planning in Upper Airspace is increase of airspace capacity. Simulation results have confirmed that and in addition is was proved that the best effect of increase capacity is for a large area, what was in fact expected. Second obvious result was that capacity of airspace also increasing for a lower safety buffer around the aircraft e.g. 5NM instead of 7NM. Third main result from simulations was determination of the most favourable solutions for conflict avoidance. Based on output from the simulation the speed reduction of the given aircraft and change of bearing with speed reduction of aircraft in the same time have been the most numerous in the simulating samples. It was interesting taking into account that one of the faster and effective manoeuvre is change of the altitude level [9]. One of the safety argument to implement of Free Route Airspace is also reducing of potential conflicts in crossing and congestion points inside the airspace. Trajectories optimization from economical point of view means as shortest distance form entry to exit points and flight with economical speed on economical altitude for given type of aircraft. So, have also impact on decrease of air traffic delays and fuel consumption and at the end decrease aircraft operational costs.

"Trajectory-based Operations" and the role of optimal planning in an upper airspace as for example Free Route Airspace are also the subject of research in frame of SESAR Programme - Step 2 of Single European Sky II initiative and in particular its technical components.

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