The future of free route in the European airspace: A study quantifying the cost-benefits and safety-cost of its implementation

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The Future of Free Route in the European Airspace: A study quantifying the cost-benefits and safety-cost of its implementation

Addendum

to the PhD Thesis

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Technical University of Catalonia – BarcelonaTech

A dissertation submitted for the degree of
Doctor of Philosophy

November 2019 – September 2020

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List of Acronyms

ACC	Area Control Centre
AIRAC	Aeronautical Information and Control cycle
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
AO	Aircraft Operators
DDR	Demand Data Repository
ECAC	European Civil Aviation Conference
EUROFRA	European Free Route Airspace Block
FAB	Functional Airspace Block
FL	Flight Level
FPL	Flight Plan Filling
FTFM	Filed Tactical Flight Model
FRA	Free Route Airspace
ICAO	International Civil Aviation Organization
NEFRA	Northern European Free Route Airspace
NM	Nautical Mile
RAD	Route Availability Document
SID	Standard Instrument Departure Route
STAR	Standard Arrival Route
SW FAB	Southwest Functional Airspace Block
TMA	Terminal Manoeuvring Area

Aim of this addendum

During the last five years I have been simultaneously working in a full-time job, and thus, part-time in this PhD. Both jobs were related to the air traffic management world. After these years I have learnt that the way to document the work done in both worlds (industry and academy) is very different. While industry documents are usually focused on the results and the conclusions, the academic world is eager to know about the methodologies, the tools, the experimental set up and the details of the formulae, metrics, conditioning, iteration counters, execution time, etc.

Throughout my research on the PhD Thesis I have published a number of articles in congresses and journals of contrasted quality. In those publications there was always space limitations that made me (wrongly) believe that the final PhD document should follow the same level of detail. For this reason, the PhD Thesis document was conceived with a limited level of detail. During the defence of my work I noticed that these (not written) details are very relevant for the research world. Being able to reproduce the experiments is a pillar for the growth of the scientific knowledge.

This Addendum aims to fill the gap that makes the difference between the written PhD document and the explanation on details that I had to give during the defence. The PhD board assessed those details very positively, so after some time, I realized that it is worth to leave those details in written form. Accordingly, the content of this addendum created for the completeness of the PhD document, is two folded:

1. To clearly set the research questions and the assumptions of the experiments, the used data sets, and the selection reasons; and
2. To provide the necessary details of the steps used in the simulation methodology, for those who want to rerun the experiments, compare results, or extend the research with new contributions.

Each of these points corresponds to each of the two sections that the reader will find in this Addendum.

This document has not value by itself alone. For this reason, the reader will not find any conceptual explanation about free route, nor conclusions, neither introduction other than this short text. Interested readers shall find all this in the original PhD Thesis document, which is completely valid and full contained by itself.

1 Research questions and assumptions

This section presents the research questions and assumptions considered through the PhD Thesis. The research questions were written at the initial phase of the PhD Thesis, providing a guide to follow during all the research, and conducting the underwriting of the PhD Thesis results. Furthermore, the assumptions described in this section aim to support other researchers who want to reproduce the airspace environment and the simulations of this PhD, as the starting point or extension of their studies.

1.1 Research questions

The research questions of this PhD Thesis were:

- Which are the limits of the beneficial impact that the airspace users could expect in case of implementing a complete free route airspace in Europe? How much distance and flight time could be saved with free route?
- How complex the airspace turns with the implementation of free route? Which changes are expected in traffic complexity for a complete European free route scenario?
- How impact free route airspace in horizontal and vertical traffic conflicts? What is the increment of interactions between aircrafts with free route?

  How affects airspace fragmentation to free route benefits and complexity? Are all the free route airspaces running with same performance? How partial implementation affects to airspace benefits?

1.2 Assumptions

To assist other researches to extend their work from the airspace design and traffic simulations carried out in this PhD Thesis, the following assumptions have to be noted:

➔ **Selected trajectories are the planned trajectories**

The study considers trajectories based in the last filled flight plan, the last one submitted by aircraft operators (AO) to the network manager. These trajectories are named FTFM (Filed Tactical Flight Model), M1 traffic or Initial flight plans. The details of the trajectory processing are contained in the section 2: “Thesis methodology” of this document. For more detailed information about this M1 traffic is given in section 3.2 of the PhD Thesis document and in the NEST User Manual, Version 1.6, Eurocontrol, 2018. Initial flight plans should not be confused with the first filed flight plan from an AO. An AO could file an FPL (Flight Plan Filling) and then update/change it several times. Such FPL change log is not available for download, but only the last filed FPL.

For the distance calculations of the trajectories, this PhD considers great circle distances from origin to destination (also known as orthodromic) as the optimum distance trajectories. The selection of great circle distance as a model for comparison with the FTFM trajectories was based in that great circle distance is the shortest distance between two points, and it was an available data that could be obtained for all traffic samples, resulting in an effective way for study free route trajectories and their performance.

- ➔ Weather uncertainties and regulations

  No weather uncertainties and no traffic regulations were considered to affect the last filed flight plan. The study only considered regulations and/or weather conditions being processed until the last filed flight plan. Of course, those are not definitive, because, after aircraft take-offs, new weather conditions and regulations could appear that would affect the trajectories. Those changes were considered out of scope of this doctoral research.

- ➔ Transition from cruise to airport procedures

  Defining a FRA includes the setting of a number of fix waypoints. In particular, the fixes for arrivals (A) and departures (D) are the ones that provide the connections with the airport procedures for departures and approaches. NEST needs them to generate the complete routes, from departure and arrival airports. In our FRA designs, when the A/D fixes did not exist for an airport, we have simply create a new fix at the same latitude and longitude of the airport, and a SID (Standard Instrument Departure Route) and STAR (Standard Arrival Route), segments from it to the airport.

  As the study is focused on the FRA and this contains only en-route segments, the trajectory segments inside the TMA were excluded from any computation. For instance, in the case of the route distance calculation, we could either subtract the fixed route length of the SID and the STAR or remove the route part lying in the first 30 nm around departure and arrival airports. In the PhD the distance computation was done using the route length algorithm provided by NEST. More details can be found in reference NEST User Manual, Version 1.6, Eurocontrol, 2018.

- **ECAC zone**

  The EUROFRA free route proposed PhD Thesis was evaluating the implementation of free route in all European airspace, considering the European airspace to be equal to the ECAC (European Civil Aviation Conference) zone. The ECAC zone covers the widest grouping of Member States of any European organisation dealing with civil aviation. Currently it is composed of 44 Member States.

- **Cruise level and sector configuration**

  The study was developed in the main free route area of application, "the cruise level". The vertical limits of the defined airspace started from FL (Flight Level) 245 to FL660, except if the airspace under study was already existing with different limits. The configuration of sectors during the day was considered as fixed and corresponded with one of the current sectors configuration of the existing opening schemes, to simulate the closest free route environment.

2 Thesis methodology

To finding the answers to the initial research questions and to reaching the established objectives, the airspace had to be defined and a number of traffic simulations had to be performed to obtain the data for the analysis of the PhD Thesis results. The steps followed by the PhD Thesis are summarized in the following points:

- Background and State of Art review.
- Airspace metrics definition.
- Free route airspace simulations.
- Thesis results analysis and discussions.

Along with this doctoral research, literature reads, and reviews of free route airspace concepts were carried out continuously, and based on the state of art reviewed, metrics and simulations were defined. Once the state of art had been studied and the review of air traffic management (ATM) metrics were completed, the simulation framework had to be set up and the traffic simulations performed. Only after this the results interpretation and analysis were possible.

The details of this section focus on the free route simulations. The simulation framework was developed using the NEST tool, a strategical simulation tool from Eurocontrol, freely available until the last year of the PhD Thesis, capable of fast time simulations (see more details in section 3.5 of the PhD Thesis document, and also at the PhD Thesis reference NEST User Manual, Version 1.6, Eurocontrol, 2018). NEST simulations involved airspace design, scenarios creation, trajectory preparation and an extensively use of its algorithms for trajectory generation and analysis.

2.1 Steps of the free route simulations

The PhD Thesis simulations included multiple free route scenarios. Additionally, each scenario had to be evaluated according to several metrics, such as flight efficiency, potential separation losses (or conflicts), airspace complexity, etc. Metrics were measured for each scenario with and without free route, to understand how free route airspace configurations affect the ATM system. The process used for the simulations is summarised in Figure A-1, where four stages are clearly defined.

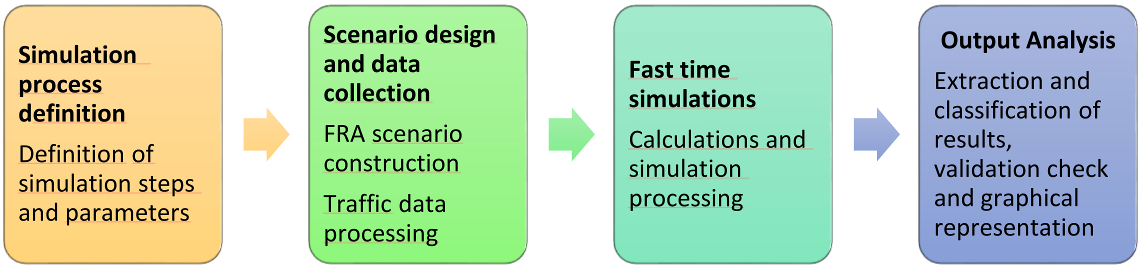

Figure A-1. *Simulation process*

The first stage, **Simulation process definition**, involves the definition of a simulation roadmap, for the later simulation execution, clarifying the data extraction, the scenarios to be designed and the data pre-processing. Here, a detailed roadmap was defined for each of the simulations described in the Appendix B of the PhD Thesis document. Additionally, through this stage, parameters like vertical/horizontal separation, uncertainties, etc. were defined.

The second stage, **Scenario design and data collection**, is centred on obtaining and preparing all data required for simulation runs. The combination of both, scenario generation and traffic sample data, enabled to run the simulation tool (NEST). Scenario generation involves the airspace design, which consisted in creating a number of files in the NEST required format considering the changes in the airspace waypoints, flight levels, airspace blocks, borders, etc. Current, future and/or past configuration airspace files had to be created to analyse compare in the next stage. The traffic sample files needed to be filtered, selecting the trajectories of the flights with the defined parameters. With all this, between 25,000 and 35,000 trajectories were processed before the simulations of each scenario.

The third stage, **Fast time simulations**, demanded a high computer effort, because the scenarios and data proposed in the PhD Thesis involved a high number of flight trajectories generation and analysis. By combining the flight data with the scenarios, it was possible to produce the 4D trajectories derived from free route.

Finally, the fourth stage, **Output Analysis**, took the output files of the NEST simulations and prepared them for the results analysis. This included the results extraction and classification, their validation check, and the graphical representation of results.

2.2 Simulation set up

Regarding the traffic data collection and the airspace configurations, there are a set of statements that the PhD had followed. The next statements were considered in order to run the fast time simulations:

- ➔ The PhD Thesis defined three different sets of traffic samples:
  - Pre-free route or partial,
  - current, and
  - full free route.

  In the case of airspace scenarios, there were two defined:
  - pre free route or partial free route, and
  - full free route.

  The PhD Thesis in Table 3.6 provides how each area and traffic sample were combined.

- ➔ The pre-free route or partial free route scenario was extracted from the Eurocontrol historical traffic data, specifically from the data demand repository version 2 (DDR2) database before the FRA was established or completely implemented.
- ➔ The future traffic presented in Table 3.6 from the PhD Thesis document was provided using the traffic forecast for 2024 from the baseline samples from 2018. The traffic forecast method considers a medium-term forecast that combines the flight statistics with the economic growth and with the models of other important drivers in the industry, such as costs, airport capacity, passengers, load factors, aircraft size, etc. The reason of presenting two scenarios was to obtain measures in both, the short term (more realistic and accurate) and the long term (best suited for the free route long term implementation).
- ➔ The traffic selection criterion was to consider normal operational days of different seasons and not affected by non-common phenomena, such as adverse weather, strikes, holidays, or any other external perturbation. Seven days were selected including Monday to weekend, for all the scenarios studied. The selected days were from different AIRAC (Aeronautical Information Publications) cycles for each scenario. The traffic trajectories were filtered to contain only the segments inside the airspace under study: NEFRA (North European Free Route Airspace), SW FAB (Southwest Functional Airspace Block) and ECAC area.

2.3 SO6 trajectories preparation

With the objective of assessing the evolution of the free route across different airspaces and different stages of deployment, a total of **126 traffic samples** were prepared and processed as is described in the Appendix B of the PhD Thesis. These traffic samples are SO6 formatted files, containing each all the 4D flight segments of the M1 trajectories crossing the selected airspace. The total number of values that had to be calculated in this doctoral contained up to **1,756 metrics**. The following points describe the main stages for the processing of each traffic sample:

1. Traffic extraction from DDR Eurocontrol.
2. Airspace filtering to consider only the area under study: SW FAB, NEFRA or EUROFRA.
3. Airspace/traffic intersections calculation (T5 file).
4. Free route processing function, converting the Initial trajectories to a 2D trajectory file (EXP2) and a flight level constrains file (FLC).
5. Generation of the final 4D trajectory file (SO6) considering the free route and the BADA aircraft performances.
6. Trajectory check identify any flight unable to be processed by NEST.
7. Selection of only the exact matched flights in both traffic samples, for fair comparison.
8. Run evaluation functions: PRU complexity, conflicts calculation and route efficiency. For the last one, the TMA area (defined as 30 nm around airports) were not considered.
9. Extract the results and generate the graphics.

Figure A-2 shows an example of one SO6 trajectory. Each of the SO6 trajectories contains dozens of entries related to trajectory legs or segments. Each segment has data for the main characteristics of the 4D trajectory, including fields such as latitude, longitude, altitude and time of the segment begin and end.

2.4 Scenarios design

Intermediate fixes need to be entered in all FRA scenarios. For the special case of EUROFRA, a large number of them need to be also created. For this, we used a uniform waypoint network were Intermediate points were located one degree apart in Latitude, and two degrees apart in Longitude. In the worst case this separation rule was giving a distance between neighbour fixes of 60 nm. Which such configuration, the segments of a flight plan defined over this grid will be always below the 200 nm, the maximum limit set by ICAO Doc 4444 for the distance of a leg. In the end this process generated of more than 2,600 Intermediate fixes.

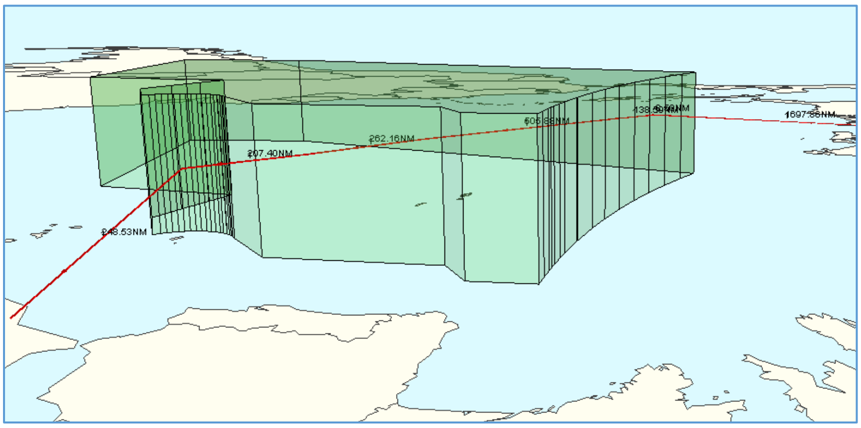

Figure A-2. *Example of S06 trajectory*

Figure A-3 shows the design of the border (Entry/Exit) fixes and the Intermediate fixes of the designed EUROFRA. The Entry and Exit points were constructed by selecting the existing navigation points in the border sectors of the ECAC. A large manual processing of the existing sectors was needed. Finally, if distances between consecutive Entry/Exit points were higher than 60 nm, new Entry/Exit points were also defined at the ECAC borders.

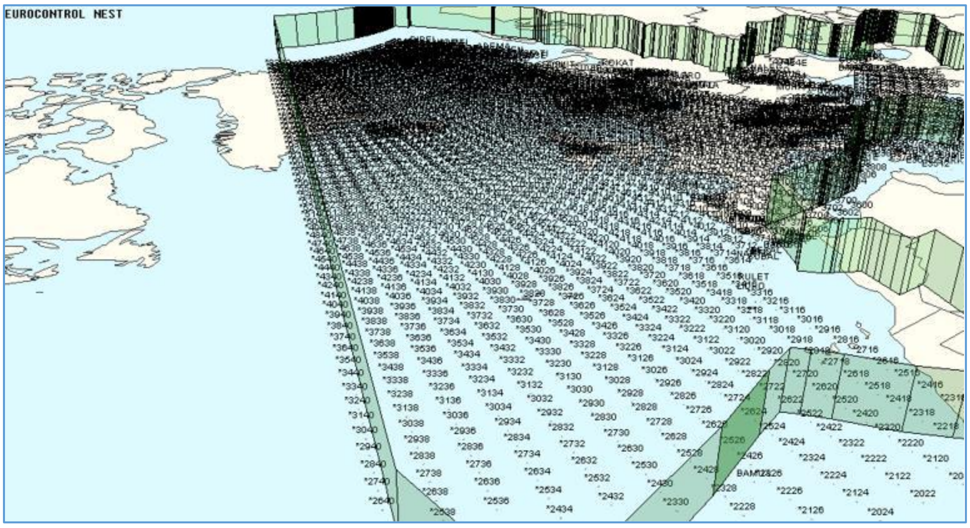

Figure A-3. *EUROFRA waypoint design*