European Airspace Measures towards a more Sustainable ATM

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ABSTRACT

The rapid increase of air traffic movements continues to grow and estimated predictions for the future several decades’, state that the current Air Traffic Management system will not be able to support such increase in demand of air transportation with required levels of safety and sustainability. For this reason, organisation managing the European air navigation services - Eurocontrol has decided to create a new balanced program for the future improvements of Single European Sky.

Single European Sky, supported by SESAR, aims to bring all the necessary advanced technological inputs and procedures with a view for modernising and optimising the future European ATM Network. With the main idea of providing a high-management infrastructure that will allow safe and friendly development of air transport in Europe and its neighbouring countries.

In order to accelerate the essential development steps to support the increase in air transportation demand, a significant contribution towards the Single European Sky objectives will be required. Future optimisation tactics for the European airspace will require collaboration between airspace organisations, their users and entire ATM system.

The purpose of this project is to look at the current airspace situation and apply some of the possible solutions to reduce the environmental impact. One of such solutions is to look at how the aircraft plans its route and apply the feasible solution to reduce the distance it travels and decrease its environmental impact.

The findings demonstrated that the current airspace route network structure is complex and non-efficient. With performing flights at much shorter routes and more optimised course of flight a significant changes towards more sustainable airspace are possible to be achieved. With additional improvements applied towards the aircraft perfection, even further efficiency gains could be achieved.
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List of Abbreviations

2D – two-dimensional
3D – three-dimensional
4D – four-dimensional
AMEBA – Advanced Model Engineering for BADA
AIRAC – Aeronautical Information Regulation and Control
ANS – Air Navigation Services
ANSP – Air Navigation Service Providers
AOM – Aircraft Operating Manual
ATS – Air Traffic Services
ASCII – American Standard Code for Information Interchange
ATFM – Air Traffic Flow and Capacity Management
ATC – Air Traffic Control / Controller
ATM – Air Traffic Management
BADA – Base of Aircraft Data
CTA – Control Area
CTR – Control Zone
DDR – Demand Data Repository
ECAC – European Civil Aviation Conference
ESRA – Eurocontrol Statistical Reference Area
EU – European Union
FUA – Flexible Use of Airspace
FMS – Flight Management System
FL – Flight Level
GCD – Great Circle Distance
ICAO – International Civil Aviation Organization
IFV – Instrument Flight Rules
KPA – Key Performance Areas
KPI – Key Performance Indicators
NM – Nautical Miles
NM- Network Managers
SES – Single European Sky
SESAR – Single European Sky ATM Research
TMA – Terminal Manoeuvring Area/ Terminal Control Area
TAS – True Air Speed
SID – Standard Instrument Departure
STAR – Standard Terminal Arrival Route
SWIM – System Wide Information Management
VFR – Visual Flight Rules
INTRODUCTION

The world of air transport is changing, not only through the technological evolution and economy, but also as an interaction of society demands, in term of future strategies. Change in air traffic management can be addressed from many different perspectives. It is evident that European ATM is undergoing a process of change in many of its aspects and the infrastructure side of ATM needs improvement and modernisation.

Despite worldwide challenges, growth for demand in aviation continues to increase. However the benefits cannot be achieved with the current situation. Commercial air transport is a relatively young industry, and current forecasts indicate that it will continue to grow over the next few decades. Air transport provides mobility to citizens and goods with a continuing growth in demand, which is an indicator of success for aviation industry;

While bringing considerable benefits to the economy and society, air transportation also brings negative impacts to business, society and the environment. Therefore, while growth of demand is beneficial to business and industries, at the same time it is not as efficient as it could be. Such growth in demand has generated new challenges for capacity and safety as well as the environmental impact. One of the problems to be addressed is that with current airspace situation aircrafts consume significant amount of fuel which is directly related to the CO2 emissions.

One of the most frequent quotes from ‘Our common future’: “Sustainable development is development that meets the needs of the present without compromising the ability of future generation to meet their own needs”. This can be directly related to the utilisation of air transportation in respect to fuel consumption and the emissions it creates. As growth in air traffic increases, so do the emissions, which pollute the local air at the higher atmospheres [1].

Eurocontrols’ initiative to adopt Single European Sky regulation to reduce airspace division from national borders carries a potential possibility of restructuring air navigation in Europe. The change of such initiative will bring reorganisations of air navigation services that were tied to the national borders, to a more efficient structure.

A major European programme for such modernisation of the air traffic management infrastructure, supporting the Single European Sky initiatives is SESAR project. It aims to define and implement new air traffic management concept of operations to overcome current capacity, environment and safety issues. SESAR has set the definition for the 2025 performance targets, which covers a broad spectrum of such areas, and targets represent the initial values to deal with further analysis and validation.
SESAR programme aims at bringing the point of readiness for deployment of new trajectory management procedures and technologies for the European ATM system. In this work we will be referring to SESAR proposals and objectives for the future improvement of fuel consumption and the environmental impact.

The primary focus of these programs is concerned with aircrafts path and trajectory. It will support the combined decision making processes, using end-user preferences and exploit that power of shared information. Business trajectory emphasises that the flight course has a purpose, be it commercial or mission related. Overall the operational performance for the business trajectory lies at the core of SESAR proposal, with the aim of executing each flight as close as possible for the end-user. Soon in the world the air navigation service providers will benefit from a new resource to help plan the ATM improvements.

Aircraft manufactures are constantly working on improving the engine technologies to reduce the fuel consumption and its impact regarding the CO2 emission. Manufacturers developing newer technologies are leading to adapt new possibilities. However in this work we will be looking at the possibilities of reducing such emissions and fuel consumption without the necessity of change towards the aircraft or engine technological advances.

1.2 Report Outline

The report is composed by the following chapters:

**Introduction:** Provides a general description for thesis drive towards more sustainable solution.

**Change for the European Airspace:** This chapter describes how the current Air Traffic Management (ATM) limits regarding the controllers’ workload and the current/future solutions, with SESAR proposals towards a more organised and respectable use of European airspace.

**Theory and Tools:** Provides all the necessary material required for the process of obtaining the results.

**Current and Future Airspace Exploitation:** In this chapter we covered the aspects of the current flight route structure system, and made the necessary assumptions for the future proposed airspace system.

**Fuel Consumption and CO2 Emissions:** Here we described the results obtained for fuel and CO2 emissions,

**Conclusion:** Summary of the work performed, with respect of the values obtained as well as the suggestions for future work that could benefit the future estimations.
Chapter 2

CHANGE FOR EUROPEAN AIRSPACE

2.1. Growth in European Airspace

Back in the middle of the 20th century, more than thirty states participated in the meeting for establishing the International Civil Aviation Organisation (ICAO), in which the main set of fundamental rules and regulations for air navigation system were created around the world.

A pilot planning a flight can choose between two flight rules. First is - Visual Flight Rules (VFR), where the pilot is responsible for maintaining visual reference and contact with other airspace users, if the visual reference is lost, such as entering a cloud or flying in conditions with reduced visibility – the results may be disastrous. Second is Instrument Flight Rules (IFR), in which majority of aircrafts are navigated from point to point by ground and satellite-based systems as well as communication with ATC, but aircrafts can perform IFR operations if they have the appropriate on-board instruments. Aircrafts performing any of these flights are also provided with weather information for their departing and arrival destinations [2].

During the first years of aviation the number of flights was sufficiently low, so it was for captain alone to be responsible for safety of the aircraft avoiding ground obstacles and terrains. With increase in air movements and large development of traffic, air traffic controllers took charge to carry out required task and measures to guarantee a safe flight. The full air traffic management (ATM) system represents itself as a complicated man-machine system, in which air traffic controllers' (ATC) tasks is to manage actions and decision making to ensure the safety of flight. ATC are responsible for safety of flights as well as throughput of a sector or control area, which in turn depends on the temporal load on the ATC. In Europe the capacity of an ATC sector is defined as the ‘maximum number of aircraft that can enter an ATC sector in a specified period’. For planning purposes of the ATM, the system is designed and modelled in the interest of eliminating workload on ATC, however the ATM is used to describe activities associated with organisation and traffic management of airspace, which is carried out with corresponding aviation authorities in borders of their responsibility. Common ATM goals are to provide aircraft operators with opportunity to satisfy their demands concerning planned departure and arrivals, as well as to keep up with their flight profile without jeopardising agreed levels of safety [3].

Nowadays due to improved technologies the need to report position is becoming rare, which also reduces controllers’ workload. However there are still places were to report aircraft position is required, usually referred to as a waypoint. According to some of the ICAO regulations a waypoint may be of two types: Fly-by waypoint, which marks the intersection of two paths and transitioning aircraft from one path to
another; Fly-over waypoint is a point at which a turn in initiated in order to join the next segment of a route. In addition an airline company may insert waypoints into the Flight Management System of an aircraft to help better navigate a continuous descent approach [2].

Air travel in Europe continues to grow at a rapid rate, which in result is heavily dependent on ATC workload, physical and mental that controllers must undertake to safely conduct air traffic under their jurisdiction. The consequences of on-going growth in the current European ATM system will be reflected in the struggle to cope with the air traffic, which may result in delays and flight inefficiencies.

2.2 Single European Sky

The initiative to reform air traffic management started in the early 21st century with the broad preparation of different packages for the implementation intention. With Eurocontrol collaboration it initiated number of programmes to introduce improvements to ATM system across Europe, providing several functions of common interests and agreements to pursue the common policy for improvement and apply the necessary changes for the future development.

The global air transportation system plays an important role of the world economy and the growth in air traffic is necessary to support the economic development and produce economic wealth. In order to accommodate the increased traffic demand, the system had to radically change from the current one. In order to have a response to such dramatic air traffic growth European commission decided on creating Single European Sky (SES).

At first each European state was responsible for provision of air traffic services and suggestions only over its territory. From that time the main objective for the improvement of ATM in Europe and to cope with increased number of air traffic operations under the safest, flight-efficient and environmentally friendly conditions went away from national border to a broader viewpoint. In order to meet all common rules and procedures at the European level, SES was born to meet their needs and to obtain the operational efficiency gains through common procedures and training of air traffic controllers [4].

Single European Sky is a balanced programme for developing collaborative ways and bringing requirements of numerous States into a joint undertaking. Single European Sky initiative leads the joint work programme that organises necessary technical inputs into future European airspace. The current ATM system currently handles around 25 to 28 thousand daily flights, and with predicted forecasts they are likely to double. The SES structure capabilities have been improved through the establishment in 2007 a joint undertaking (JU) on research and development
(SESAR JU). SESAR is dealing with the new generation European air traffic management, but we will come back to it later in this chapter [5].

SES relies on the policy of European Union in the field of international relations. This policy also considers the added value of regional cooperation activities carried out at the level of international organisations such as ICAO and Eurocontrol, and ensuring stability between its actions in the external field and actions undertaken under support of such organisations.

SES is supported by the Single European Sky ATM Research (SESAR) programme, which will provide advanced technologies and procedures with a view of modernising and optimising the future European ATM Network. Eurocontrol is contributing to such improvements with support to both regulatory and technology elements of the Single European Sky by identifying needs for new regulations for complex ATM technologies and procedures delivered by SESAR.

Investments in such technology will also allow safer and more punctual flights as well as support the airspace users to reduce the environmental impact by maximising the use of the available airspace. The SES process is relatively young, and much work still needs to be done. Member States and air navigation service providers are expected to make substantial progress towards the creation of perfect airspace system.

2.3 SESAR

Within the Single European Sky (SES) activity, the European ATM is agreed on guidelines for leading the modernisation of current ATM system with the deployment of SESAR (Single European ATM Research) program. SESAR is a program that will give Europe a high-performance air-traffic management infrastructure, which will allow safe and friendly development of air transport.

The SESAR program is the European Air traffic Management project, which combines technological, economic and supervisory features and will use SES regulation to synchronise the plans for future actions for different stakeholders and gather resources for the development and implementation of the required improvements throughout Europe, in airborne and ground system.

In Key Performance Areas (KPA), quality of service is closely linked to capacity and it can directly show on how there is an effective and efficient use of it. Therefore, it must be noted that the objective related to the increase of capacity is aiming at improving the overall quality of service provided to the Airspace Users. SES goals vary across all of KPA, for some the capabilities developed by SESAR are designed to address much of the proposed SES strategic performance objectives and therefore meeting SES goals. Table 2.1 is taken from SESAR Master Plan and
shows the best estimation of traffic growth and objective to be met for the Deployment Baseline step 1, benefit estimates that can be derived from the SESAR validation targets.

Table 2.1 Proposed SES Strategic Performance Objectives at European Network Level [6]

<table>
<thead>
<tr>
<th>KPA</th>
<th>Key Performance Indicator (KPI)</th>
<th>Strategic Objectives (as compared to 2005)</th>
<th>SESAR Step1 + Baseline Contribution (as compared to 2005)</th>
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<tr>
<td>Safety</td>
<td>Improve Safety performance by a factor of 10</td>
<td></td>
<td></td>
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<tr>
<td>ECAC annual accidents</td>
<td>No increase in number of accidents with ATM contribution per annum</td>
<td>No increase – irrespective of traffic growth</td>
<td>No increase- irrespective of traffic increase addressed by SESAR</td>
</tr>
<tr>
<td>Safety risk</td>
<td>Safety risk per flight hour</td>
<td>No increase – irrespective of traffic growth</td>
<td>-40%</td>
</tr>
<tr>
<td>Environment</td>
<td>Enable a 3-fold increase in ATM capacity to be deployed where needed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airspace capacity</td>
<td>En-route capacity</td>
<td>x3</td>
<td>+27%</td>
</tr>
<tr>
<td>Airport capacity</td>
<td>Runway capacity for best-in-class Airports</td>
<td></td>
<td>+14%</td>
</tr>
<tr>
<td>Environment</td>
<td>Enable a 10% reduction in the effects flights have on the environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight efficiency</td>
<td>Gate-to-gate Overall ANS related CO2 Emissions Index</td>
<td>-10%</td>
<td>-2,8%</td>
</tr>
<tr>
<td>Cost Efficiency</td>
<td>Provide ATM services at a unit cost to the airspace users which is at least 50% less</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct ANS cost per Flight</td>
<td>Total annual en-route and Terminal ANS cost in Europe, €2005/flight</td>
<td>-50%</td>
<td>-6%</td>
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SESAR is expected to bring benefits in a variety of areas: reduction in fuel consumption through better flight profiles and fewer delays, a decrease in air navigation services (ANS) cost per flight, an increase in capacity of airports and in the airspace to meet traffic demand. Considering the current limited availability of validation results, the best possible approach to quantifying the benefits is to use the validation targets. The values of benefits depend on the traffic growth, deployment scenarios, and research and development. The benefits of SESAR will be monitored with validation targets for periods of time.

The SESAR programme will provide an effective solution to air transport capacity bottlenecks, fill the gaps in air traffic management system, enable significant reduction of CO2 emissions, increase safety levels, and reduce overall costs, benefiting all European stakeholders and extending beyond the air transport industry. As early as 2008, the definition phase of SESAR concluded that with SESAR’s contribution, SES could achieve the following targets by 2020 [6]:

- Enable a 3-fold increase in capacity, SES high-level goal: +200%;
- associated improvement in safety so that the total number of ATM-induced accidents and serious risk bearing incidents would not increase despite traffic growth
- 10% reduction per flight in environmental impact compared to 2005;
- 50% reduction in cost per flight compared to 2004.

SESAR project is the European air traffic control infrastructure modernisation programme, which aims at developing the new generation air traffic management system capable of ensuring safety and fluidity of air transport worldwide over the next several decades. It has 3 main phase steps through which the target concept is realised.

The first phase of SESAR is the definition phase, which ended in 2008, delivering ATM master plan, defining the content, development and deployment plans of the next generation of ATM systems, which was led by Eurocontrol, and co-funded by the European Commission.

The second is the development phase, which produced the required new generation of technological systems and components previously defined in the definition phase. Here the European Commission proposed the creation of a joint undertaking, based on Galileo model, which will join private and public funds, and guarantee a single management structure for the project.

The third is the deployment phase, starting from 2013 will seek to build the new infrastructure at a wide scale both in Europe and in partner countries, and will be carried out under the responsibility of the industries.

The major developments have been possible due to the enhanced cooperation with Eurocontrol and the extensive involvement of stakeholders from the ATM community. History has shown that it often takes a long time to implement improvements to the ATM system, and that there are often long delays until a deployment is complete.

An optimised financial solution must therefore be developed, which will result in a coordinated combination of public and private funds. In order to ensure timely implementation, it is estimated that SESAR deployment would require at least 3 Bn€ in EU funds in the next financial perspective of the European Union starting in 2014. EU funding should facilitate the synchronisation and coordination between stakeholders and be focused on Essential Operational Changes identified in the Master Plan. An important part of the public funds is estimated to be required during the period 2014-2024 where investments to implement SESAR Deployment Baseline and Step 1 will overlap.

For the development of aviation system block upgrades, ICAO made use of the material provided by SESAR and NextGen, and from SESAR perspective, mapping such initiatives is important to achieve global interoperability and synchronisation where and when necessary.
Chapter 3

THEORY AND TOOLS

3.1 Eurocontrol & ECAC

Eurocontrol, is an intergovernmental organisation of 40, or even more member states, started in 1960 and is describing itself as the European Organisation for the Safety of Air Navigation. It provides skills and technical expertise for aeronautics and flight across Europe and is working on the building of a homogeneous European ATM system, to fully respond to the continuing increase in air traffic, while respecting the essential aspects of maintaining high levels of safety, conservation of environment and reduction of costs.

Eurocontrol manages the flow of more than 42 markets which participate in the European Civil Aviation Conference (ECAC) to ensure that the user demand will not overload the capacity requirements. Here it should be noted that the control area is larger than number of member states consisted in Eurocontrol. By 1996 Eurocontrol had taken over the responsibility for the range of Air Traffic Flow Management (ATFM) services in Europe, which were previously handled by the regional management units.

Updates for the Eurocontrol forecasts are published for short term, medium term and long term, two, seven and 20 year respectively, for forecasts of the number of flights in over 42 markets across Europe. As an air traffic management body, its focus is on the number of flights, or air traffic movements, which does not forecast passenger numbers. European airspace lies in the EUROCONTROL Statistical Reference Area (ESRA08) as can be seen from figure 3.1.

Figure 3.1 ESRA08 – Eurocontrol Statistical Reference Area
The real traffic movements are often not the same as the predicted statistical forecasts, so it is hard to estimate the exact number of flights for future references. As an example: “Traffic levels in 2012 were below the forecast published by Eurocontrol in Feb-2012, with the end of winter 2011-2012 and the start of winter 2012-2013 being weaker than expected”[7]. Here it can be also emphasized that there is no typical pattern, the flights can vary on season and special events, such as FIFA World Cup, school vacation days, Olympics etc... Figure 3.2, taken from Eurocontrol Seven-Year Forecast is showing the actual and the forecasted number of flights during one year. It was also stated that the total number of flights during the year declined by 2.4% in Europe in 2012, comparing to 2011.

![Figure 3.2 Actual traffic of 2012 compared with the forecast of February 2012. [7]]

In 2010, the European ATM system has controlled 9.5 million flights and on busy days an average of 33,000 flights. On the other note, the future forecast for demand on the aeronautical activity predicts an average increase of 1.5% annually, and by the year 2035 we will be looking at an annual of 15 millions flights.

Eurocontrol plays a major role in predicting the future for airspace traffic demands. It acts as a key participant in gathering all the required information for the traffic analysis and aircraft performances. Eurocontrol is the main provider of all required data of monitored flights and is a main contributor for the future development of European airspace.

In our project we have used, with an agreement of Eurocontrol, all the required tools and data that was provided by this organisation, because it is the main supplier of all the necessary data/values for our evaluation.
3.2 Nest Modelling Tool.

Airspace design requires mature modelling and efficient simulation tool to process and validate airspace design proposals. It must carry out and operational analysis of airspace structure combined with numerous traffic distribution options. The main objective of airspace modelling is to conduct quantitative of potential European airspace changes, assess their impact on capacity planning and flight efficiency using mathematical simulation models. The scale of modelling can range from changes concerning individual Air traffic services to those that include the entire European airspace and ATS route network. Such modelling tool is now being available from Eurocontrol for the airspace structure design and development.

Nest - the Network Strategic Tool, which is a combination of previous NEVAC & SAAM tools. Nest is a desktop application tool that is used for scenario preparation and real-time simulation at local and network levels. It is used by Eurocontrol Network Managers and Air Navigation Service Providers (ANSPs) for airspace structure design and development, capacity planning, designing the network routes and airspace, as well as to analyse past and future traffic flows [8].

Nest is a powerful scenario-based modelling engine, capable of performing a wide range of complex operationally relevant optimisation and analysis functionalities. It can process large quantities of data for multiple years and as well observe micro-levels for short periods of data, allowing users to detect movements and carry out detailed analysis. The screenshot of Nest window may be seen in figure 3.3.

Nest provides a set of data visualisation features for creating 2D/3D representation of data and 4D time-based actions. Scenario data can be exported as a single or multiple files, in which changes are allowed to be made and imported back into the scenario model. The file format depends on the output to be created, it can be as a single excel file, or .so6 file format, which can be opened as a text composition [8]. An example of .so6 file may be seen in Appendix A.

We have already mentioned that Nest covers a huge variety of possibilities to be analysed and modelled. In order to access the modelled scenario, a default dataset for Nest is available for download from Eurocontrols extranet portal (https://extranet.eurocontrol.int) [9]. The default datasets for Nest are developed by European airspace and route network, are provided by Eurocontrol at the end of each AIRAC cycle.

The planned updated to key aviation data occur on a fixed, 28-day cycle, known as Aeronautical Information Regulation and Control (AIRAC) cycle. Updated are distributed in advance of the cycle’s effective date to allow time for system to be updated with the new data before it takes effect. Figure 3.4 shows DDR –Historical Page, which can be accessed from Eurocontrol’s portal to download the required AIRAC dataset [9].
European Airspace Measures towards a more Sustainable ATM

The tool-set complemented by a full-set database of past, present and future airspace demand data is called Demand Data Repository or DDR. DDR provides through web application a simple and full interface for generating and downloading traffic samples future and past, for planning and post-operations traffic movement analysis.

As mentioned earlier AIRAC file can be chosen for any required period of time. Four our project we have chosen a date where no cancelled flights occurred in the middle of August, or to be precise, Friday August 10th 2012. During that day Nest modelling tool showed that that a total number of 31,650 flights passed through Eurocontrols
controlled airspace over European airspace. Figure 3.5 shows a picture from Nest tool, showing the actual and total number of flights.

![Figure 3.5](image)

**Figure 3.5** Taken from Nest modelling tool. Actual Traffic on 10th of August 2012.

For our project we are going to take only aircraft types, to which the operation performance parameters were established. These types of aircrafts could be seen in the table 3.2 and as it is mentioned in Eurocontrols Cost Benefit Analyses, these types of aircrafts represent approximately 50% of the fleet.

The final number of flights we are going to have for the date of August 10th 2012 will be 20,792 flights, which in the end is more than 65% of total flights on the selected date. In table 3.1, you can see the amount of flights carried out, on a chosen/given date, by different aircraft types.

**Table 3.1** Quantity of flights on a given day

<table>
<thead>
<tr>
<th>#</th>
<th>Aircraft Type</th>
<th>Number of flights</th>
<th>#</th>
<th>Aircraft Type</th>
<th>Number of flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A319</td>
<td>3,027</td>
<td>14</td>
<td>B763</td>
<td>502</td>
</tr>
<tr>
<td>2</td>
<td>A320</td>
<td>4,535</td>
<td>15</td>
<td>B772</td>
<td>366</td>
</tr>
<tr>
<td>3</td>
<td>A321</td>
<td>1,591</td>
<td>16</td>
<td>B77W</td>
<td>324</td>
</tr>
<tr>
<td>4</td>
<td>A332</td>
<td>475</td>
<td>17</td>
<td>BE20</td>
<td>183</td>
</tr>
<tr>
<td>5</td>
<td>A333</td>
<td>339</td>
<td>18</td>
<td>C56X</td>
<td>188</td>
</tr>
<tr>
<td>6</td>
<td>A343</td>
<td>227</td>
<td>19</td>
<td>CL60</td>
<td>86</td>
</tr>
<tr>
<td>7</td>
<td>AT72</td>
<td>659</td>
<td>20</td>
<td>F900</td>
<td>53</td>
</tr>
<tr>
<td>8</td>
<td>B733</td>
<td>828</td>
<td>21</td>
<td>H25B</td>
<td>110</td>
</tr>
<tr>
<td>9</td>
<td>B735</td>
<td>404</td>
<td>22</td>
<td>MD82</td>
<td>217</td>
</tr>
<tr>
<td>10</td>
<td>B737</td>
<td>747</td>
<td>23</td>
<td>MD11</td>
<td>94</td>
</tr>
<tr>
<td>11</td>
<td>B738</td>
<td>4,695</td>
<td>24</td>
<td>PA34</td>
<td>61</td>
</tr>
<tr>
<td>12</td>
<td>B744</td>
<td>409</td>
<td>25</td>
<td>LJ45</td>
<td>33</td>
</tr>
<tr>
<td>13</td>
<td>B752</td>
<td>639</td>
<td></td>
<td></td>
<td><strong>Total of 20,792 flights</strong></td>
</tr>
</tbody>
</table>

This project will take a look in the fuel consumption part for the specific aircraft types that are mentioned in the chapter 5.
3.3. Fleet Size

The document of data inputs provides a standard set of data commonly used in economic and financial ATM-related analyses and evaluations. In the last 2013 edition of the document the improvements for 2012 data model and obtained values were prepared, as well as update on prices for the year 2012 to Euros, unless specified otherwise [10].

The standard inputs have been compiled from EUROCONTROL and are publicly available documents. The document also gives details of the sources of information and a discussion of the applicability and use of the values. They are average values and may not be appropriate in all circumstances, but for our purpose the information enclosed in the document, suits as guidance for the assessment measures.

To begin with, we will look to the aircraft fleet size operating in Europe. That is the number of civil aircraft operating in Eurocontrol Network Manager Controlled airspace in Europe or as is it has been referred to as ECAC airspace. The table 3.2 is taken from the standard inputs cost benefit analyses, sorted in the alphabetical order [10].

The number of aircraft presented were derived from flight plans submitted to Eurocontrol Network Managers during the year 2012, saying that these aircrafts were active in European airspace at that time. Aircrafts presented in the table, are based on the submission of the flight plan to the Network Manager, and it excludes aircrafts that do not fly under the controlled airspace and the ones that do not submit their flight plans to the Network Manager. Such aircrafts are lying in the group sorted as Military fleet and aircrafts operating under the Visual Flight Rules (VFR) [10].

It is worth mentioning that, not for every type of aircraft presented in the table 3.3 we were able to find the operational performance parameters, so the future calculations that were made are based on aircrafts provided form both Eurocontrol’s cost benefit analyses and some of the most exploited aircrafts for the duration of the chosen date. The number of most exploited aircrafts could be obtained from the Nest modelling tool, and the full table of chosen aircrafts that were included in this work can be seen in table 3.3.

As we will mention in the future, BADA provides the operational performance characteristics for most of the directly available aircrafts. The value for different aircrafts performance was from the BADA, which we mention in section 3.4 of this document.

In table 3.3 we have also included for every chosen aircraft type its most optimum or the minimum fuel consumption, which is directly related to the Flight Level the aircraft is flying and its recommended speed. It so happens that for most aircraft types, flying higher would result in lower fuel consumption values. The numbers presented in the table 3.3 represent the least amount of fuel needed to fly at its highest altitude, and that these values are taken only for the cruise part of the route. In the table 3.3 we
have also given the aircrafts recommended operational true airspeed (TAS) at a given altitude, which is measured at aircrafts flying level.

**Table 3.2** Fleet size, operating in controlled airspace in Europe. Period: year 2012

<table>
<thead>
<tr>
<th>#</th>
<th>Aircraft Type</th>
<th>Number of aircrafts</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A319</td>
<td>854</td>
<td>2.50%</td>
</tr>
<tr>
<td>2</td>
<td>A320</td>
<td>1,833</td>
<td>5.37%</td>
</tr>
<tr>
<td>3</td>
<td>A321</td>
<td>517</td>
<td>1.52%</td>
</tr>
<tr>
<td>4</td>
<td>A332</td>
<td>455</td>
<td>1.33%</td>
</tr>
<tr>
<td>5</td>
<td>A343</td>
<td>284</td>
<td>0.88%</td>
</tr>
<tr>
<td>6</td>
<td>AT72</td>
<td>265</td>
<td>0.88%</td>
</tr>
<tr>
<td>7</td>
<td>B733</td>
<td>299</td>
<td>0.88%</td>
</tr>
<tr>
<td>8</td>
<td>B735</td>
<td>203</td>
<td>0.90%</td>
</tr>
<tr>
<td>9</td>
<td>B737</td>
<td>336</td>
<td>0.98%</td>
</tr>
<tr>
<td>10</td>
<td>B738</td>
<td>1,167</td>
<td>3.42%</td>
</tr>
<tr>
<td>11</td>
<td>B744</td>
<td>607</td>
<td>1.78%</td>
</tr>
<tr>
<td>12</td>
<td>B752</td>
<td>401</td>
<td>1.18%</td>
</tr>
<tr>
<td>13</td>
<td>B763</td>
<td>555</td>
<td>1.63%</td>
</tr>
<tr>
<td>14</td>
<td>B772</td>
<td>418</td>
<td>1.22%</td>
</tr>
<tr>
<td>15</td>
<td>B77W</td>
<td>378</td>
<td>1.11%</td>
</tr>
<tr>
<td>16</td>
<td>BE20</td>
<td>413</td>
<td>1.21%</td>
</tr>
<tr>
<td>17</td>
<td>C130</td>
<td>892</td>
<td>2.61%</td>
</tr>
<tr>
<td>18</td>
<td>C172</td>
<td>583</td>
<td>1.72%</td>
</tr>
<tr>
<td>19</td>
<td>C525</td>
<td>341</td>
<td>0.90%</td>
</tr>
<tr>
<td>20</td>
<td>C56X</td>
<td>228</td>
<td>0.67%</td>
</tr>
<tr>
<td>21</td>
<td>CL60</td>
<td>545</td>
<td>1.60%</td>
</tr>
<tr>
<td>22</td>
<td>DA42</td>
<td>315</td>
<td>0.92%</td>
</tr>
<tr>
<td>23</td>
<td>F2TH</td>
<td>337</td>
<td>0.99%</td>
</tr>
<tr>
<td>24</td>
<td>F900</td>
<td>442</td>
<td>1.30%</td>
</tr>
<tr>
<td>25</td>
<td>GLEX</td>
<td>348</td>
<td>1.02%</td>
</tr>
<tr>
<td>26</td>
<td>GLF4</td>
<td>634</td>
<td>1.86%</td>
</tr>
<tr>
<td>27</td>
<td>GLF5</td>
<td>540</td>
<td>1.58%</td>
</tr>
<tr>
<td>28</td>
<td>H25B</td>
<td>316</td>
<td>0.93%</td>
</tr>
<tr>
<td>29</td>
<td>K35R</td>
<td>438</td>
<td>1.28%</td>
</tr>
<tr>
<td>30</td>
<td>SR22</td>
<td>511</td>
<td>1.50%</td>
</tr>
<tr>
<td>31</td>
<td>P28A</td>
<td>539</td>
<td>1.58%</td>
</tr>
<tr>
<td>32</td>
<td>PA34</td>
<td>412</td>
<td>1.21%</td>
</tr>
<tr>
<td>33</td>
<td>PC12</td>
<td>261</td>
<td>0.76%</td>
</tr>
<tr>
<td>34</td>
<td>TRIN</td>
<td>261</td>
<td>0.76%</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>17,717</td>
<td>49.78%</td>
</tr>
<tr>
<td></td>
<td>Total:</td>
<td>34,123</td>
<td>100%</td>
</tr>
</tbody>
</table>

The 34,123 aircrafts form the recommended values, consists of 507 different aircraft types, of which 34 aircraft types represent approximately 50% of the fleet. These numbers are taken from the recommended values section and are based on flight
plans, excluding many of the aircrafts from the military fleet statistics and other aircraft types operating under the Visual Flight Rules.

**Table 3.3** Aircraft list included in calculations and their most optimum data values for cruise.

<table>
<thead>
<tr>
<th>#</th>
<th>Aircraft Type</th>
<th>Min Fuel consumption in kg/min</th>
<th>Optimum Flight Level</th>
<th>Mach</th>
<th>Speed - TAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A319</td>
<td>33.9</td>
<td>390</td>
<td>0.78</td>
<td>447</td>
</tr>
<tr>
<td>2</td>
<td>A320</td>
<td>38.0</td>
<td>390</td>
<td>0.78</td>
<td>447</td>
</tr>
<tr>
<td>3</td>
<td>A321</td>
<td>43.5</td>
<td>390</td>
<td>0.78</td>
<td>447</td>
</tr>
<tr>
<td>4</td>
<td>A332</td>
<td>88.2</td>
<td>410</td>
<td>0.82</td>
<td>470</td>
</tr>
<tr>
<td>5</td>
<td>A333</td>
<td>72.0</td>
<td>410</td>
<td>0.82</td>
<td>470</td>
</tr>
<tr>
<td>6</td>
<td>A343</td>
<td>95.7</td>
<td>410</td>
<td>0.80</td>
<td>459</td>
</tr>
<tr>
<td>7</td>
<td>AT72</td>
<td>9.7</td>
<td>240</td>
<td>0.45</td>
<td>272</td>
</tr>
<tr>
<td>8</td>
<td>B733</td>
<td>37.0</td>
<td>370</td>
<td>0.74</td>
<td>424</td>
</tr>
<tr>
<td>9</td>
<td>B735</td>
<td>42.3</td>
<td>370</td>
<td>0.74</td>
<td>436</td>
</tr>
<tr>
<td>10</td>
<td>B737</td>
<td>35.5</td>
<td>410</td>
<td>0.78</td>
<td>447</td>
</tr>
<tr>
<td>11</td>
<td>B738</td>
<td>37.0</td>
<td>410</td>
<td>0.78</td>
<td>447</td>
</tr>
<tr>
<td>12</td>
<td>B744</td>
<td>119.3</td>
<td>450</td>
<td>0.84</td>
<td>482</td>
</tr>
<tr>
<td>13</td>
<td>B752</td>
<td>58.0</td>
<td>410</td>
<td>0.80</td>
<td>459</td>
</tr>
<tr>
<td>14</td>
<td>B763</td>
<td>68.8</td>
<td>430</td>
<td>0.80</td>
<td>459</td>
</tr>
<tr>
<td>15</td>
<td>B772</td>
<td>98.5</td>
<td>430</td>
<td>0.84</td>
<td>482</td>
</tr>
<tr>
<td>16</td>
<td>B77W</td>
<td>97.0</td>
<td>430</td>
<td>0.84</td>
<td>582</td>
</tr>
<tr>
<td>17</td>
<td>BE20</td>
<td>1.7</td>
<td>310</td>
<td>0.48</td>
<td>282</td>
</tr>
<tr>
<td>18</td>
<td>CS6X</td>
<td>7.5</td>
<td>330</td>
<td>0.73</td>
<td>336</td>
</tr>
<tr>
<td>19</td>
<td>CL60</td>
<td>12.0</td>
<td>410</td>
<td>0.77</td>
<td>442</td>
</tr>
<tr>
<td>20</td>
<td>F900</td>
<td>10.6</td>
<td>470</td>
<td>0.80</td>
<td>459</td>
</tr>
<tr>
<td>21</td>
<td>H25B</td>
<td>15.7</td>
<td>410</td>
<td>0.85</td>
<td>430</td>
</tr>
<tr>
<td>22</td>
<td>MD82</td>
<td>47.0</td>
<td>370</td>
<td>0.76</td>
<td>436</td>
</tr>
<tr>
<td>23</td>
<td>MD11</td>
<td>122.6</td>
<td>430</td>
<td>0.83</td>
<td>476</td>
</tr>
<tr>
<td>24</td>
<td>PA34</td>
<td>2.8</td>
<td>140</td>
<td>0.34</td>
<td>161</td>
</tr>
<tr>
<td>25</td>
<td>LJ45</td>
<td>6.1</td>
<td>490</td>
<td>0.76</td>
<td>436</td>
</tr>
</tbody>
</table>

And as it was mentioned before, this table above gives the fleet size that will be included in the future calculation process. The values for minimum fuel consumption and for true air speed are given at the optimum flight level for the cruise condition.
3.4 Analytical model from BADA

An efficient ATM system requires planning of traffic flows that rely on accurate estimation of aircraft performances. An Aircraft Performance Model (APM) is the core of trajectory prediction and therefore plays a central role in the development and evaluation of the future ATM systems. Depending on the approach and techniques used in modelling there are different forms of aircraft performance models.

Base of Aircraft Data (BADA), is an aircraft performance database based on the kinetic approach, with modelled forces acting on the aircraft, to aircraft performance model that has been developed and maintained by Eurocontrol Experimental Centre (EEC). To achieve the realistic aircraft performances in a simulated environment, accurate aircraft performance model plays a significant importance.

BADA is a model developed and maintained by Eurocontrol, through active cooperation with aircraft manufacturers and airline operators. The information contained in BADA is designed for simulation predictions performances and aircraft trajectories. Used namely for trajectory simulation in the air traffic modelling and simulation tools which are used to support Research and Development. To better plan traffic flows, reduce delays, operating costs and minimise environmental impact, in terms of aircraft emissions assessments.

In the past the main sources of aircraft performance data were Aircraft Operations Manuals (AOMs), published by aircraft manufacturers or the operating airlines. AOMs provided a valuable knowledge on aircraft limitations and its performances. Aircraft performances are given in the form of integrated flight profiles that specify speed, distance and fuel to climb/descent from/to a specified flight level [11].

As the original data for aircraft performance including specific fuel consumption was, and still is barely available, a choice of using the 2004 BADA version for aircraft data profile was taken into assessment. BADA is a collection of American standard code for interchange of information (ASCII) files which specifies operation performance parameters, airline procedure parameters and performance summary tables for more than 400 aircraft types. This information is designed for use in trajectory simulation and prediction algorithms within the domain of Air Traffic Management. This document describes the mathematical models on which the data is based and specifies the format of the files which contain the data [12].

The main requirement is to simulate realistically as much as possible the aircraft behaviour under the nominal operating conditions. Aircrafts operating speeds may vary depending with the aircraft mass and so, the variation can be calculated according to the formula 3.1. There are four main wake categories that aircraft can follow, usually depending on its size, and the values are as follows: Jumbo, Heavy, Medium, and Light. Specified Mass limits are taken from aircraft performance reference data which is available in the BADA library, a particular aircraft version of a given aircraft type/model may have different limits.
\[ V = V_{ref} \cdot \sqrt{\frac{m}{m_{ref}}} \]  

(3.1)

In the formula 3.1 the aircraft reference speed \( V_{ref} \) is given for the reference \( m_{ref} \). The speed at another mass, \( m \), is then calculated as \( V \).

Depending on the engine for the different aircraft types, the fuel consumption is calculated with respect to it. For the jet and turboprop engines, equation 3.2 and 3.3 respectively, the thrust specific fuel consumption \( \eta \) [kg/(min*kN)] is specified as a function of the true airspeed, \( V_{TAS} \) [kt]

Jet: \[ \eta = C_{f1} \cdot \left( 1 + \frac{V_{TAS}}{C_{f2}} \right) \]  

(3.2)

Turboprop: \[ \eta = C_{f1} \cdot \left( 1 - \frac{V_{TAS}}{C_{f2}} \right) \cdot \left( \frac{V_{TAS}}{1000} \right) \]  

(3.3)

The nominal fuel flow \( f_{nom} \) [kg/min], can then be calculated using the thrust \( Thr \)

\[ f_{nom} = \eta \cdot Thr \]  

(3.4)

The equation 3.4 can be applied to both jet and turboprop types. However these expressions are used in all flight phases, expect during idle descent and cruise. For the Cruise fuel flow, \( f_{cr} \) [kg/min], is calculated using the thrust specific fuel consumption \( \eta \), Thrust and a cruise fuel flow factor \( C_{cr} \)

\[ f_{cr} = \eta \cdot Thr \cdot C_{cr} \]  

(3.5)

The piston type engines are usually used in a much smaller aircrafts, therefore they follow a much simpler calculations. The nominal fuel flow \( f_{nom} \) [kg/min], is specified to be a constant:

\[ f_{nom} = C_{f1} \]  

(3.6)
Similarly as with jet and turboprop, the above expression is used in all flight phases except during descent and cruise. For the minimum fuel flow \( f_{\text{min}} \) [kg/min], and for the cruise fuel flow \( f_{\text{cr}} = C_{f1} \ast C_{fcr} \), respectively the expressions are as follows.

\[
f_{\text{min}} = C_{f3}
\]

(3.7)

\[
f_{\text{cr}} = C_{f1} \ast C_{fcr}
\]

(3.8)

In BADA model, the cruise fuel flow correction factor has been established for most of the aircraft types, where the reference data for such is available, for others the factor is set to 1.

BADA family data sets are provided with three different files, providing all the necessary data for the calculations that are available for each directly supported aircraft type. The example of such files can be seen in Appendix B, but we can distinguish three most important ones:

Operations Performance file (OPF) – File holding all the values and data for mass, drag, engine thrust and fuel consumption and their coefficients that are to be used in the Total Energy Mode together with information on weights, speeds etc...

Airline Procedures File (APF) – File specifying nominal manoeuvre speeds, default operational climb, cruise and descent speed schedules that are likely to be used by an airline.

Performance Table File (PTF) – File presenting a summary table of speeds, climb/descent rates and fuel consumption at various flight levels. It gives the User direct access to average performance data, without necessity to implement the complete Total Energy Model calculations [12].

For each BADA aircraft model, airline procedure default model for climb, cruise and descent is provided. The values are determined by taking into account information aircraft operations from: Aircrafts manufacturers documentation, which provides typical nominal operating speeds for each flight phase. Operational data i.e. radar recordings and flights plans from several locations. Pilots and Air Traffic Controllers input based on the real-life experiences.

The procedures are used to determine the default values for each BADA model, flight phase and speed type are coming from set of trajectories and performance; from the available operational data; mean observed speed; and finally the speed is observed in real flights, compared to the speed ranges used for modelling and an educated guess is made to select the proposed speed values.
The current model of BADA documentation is linked to 3.x family documentation. It has been developed using reference aircraft performance data sources originating from aircraft manufacturers, AOMs or aircraft performance software data sources that are available at Eurocontrol. The existing aircraft models are regularly updated, provided that the better quality data will become available. In today’s standard for aircraft performance modelling providing a 90% coverage of the current aircraft types operating in the ECAC airspace, which primary objective is to model aircraft behaviour over the normal operations part of the flight and to meet today’s requirements for aircraft performance modelling and simulation [13].

In the nearby future there will be a newly developed model intended to meet advanced functional and precision requirements of the new ATM systems. BADA 4.x family will provide a more accurate modelling of aircraft over the entire flight and will enable a modelling and simulation of advanced concepts of future systems.

Advanced Model Engineering for BADA (AMEBA) is an on-going research challenge that supports definition of the next-generation BADA performance model. The work is performed in cooperation with Boeing Research & Technology Europe, whose main objectives are to provide a realistic and accurate complete aircraft performance model. The more realistic and accurate modelling of forces and fuel estimations will enable the computation of new flight management techniques, such as climbing capabilities and minimum fuel required [14].
3.5. Workflow plan

Here we will briefly describe the process of how the results were obtained from a combination of multiple sources. Figure 3.6 shows in graphical representation of how all the required information for the results was put together.

First of all, for our purpose we had to choose information of a historical traffic data. As it was mentioned earlier, Eurocontrol has a database with all previous traffic demand data available at https://extranet.eurocontrol.int and an AIRAC file for a specific period of time can be obtained.

Using Nest modelling tool, we are able to upload the chosen AIRAC scenario into the modelling tool to find the number of flights, their trajectories and almost everything related to the aircraft operational performance. From Nest we are able to obtain a certain file (in our case the file extension name is .so6 – Traffic file), in which it describes the flight 4D trajectories, with 20 different identifiers for every flight, here are some of the identifiers: Origin, Destination, Aircraft type, Time segment begins...
and ends, Flight Level at start of segment and at the end, Status (climbing, descending, cruising), Date, Latitude, Longitude and Segment Length. See Appendix A for the example of the file. From Nest it was also possible to derive the route length file from origin to destination for all flights during the chosen day, in figure 3.7 we show a sample taken from the Detailed Route Length file.

<table>
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<th>S</th>
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<td>1015.15</td>
</tr>
</tbody>
</table>

Figure 3.7 Route length file, obtained from Nest tool.

The second set of data was obtained from BADA 3.x family database that theoretically is available from Eurocontrol. For every type of aircraft three supporting files are available .OPF, .APF and .PTF, from which all the necessary aircraft performance description is available. Choosing only the required set of aircrafts with their performance characteristics we combined them into a separate set of files for the future calculation procedures. One set of aircrafts performance description, with true speed and fuel consumption can be seen in the table 3.3 and as an example for the fuel consumption at different flight levels can be seen in figure 3.8, due to some limitation, the full set of values did not fit, so we took a screenshot for the most appropriate size.
For the calculation procedure we used a multi-concept mathematical programming language to perform all the necessary calculations. The solution from the program of performed calculation can be seen in Appendix E. From all of the performed calculations, the output was given in a set of files that in result we were able to analyse and combine in order to obtain the necessary set of results.
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Chapter 4

CURRENT AND FUTURE AIRSPACE SITUATION

4.1. Trajectory Management.

Every flight following the IFR rules undergoes a procedure for filling the flight plan that is submitted, processed and confirmation for the proposed flight plan is agreed. These types of flights usually follow all the necessary procedures that are followed in the flight plan.

Flight plan procedure is essentially planning, mapping out and understanding all the necessary criteria, materials and routes of a flight that you are undertaking. Flying is not like driving a car, you need to be prepared, you need to know exactly the route you are taking and plan thoroughly what happens when you arrive, land and depart to or from your position. One of the most important factors in the flight planning is fuel consumption, every pilot should study their flight planning with caution as aircrafts fuel consumption is very high indeed and so, planning the route and taking the fastest route possible could save a lot of money. Main aspect for considering fuel consumption and ATC requirements is to ensure that an aircraft can safely reach its destination and minimise the risk of mid-air collisions.

Flight plans are detailed documents that are filled by pilot prior to departure, which indicate the plane’s planned route. Flight planning requires accurate weather forecasts so that fuel consumption calculations can account for the effect of winds and temperature outside. One of the basic purposes of a flight planning system is to calculate how much trip fuel is needed, by an aircraft, in its all air navigation process when flying from an origin to a destination airport. Aircraft must also carry some reserve fuel to allow for unseen circumstances, such as an inaccurate weather forecast, or Air Traffic Control requiring an aircraft to fly at a lower altitude than optimum due to congestion, or some last minute changes [15].

IFR type of flights usually follows the predetermined flight routes. These routes are fixed and aircraft passing through different routes or during its flight is contacted with en-route traffic advisor to specify their location and if necessary to change the direction or request a holding procedure, which in the end would result in different distance travelled and fuel consumed. For this reason we have looked at the total distance travelled by aircrafts during one day, showing their two route lengths, Actual and Initial.

The Initial route length is the distance of the Filled route, in other words, it is the estimated length the aircraft would have to follow, usually as it is specified or submitted in the flight plan, prior its departure. The Actual route length is the distance that the aircraft has actually travelled during its flight profile. The comparison of these values between proposed and actual distance travelled can be seen in the figure 4.1.
Using Nest modelling tool, it is possible to obtain two different scenarios. First scenario is one that was planned i.e. the Initial, in which the model is constructed the way as the aircraft operator would or should have carried out their tasks as it was pre-determined by the flight plan. The second scenario model is the Actual one, in which it shows the actual path and route length that was carried out by the aircraft operator, usually resulting with some difference if compared to the initial.

<table>
<thead>
<tr>
<th>Length in NM</th>
<th>Initial</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>29,219,190.79</td>
<td>28,939,274.28</td>
</tr>
</tbody>
</table>

- **Figure 4.1** Total distance of flights travelled during one day

The results shown in figure 4.1 are representing the total length from origin to destination, for all aircraft types flying over the European airspace in one day. From the obtained values, we can see that the total for Actual route length is approximately 280 thousand Nautical miles shorter, than the Initial scenario proposed.

You may ask how it is possible, that the initial length of a distance is longer than the actual distance travelled. The answer lies somewhere between the communication and coordination of ATC operator and pilot of that aircraft. In some cases, if there is an opened ‘window’ during a flight, the pilot may ask whoever is responsible to monitor the flight at that stage, an air traffic controlled or the network manager, to take deviation or in simple term a shortcut. This is so called an alternative route, in which it is possible to save time and fuel consumed as well as reduces the distance travelled. Generally pilots stick to the flight plan, but in some cases they may ask for such a deviation, and they may vary depending on the situation. Usually due to the weather and wind conditions pilot may request slight flight changes in its flight profile if the weather and wind conditions are good at higher altitude. In most cases, requesting the modified flight route will vary, depending on traffic, aircrafts current flight level and air traffic controllers’ workload at that time, but if traffic is not intense, some air traffic controllers will allow such deviation.
In order to show these deviations, we used Nest tool to choose and track a randomly chosen flight and show its actual flight profile versus the planned flight profile. The deviations performed by pilots during the flight, in the end shortened the flight path between origin and destination. The graphical representation of flight profile can be seen in the figure 4.2. Flight originating from Germany and taking its route to Italy, will save on average 19 NM or 35 km, and you can see from the figure, how and where the route changes were made.

![Figure 4.2 Planned (Initial) and Actual Flight route comparison between two points.](image)

As it was mentioned earlier, pilot may request the higher altitude in order to reduce fuel burn and increase true airspeed, which also results in the reduced route lengths.

So another way to look at the flight profile is how the initial vertical flight path was planned, against what the actual route was taken, when an aircraft operator/pilot took place to contact with the Network traffic manager at the navigation point. Most navigation points include recommended flight level, speed suggestions and trajectories, but they can be changed and/or altered with the agreement of traffic controller, depending on its current traffic situation.

In another example we will look at an ordinary medium wake type Airbus A320 type of aircraft, flying from Manchester UK, to Heraklion Crete. Table below summarises all the necessary information concerning the flights time and distance travelled.
Table 4.1 One flight from UK to Crete

<table>
<thead>
<tr>
<th></th>
<th>Take off time</th>
<th>Arrival time</th>
<th>Route Length (NM)</th>
<th>Flight time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
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<td>1:00</td>
<td>1688.7</td>
<td>3:40</td>
</tr>
<tr>
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<td>21:22</td>
<td>0:59</td>
<td>1664.1</td>
<td>3:37</td>
</tr>
</tbody>
</table>

Reduced flight length by approximately - 24.6 NM or 45.6 km

In the figure 4.3 you can see the full vertical profile for the A320 flight, where the triangles represent the Navigation points. These points indicate the standard reporting points located on airways, usually reporting, speed, heading and its destination. In our case aircraft maintained half of the route on the proposed flight level, but at a Navigation point LUPAR, aircraft operator either requested or was asked to increase his Flight Level from 350 to 370. The final results for the distance travelled show us that deviations from the planned route are normal occurrences and flying more direct routes would save fuel and reduce CO\textsubscript{2} emissions.

Figure 4.3 Vertical Profile of a flight from Manchester, UK to Crete.

(Note: From all A320 aircraft flights, the average Referenced Flight Level-340)

On the other hand, this will not work if the air traffic controller or the area where the flight is taking place is saturated with intense traffic. In this case the, if there is no opening slot, air traffic controller may ask the pilot to prolong the flight, or ask the pilot to proceed for the holding pattern, which will also increase the distance travelled and time spent in air.

The alternative routes can have better wind conditions and less turbulence, so the pilot can save both time and fuel. For some flights most pilots are beginning to fly, with user preferred routes, beside route and points that are mentioned in the flight plan, which was filed before the departure of the aircraft.

“Majority of the pilots who fly over southern airspace said they were increasingly asking air traffic control for the highest altitude to be able to fly faster to their destination. A preliminary trial conducted recently comparing flight plans and actual routes flown shows that airlines could save 730kg fuel and seven minutes per aircraft on Gulf-Australia, Asia-South Africa and Africa-Asia routes”[16].
Some of these procedures can be enabled by partnership among countries and controlled airspace regions, which have formed air traffic management coordination group to help airlines cut fuel costs and control emissions. The main idea is to provide a seamless sky for flights crossing their control regions. Harmonising upper airspace will allow providing direct routes and higher altitudes for aircrafts to save fuel, reduce emissions and save time.

4.2. Optimum Trajectory – Flexible use of airspace

Previous studies have demonstrated that air routes in Europe comparing them to its optimum trajectory, are not optimally designed, resulting in flight routes being longer and not as efficient as they could be.

Deviation from the optimum flight trajectory i.e. flying by the pre-determined flight routes, generate additional flight and engine running time, fuel burn, gas emissions and high costs to the industry. The extended air routes are a result of: non-optimal airspace design, civil-military restricted zones, and inappropriate flight planning and route utilization. The current environmental and economic challenges facing the aviation industry, demand rapid and fundamental progress in flight efficiency.

Starting in 2012, EU-wide performance targets agreed under Single European Sky legislation, that it will provide a formal framework for development of safer and more efficient European airspace, with straighter and shorter routes. The Single European Sky performance scheme specifies that by 2014 route extension in Europe must be reduced by 0.75% when compare to 2009 situation [17].

The free Route Airspace programme, is the first step towards the implementation of aircraft operators’ preferred business trajectories, which will allow pilots to choose their entry and exit points freely in a given airspace and fly their preferred route.

Free Route airspace will refer to a specific or full portion of airspace, in which aircraft operators will be able to plan a route freely, with the possibility of deviating from their original path, through intermediate navigation points, without referencing to the fixed route network. So far there has been seen progress, where air traffic controllers have been offering aircraft operators’ direct routes as far as possible, however these routes – have not been reflected in the flight plan, which is always referred to the fixed route network [17].

In the future we will be looking at the ATM systems that will be heading to give aircraft operators freedom to dynamically allocate their preferred flight profiles. The Free Route airspace or a Free-Fly concept is one example of the drive towards more autonomy of flight. This is still a reasonably new concept being developed to take the place in the current ATM methods through the use of technology. It will eliminate the
need for air traffic control operators to constantly make contact with aircraft operator, by giving the responsibility to the pilot. Allowing pilot to change trajectories mid-flight and with the aid of computer systems, pilots will be able to make more flight path decisions independently. Cooperative decision making is believed to be more efficient than the centralised control characterised by the current more of air traffic management.

In order to meet the increased levels of both civil and military airspace, close cooperation will be the key role in order to take the full advantage of the growing airspace utilisation. Military exercises that are likely to affect civil flight operations, should be scheduled in advance whenever possible, in order not to overlap with peak period of airspace traffic for the civil aviation. So under the leadership of Eurocontrol, since 1996 the Flexible use of airspace (FUA) concept has been introduced in most ECAC member States, in which all users may have accessed and, based on their needs and requests, ask for permission to use the requested airspace. Then, as a result, it was managed to achieve the most efficient use of airspace.

Throughout the years the different understanding to the FUA concept grew into “Advanced Flexible Use of Airspace” coupled together with the Mission Trajectory, which expected to provide more flexibility based on dynamic airspace management. As an example the ‘reserved’ military airspace has now become available to the commercial use... [18].

Military aviation is playing one of the most important aspects in the security of each state. Therefore it is necessary that each state to enable military forces to liberate, to some extent, their security and defence responsibilities.

States will be aiming at creation of one single integrated system providing services to both civil and military requirements. The related organisation of the airspace should satisfy the requirements of all users in an optimum way. Creating a cooperation and coordination to both users to ensure or notify, if required, the built-in civil and military air traffic separation.
4.3 Direct Route (Great Circle distance)

Ideally, aircrafts want to fly the most fuel-efficient routes between their points of departure and their destination. Currently various ATC systems have the inability to safely separate and handle large amounts of traffic on random routing, hence a while ago a series of routes and airways were established around the globe. However these route structures are generally inflexible. In figure 4.4 we can show the simplified version, of how the route structure can be allocated for a flight. Optimum flight conditions vary depending on all sorts of factors, such as weight, weather factors and airspace they are currently flying. The previous airspace structure was made from predefined paths, altitudes and speed constraints, which weakly reflected efficiency of airspace exploitation with today’s growing demand in aviation industry.

![Current, Actual flight path](image)

Figure 4.4 Current – Actual flight track

The conventional airspace organisation of flight information regions and their supporting infrastructures of ATS routes are ground-based facilities and services are largely based on national requirements. As a result, fragmentation of the airspace, and a diversity of national systems prevent optimum use of the airspace (ICAO 1995i). As an example, some countries have a passed law, restricting the number of flights above 30,000 ft., in order to allow more overflights.

Because of the limitations of air traffic control systems to separate numerous aircrafts on random routings and a lack of automation to assist with conflict detection and resolution, aircrafts must plan their flights along routes and be carried to a certain degree, in order for the air traffic control system and the people that operate it, to safely keep aircraft separated from each other.

A general objective of ATM is to enable aircraft operators to meet their planned times of departure and arrival and to hold on to their preferred flight profiles with minimum constraints without compromising agreed levels of safety. The primary objective of air traffic control is, and will continue to be, centred on the need to ensure the maximum degree of safety. Air traffic control functions to prevent collisions while accelerating and maintaining a safe and orderly flow of traffic.

It is worth mentioning that ATM is rather a system of rules and procedures, and air traffic controllers and future air traffic managers apply those rules and procedures to achieve a safe and efficient system. In fully developed ATM system, traffic on direct routing will be more easily controlled.
Wherever possible to reduce the flight distance, a flight will normally plan to follow a direct route. For almost every flight the most direct route follows a great circle distance. The great circle distance between two points may give a better approximation of the shortest flight length. The most famous use of great circles is for navigation, it represents the shortest distance between two points on a sphere. Even today, great circle routes are used for long-distance travel because they are the most efficient way to move across the globe. A flight route must also take into account the weather conditions, wind currents, and fuel economy. An example of a transcontinental flight in the direction to east will often take a more southern route rather than a great circle route in order to take advantage of the jet stream.

Great circle distance represents the shortest path between two points, anywhere on the Earth’s surface, measured along the surface of the sphere and they are commonly used by aircrafts, where wind currents and other weather anomalies are not a significant factor.

Taking in consideration the knowledge that the shortest path travelled by the aircraft, is the one travelled by the great circle distance, we used Nest tool to identify all the necessary distance lengths for the same amount of flights during selected date. The output showed us the total length, it would take to travel by the great circle distance. These ranges are measured from the flights origin to its destination, similarly as what was done with the Initial and Actual routes. For this project, we will be considering that travelling by the great circle distance will be like taking the shortest route possible from its origin and destination, and presume that it is direct route.

The result shown in figure 4.5 is representing the total length from origin to destination, for all aircraft types executed on the chosen date (the values are represented in million Nautical Miles).

![Figure 4.5 Actual vs. Direct route i.e. shortest distance between origin and destination](image)

Average 1.4 million NM miles can be saved during that day, which will result in fuel economy and reduce CO2 emissions. On average a flight might decrease 44.3 NM per flight from its origin to destination.
4.4 Terminal Manoeuvring Area

In controlled airspace, air traffic control is provided to all flights, and the controlled airspace may be divided into various aerodrome/landing areas, such as shown in the figure 4.6, Control Zones (CTR), Terminal Control/Manoeuvring Areas (TMA), Control Areas (CTA) and airways. CTR is airspace around a certain aerodrome in which ATC is provided to all flights. A Control zone extends from ground level to a specified altitude or a specified Flight Level. Exceptionally busy airports can be situated in Class A control zone. CTA is a portion of airspace on which ATC is provided to all flights, and which extends upwards from a specified limit above the earth to a specified upper limit. TMA is a control area established at the junction of controlled airspace routes surrounding areas of one or more major aerodromes. An airway is a form of a corridor and is defined by radio navigation aids. Basically, you can fly underneath a CTA, but you cannot usually fly underneath all parts of a CTR.

![Figure 4.6 Control Zone (CTR), Terminal Control Area (TMA), and an Airway](image)

Aerodrome traffic zones exist at many aerodromes within States Control Zones. A certain amount of airspace surrounding most aerodromes in the country has been designated as Aerodrome Traffic Zones, usually because of the intensity of aerial activity. Throughout the year’s air traffic controlled moved to automatically route traffic of the airways, to final approach procedures by providing vector heading to the pilot. Later they became more involved with the technology equipment and the necessary procedures knowledge for arrival and departure, thus creating the TMA entry points, as well as introducing the concept of Standard Instrument Departure (SID) and Standard Terminal Arrival Routes (STAR). This was done in order to increase capacity and flexibility of airport operations. Both are similar in many aspects and offer the pilot a pre-planned IFR procedure.

SID and STAR may be both included in one type of flight plan, but not in advance, clearances issued to the aircraft have to confirm these SID and STAR to be used. Because even after the flight plan has been filled, SID and STAR that were planned to be used, might be tactically changed by the ATC, depending on traffic volumes, runways in use, weather and so on.
Standard terminal arrival routes (STAR) are designed to accelerate arrival procedure and to assist transition between en-route and instrument approach segments. If STAR needs to be changed, the pilot is usually informed of the new STAR to be used sometime before Top of Descent, at which point it is entered into the Flight Management System and maintains new route. STARs are used to accelerate approach flows and to give a more regular approach to an airport. Typically, the controller will then a series of heading/vectors to line up the aircraft on the Instrument Landing System, after leaving STAR. Instrument Landing System is a navigation aid which includes the most common precision approach currently in use and is designed to provide an approach path for exact path for exact alignment and descent of an aircraft on final approach to the runway. Similarly if changes have to be made to SID, before aircraft takes off, this may be broadcasted by the ground controller and the new instructions will be entered by the pilot into the Flight Management System [2].

Terminal Manoeuvring Area is referred to as a block of airspace above an airport, sometimes may be specified to Terminal Control Area. Essentially TMA is a special type of airspace over aerodrome area designed to handle departing and arriving aircrafts that are controlled within its regions. Depending on airport structure and size TMA may have different shapes and they can be considered as one of the most complex parts of airspace where only IFR type flights are allowed in it. For example: London TMA covers all five London airports, and extends to Upper airspace up to 24,500 ft, and unlike many other airports contains a ‘holding stack’, where aircrafts may be asked to circle for some time, until there is a slot to land the aircraft. As it was mentioned, the length and size of a TMA may vary depending on the aerodromes level of importance and capacity capabilities.

Airport operations are very important aspects in air traffic control, however in many airports the ATC are managed by the Air Navigation Service Providers that manage flight traffic on behalf of a company, region or country, as an example provider for El Prat airport is Aena. The management and operation of majority of the bigger European airports are either fully or partially in the private sector. In Barcelona El Prat airport the TMA extends to Flight Level of 195 and has a strict policy for standard approach and departure procedures and VFR flights are not permitted over LEBL. “Barcelona/El Prat: Closed for visual operations, except for sanitary helicopters, state aircraft and those specifically cleared. VFR flights are not cleared to operate in airspace classified as D within Barcelona CTR”[19] (also see Appendix C).

For our purpose we will be looking at the en-route part of the route. We will not take into account TMA route in the route lengths. To do so, we can either subtract a fixed route for SID and STAR, or remove the route part lying in the first part of the flight, measured in Nautical Miles, around departure and arrival airports. In figure 4.7 we gave the visual representation of TMA around the starting and final points of the flight, and how the actual and direct routes are located between TMA exit and entry points.
Air traffic management may be involved in consultation process mainly around airports and under the flight paths in TMAs, where air transport projects have to meet the requirements with State regulations. In addition to traffic forecasts and impact studies, ATM can contribute in the form of the design of airspace, arrival and departure routes and operational procedures.

In this work, we will not look at every individual aerodrome TMA length, because as mentioned earlier, it could vary on the size and traffic around it. One of the STARs for Barcelona airport extends in length for more than 85 NM, but on the other hand, a smaller airport in Pamplona Spain – LEPP, the longest path is only 22.9 NM. Different TMA length will depend on what kind of an airport is located at the start or the ending points for a flight. Taking this in mind, we proposed to create one universal TMA around every airport.

To do so, using Nest modelling tool, we could obtain values for only the cruise or the en-route part of the flight. By knowing just the Cruise distance travelled, we are assuming that the rest part of the flight is located in Terminal Manoeuvring Areas, therefore we will not take into consideration any minor vertical deviations that are happening en-route. Figure 4.8 demonstrates us how the average TMA was taken using all the distances travelled in one day.
The results for the proposed an average universal TMA can be seen in the table 4.2. These values were taken, using the same day as mentioned previously, August 10th 2012, with a total of 31,650 flights passing through European Airspace. It is worth mentioning that, for the future part of calculations and assessments, we will use the new - averaged TMA, to find the required Direct route.

**Table 4.2** Average lengths for different flight paths.

<table>
<thead>
<tr>
<th></th>
<th>Actual route</th>
<th>Cruise route</th>
<th>Great Circle</th>
<th>Direct Cruise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (NM)</td>
<td>914.35</td>
<td>738.38</td>
<td>870.04</td>
<td>694.07</td>
</tr>
<tr>
<td>TMA (NM)</td>
<td>-/</td>
<td>86.61 (σ=51.3)</td>
<td>-/</td>
<td>86.61 (σ=51.3)</td>
</tr>
</tbody>
</table>

From the obtained values, we can see that an average TMA distance is as big as TMA for Barcelona airport, which is considered one of the largest airports in Europe. As it was mentioned, in future we are looking at more synchronised and direct routes to be followed, which will be achieved by equipping aircraft with newer, more improved technology for collision avoidance as well as trajectory predictions. The user proffered routing will be defined between published entry and exit points inside a complex area and the Air Traffic Control will be provided with all the necessary data in order to improve the flight trajectory prediction.

For now to justify this result of a TMA, we will consider that the proposed TMA is an average distance where the Air Traffic Controllers or the Air Navigation Service Providers, can start contacting and or manoeuvring the aircraft for its final approach procedures. Of course in reality it is not going to be the same, but it gives us a better approximation for the future calculations.
4.5 Direct Cruise Route.

The simplest possible route with the least number of essential parts between the two aerodromes is a direct route, however the current situation show us, that it is not so. The flight plan route consists of chain of points and airways between departure and destination aerodromes. So in today’s situation we are looking at predefined paths and altitudes, so called fixed routes and in most cases they are carried out regardless of meteorological conditions. In the tomorrow’s view of the airspace structure, we will be looking at, flying at optimum speeds and altitudes, shorter and direct routings and better flight profiles based on the weather conditions in order to take advantage of favourable wind conditions.

Starting in 2007, it was proposed the development towards the implementation of Free Route Airspace. The initiative was to implement the transition from reliance on a fixed route network to offer direct routes and modified routes in order to contribute to airspace improvements on capacity, efficiency and environment.

The definition on Free Route Airspace states that it is a specified airspace which users may freely plan a route between defined entry and exit points, with a possibility to route via intermediate way points, without references to the ATS route network, from which the Free Route operations will form an essential part of the overall European ATM network. The main aim of free route airspace is to increase airspace efficiency, enhance flexibility, bring environmental benefits and optimise the use of existing airborne system [20].

For our purpose of the project and the closing part of this chapter, we will take a look into the direct routing for the cruise part of the flight path. This will be considered as the SESARs direct cruise route trajectory, taking into account only the direct part between origin and destination, without considering the climb and descent phases of a flight. As it was mentioned earlier, the great circle distance is the shortest distance between two points and the climb and descent phases of a flight are to be considered as the averaged TMAs. So in order to find the final direct route for the cruise part between two points, we will remove this averaged TMA from the route length, from both points.

With the aid of previous calculations for the TMA we can extract those lengths from the calculation part, and assume them to be ascending and descending procedures for an aircraft when entering its final stages of a flight. The final proposed Direct cruise route can be seen in figure 4.9. We are looking at the total length of the great circle distances and taking out the TMA in order to get the final value for the Cruise part of the flight. The value and difference between Actual cruise section and Direct cruise section of the flight can be seen in the figure 4.10. The values obtained showed us, that travelling with the Direct cruise distance on average can save up to 1.4 million Nautical miles in just one day.
In the proposed section, we have simplified the potential aircraft trajectories and their flight paths in order to optimise and predict the future possibilities for Cruise part of the flight. However by knowing the current situation in airspace and flight allocation system, this scenario might look too perfect in respect to flight flexibility, efficiency and trajectory management. And this is true, because currently there are technical limitations which exist in the present flight-plan data processing systems, which will make it almost impossible to implement such unrestricted ‘free-route’ operation changes straight away. When there will be generated large variations of trajectories, it will put a stress to the current navigation system. Therefore a real-time updates of the airspace situation with respect to airspace conditions, will be required in order to offer the most updated air traffic flow and capacity management situation at network/local levels.
Air space management will differ from the today’s fixed route network, aircraft operators will no longer be given information on which routes are available, but will need to know if the airspace they are flying in is available. The airspace users will need to know the activity of all relevant airspace conditions areas to enable the selection of a flight path that will avoid them. In order to fully cooperate, ATC units, military authorities, airspace users and the network managers will need to know and share the same updated information with regard to activity of airspace conditions. This will come from the Flexible use of Airspace concept and civil/military coordination in order to ensure harmonised procedures, service supply and benefit to all airspace users. ATC, aircraft operators, network managers and any other interested parties should all have the same information regarding the intended flight profile and its routing. This will require the development of appropriate tools and equipment to indicate real time and future status of the airspace conditions [20].

This proposal will be looking at a long term strategy with different implementation phases in order to establish all upper airspace as a free route airspace model.

The primary justification for this project is the environmental benefit. In the first stages it will allow improvements in the flight planning system, enabling aircraft operators to plan their flights using point to point direct routes across the entire assigned area will reduce the flights mileage, which will benefit in fuel planning, by reducing the overall fuel load required. As a result this will reduce the weight of an aircraft during flight, hence will give reduced fuel burn and CO2 emissions during the whole flight.

The end goal will consist of removing all routes and allowing unrestricted, direct routing, between any points. However there are technical constraints, which mean that it is not possible to implement unrestricted free routing with the current flight plan processing system, and ATC controller tools. Once these key operational systems have been upgraded the goal of unrestricted free route airspace will be able to be realised [21].
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Chapter 5

FUEL CONSUMPTION & CO₂ EMISSIONS

5.1 Fuel Consumption

In the current airspace situation, the limited interconnectivity of air navigation services and systems, limited data sharing and co-operative planning and less than full exploitation of the current technological capabilities, results in airspace capacity not being fully operated. Therefore leading to excessive route distance, non-optimal flight profile and not realising savings in fuel-burn and the benefits to the environment. There are various market options available for reducing the fuel consumption of existing aircrafts, including the change of airframe and possible engine mechanisms.

The main fuel efficiency is expected to be gained in the en-route flight phase, where more direct routes and free route airspace concepts are expected to be enabled. In the current mode, the sensitivity of possible delays at the airports is considered very high, owing the fact that most inefficiency are related to the SID/STAR structure and the potential queuing for arrival. However, the TMA is unlikely to become significantly more fuel-efficient due to the benefits of improved 3D/4D routings and flight allocation system. A number of European airports have already started to introduce the continuous descent approach technique, which minimises fuel use, gaseous emissions and noise impact, by descending with idle thrust and avoiding level flight [22].

In this study will take a look in the fuel consumption of the 25 types of aircrafts during one day, and compare the current values, against the values with the future proposed implementation of Direct routing profiles. For fuel efficiency, there is no need for traffic data. Fuel efficiency is based on the analysis of one typical flight, which later can be decomposed to different flight phases.

First of all, we will look into the real/true amount of fuel used on the chosen date. In figure 5.1 we can see the difference between the Initial and Actual amounts of fuel used when the flight has travelled using the predetermined routes and real flight level i.e. the one specified in the actual flight profile – referenced flight level. The third value represents the fuel consumption, if pilots would increase their flight level to the most optimum conditions, but still would use the predetermined route flight, as shown in the table 3.3.

The difference between the Initial and Actual flight plan, differs only by 0.6%, however in reality this means absolutely nothing, because if or when during its route the aircraft will be changing its Flight Level to more optimum, the consumption will be more due to the thrust increase, and it is possible to observe that Actual flight will consume more.
Figure 5.1 Fuel consumption of Initial & Actual Referenced FL vs. Optimum Flight Level

The above figure 5.1 represents the possible fuel savings in current airspace route network. In the current situation with predetermined flight routes, it is possible to save up to 16% of total fuel, if the aircraft operators would choose to take the most optimum Flight Level, which accounts for 34.94 million kg of fuel, which in relation saves approximately 1.7 tons of fuel per flight.

The second evaluation will be taking a look at flying Direct distance from origin to destination, or as we have previously referred to it as the great circle distance. Figure 5.2 shows the possible fuel reductions, when the Direct routing will be implemented in a full scale. With comparison to the Direct routing profile, and flying at the optimum Flight Level with the minimum fuel consumption, it is possible to save up to approximately 20% of total fuel, which will result in 41.76 million kg of fuel saved. It should be noted that most of the fuel savings will result in choosing the most optimum altitude for the required flight, thus stating that these are additional fuel saving options.

Table 5.1 Fuel Consumption for Optimum flight conditions

<table>
<thead>
<tr>
<th></th>
<th>Fixed flight routes</th>
<th>Direct Route</th>
<th>Optimal Flight Level conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>References Flight Level</td>
<td>Optimum Flight Level</td>
<td></td>
</tr>
<tr>
<td>Total Fuel Consumed</td>
<td>213,106,122.3 (kg)</td>
<td>178,164,876.4 (kg)</td>
<td>171,347,767.9 (kg)</td>
</tr>
<tr>
<td>Average Fuel consumption (per flight)</td>
<td>10,249.43 (kg/flight)</td>
<td>8,568.92 (kg/flight)</td>
<td>8,241.04 (kg/flight)</td>
</tr>
<tr>
<td>Total Fuel saved to Actual situation</td>
<td>-/-</td>
<td>16.4%</td>
<td>19.6%</td>
</tr>
<tr>
<td>Average Fuel Saving (per flight)</td>
<td>-/-</td>
<td>1,780.5 (kg/flight)</td>
<td>2,008.4 (kg/flight)</td>
</tr>
</tbody>
</table>
Figure 5.2 Fuel Consumption on Actual routing vs. Future Direct routing.

The following information can be represented in the table 5.1, showing all the fuel consumption models and the future saving options that could be implemented.

All of the gathered information was taken by performing calculations with the supplied BADA documentation and Nest modelling tool, and is counting for the 20,792 flights. In the following section we will observe how much fuel consumption is used by different type of aircrafts and compare them to their newer model, as well as take a look on how the fuel consumption is related to the emissions and the environmental impact.

5.2 New aircraft model

It is worth noting that ATM contribution cannot increase beyond a theoretical maximum defined by fuel optimal trajectories for each individual aircraft flying alone in airspace. The major improvement in fuel consumption reduction and related emission decrease is expected to come from new jet engines, improved airframes and weight reductions on modern aircraft and in the longer terms the new improved aircraft designs [22].

In this section we will show the current fuel consumption of chosen aircrafts for one chosen operational day and additionally compare the fuel consumption of two most operated aircrafts, from different manufacturers, to their newer models that are and will be available for future exploitation.

The two chosen aircrafts are Airbus A320 and Boeing 737-800. They are the top two commercial and currently operational aircrafts in European airspace, as it is shown in
figure 3.4. From the previous findings and collection on data from BADA, we know the current values for the fuel consumption. However, the values obtained from BADA are based on the 2004 model and since then, there have been made a variety of improvements made on those aircrafts. We are going to take into account only the fuel consumption improvements that were made on chosen aircrafts. Below in table 5.2 we summarised all the required information regarding the two newer aircraft models, with improved savings on fuel efficiency. The full table of fuel consumption during the chosen day can be seen in Appendix D, it also includes the summary of fuel consumption for each aircraft type with additional newer aircraft consumption models.

Table 5.2 Newer aircraft models with more fuel efficiency savings.

<table>
<thead>
<tr>
<th></th>
<th>Airbus A320</th>
<th>Boeing 737-800 (B738)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimum cruise fuel consumption</td>
<td>38.0 kg/min</td>
<td>-15%</td>
</tr>
</tbody>
</table>

The following information was taken from official Airbus and Boeing web-pages available to everyone, and they are average estimates for the improvements. Judging with such improvements, we have decided to apply this model to all available to us Airbus and Boeing aircrafts. The following figure 5.3 shows even the further fuel consumption for one day of travel.

Figure 5.3 Fuel Consumption with newer Airbus and Boeing Models

The obtained results show that an additional 9.7% of fuel is possible to save with the improved fuel consumption for Airbus (-15%) and Boeing (-7%) aircrafts [23][24].
5.2 CO₂ Emissions

Advances in aircraft and engine technology have dramatically improved fuel efficiency, but on the other hand, growth in air travel has led to an increase in total environmental impact, both globally and locally. Aircraft engines produce several combustion outputs with different characteristics and impacts on the environment. The combustion process is not perfect and emissions such as nitrogen oxide (NOx), carbon monoxide and dioxide (CO & CO₂) and other oxides occur from the combustion of the engine. These emissions usually depend on the engine, fuel and mode of operation, from which carbon dioxide (CO₂) has a direct relation to the amount of fuel burned and is higher when the engine operates at its maximum thrust.

CO₂ is inevitably linked to fuel use and hence to operational and cost efficiency, meaning that emission importance increases as the fuel becomes more costly and CO₂ acquires a large value through emissions trading. Key environment strengths of the ATM target concepts are: the drive for trajectory efficiency from gate-to-gate, improved navigation capability and trajectory management which will lead to reduced fuel use [25].

Changes in current air traffic management could also make an impact. Many air traffic control sectors in Europe have boundaries aligned to national borders, with each nation taking responsibility for the airspace above it. The result is a complex routing network. Some measures have been taken to reason with such situation, including as we have mentioned earlier the development of the Maastricht Upper Area Control Centre (MUAC) that manages high altitude air traffic over several neighbouring countries.

We have already mentioned that routes travelled in today’s airspace significantly differ from the shortest distance between departure and arrival airports, therefore suggesting the fact that extra distance travelled means greater fuel consumption and more emissions. Some of the previous projects have already contributed in the medium term to involve more direct routings and optimised vertical allocation of traffic, resulting in significant efficiency gains [26].

The dependence of emissions on engine operating characteristics means that reductions can be targeted through operational measures, but that not all measures will reduce emissions. The emissions and impacts of aviation play a small but growing part in the current environment. For stabilisation purposes it would require a far below levels of current emissions, but with exploitation of technological and other opportunities this could lead to reduction of expected changes and a slower the rate at which they occur. New technologies and concepts in air traffic management will offer opportunities for the improvement of the environmental impacts. New approaches to ATM can reduce flight inefficiencies by:

- Reducing deviations from the shortest Great Circle Distance route and allowing planned routes to be followed more accurately
- Reducing in-flight diversions from the planned route. By reducing and/or avoiding potential conflict situations at an earlier stage could play a role in improving efficiency, it would optimise flight trajectories to minimise environmental impacts.

Growth in air traffic movements means that CO2 emissions from aviation continue to increase and according to SESAR study proposal in the near future improving fuel efficiency is the most potentially rewarding approach to directly reduce air transport’s climatic change and environmental issues.

**Table 5.3 Optimisation opportunities to improve fuel efficiency**

<table>
<thead>
<tr>
<th>Route</th>
<th>Aircraft</th>
<th>Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimise Speed</td>
<td>Match type to route</td>
<td>Increase load factor</td>
</tr>
<tr>
<td>Optimise altitude</td>
<td>Improve maintenance</td>
<td>Reduce unnecessary fuel</td>
</tr>
<tr>
<td>Optimise flight route</td>
<td>Reduce aircraft mass empty</td>
<td>Reduce non-revenue</td>
</tr>
</tbody>
</table>

Table 5.3 is take from minimization of fuel use and reduction in emissions and summarises the operational opportunities to minimise fuel use recommended in ICAO report (ICAO 2004). The most significant fuel savings are expected to come from improvements to communication, navigation, surveillance and air traffic management systems, which will improve the capability to fly the most fuel-efficient routes with optimised speeds and cruise altitudes [27].

There have been reports on significant environmental savings achieved to date. Throughout the daily operations of the European ATM in the flexible use of airspace concept, it has already saved about 120 KTonnes of fuel ever year, with a potential of unnecessary consumption of a further 300 KTonnes of fuel every year. The future implementation to improve efficiency could incrementally reduce even further fuel consumption with the direct relation of reducing CO2 emissions [22].

The actual operational model may vary from airport to airport, depending on traffic, environmental considerations, aircraft types and as well as the topographical conditions. The total emissions from aircraft are given by the sum of all emissions from various aircraft operations in a continuous set of flying modes. For our cause, we will base our assumptions solely on options at reducing CO2 emissions, exactly the same for every aircraft type, considering only the amount of fuel consumed during its flight, which appears to be the most practical and feasible option. To match the Sears’ expectation of a 10% CO2 emission reduction per flight is considered a challenging perspective, yet minimising the environmental impact can contribute to ATM in terms of noise, air quality, additional fuel burn and the related decrease of
CO2 emissions by optimising the flight trajectories, to which we have previously referred.

One way to calculate CO2 emissions is from fuel consumption per flight. For a short international flight typically Boeing 737 jet aircraft is estimated to consume 3.6 tonnes of fuel for a distance of 920 km, including taxiing, take-off, landing and cruise. Most of the calculations for the CO2 emissions are done using the average seat occupancy – ‘load factor’, which gives a fuel use of per passenger km following the further estimations of fuel burn and CO2 emission per hour flying.

In our situation, we are not estimating the seating capacity of an aircraft, but rather will use a general method for assumption for the CO2 emissions with the relation of the total fuel used during the operational period from departure to arrival. On average we are assuming that CO2 emissions from aviation fuel are 3.15 grams for every gram of fuel burned. Table 5.4 sums up all the calculated CO2 emissions from the day of flying. The table includes the values of the real fuel consumption for the chosen day and their emissions, as well as what would be expected to achieve in the near future, when and or if the Direct Routing from origin to destination will be available [28].

**Table 5.4** CO2 emission in one day derived from Fuel Consumption.

<table>
<thead>
<tr>
<th></th>
<th>Estimated</th>
<th>Total RFL</th>
<th>Direct Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (kg)</td>
<td>213,106,122.3</td>
<td>171,347,767.9 (kg)</td>
<td></td>
</tr>
<tr>
<td>CO2 (kg)</td>
<td>3.15</td>
<td>671,284,284.25 (kg)</td>
<td>539,745,468.89 (kg)</td>
</tr>
<tr>
<td>CO2 (Kilo tonnes)</td>
<td>≈671.3 (KT)</td>
<td>≈539.7 (KT)</td>
<td>Save up to 131.6 KT in CO2 emissions (≈19%)</td>
</tr>
</tbody>
</table>

As it was mentioned earlier, with the newer introduction of technological concepts to aircraft performance it is possible to reduce the impact on the environment on even greater scale. Table 5.5 shows the comparison of previously chosen Airbus and Boeing aircrafts with the improved fuel consumption engines.

Brief reminder: All values for fuel consumption were taken using the 2004 BADA model. The models for the improved fuel consumption were taken from Airbus and Boeing reports. The quantities of flights for a specific aircraft type are taken from the Nest modelling tool for a date in August 2012.

Air traffic management will deliver its maximum contribution to the environment, with an overall Sesars’ objective to enable a 10% reduction in the effects flights have on the environment. For this reason it is necessary to achieve the constant improvements through the reduction of gate-to-gate fuel consumption that is addressed in one of the future development goals, therefore making up to more environment sustainability. The reduction in fuel burn due to optimisation of flight profiles will translate directly to an overall reduction of emissions and the advances in
technology will have a considerable positive effect for the reduction of emissions per kilogramme of fuel. By working together on SESAR projects, the European aviation community is looking at potentially operational and ready for industrialisation, of the future air traffic management systems.

Table 5.5 CO2 emissions for one operational day between A320 and B738.

<table>
<thead>
<tr>
<th></th>
<th>Airbus A320</th>
<th>Boeing 737-800 (B738)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. cruise fuel</td>
<td>Current Model</td>
<td>Newer Model [2]</td>
</tr>
<tr>
<td>consumption (kg/min)</td>
<td>38.0 kg/min</td>
<td>-15%</td>
</tr>
<tr>
<td></td>
<td>-/-</td>
<td>37.0 kg/min</td>
</tr>
<tr>
<td></td>
<td>32.3 kg/min</td>
<td>-/</td>
</tr>
<tr>
<td></td>
<td>34.4 kg/min</td>
<td>-/</td>
</tr>
<tr>
<td>Quantity</td>
<td>Current Model</td>
<td>Newer Model [3]</td>
</tr>
<tr>
<td>(flights)</td>
<td>4535</td>
<td>4695</td>
</tr>
<tr>
<td>Direct Route Fuel</td>
<td>16,465,292 kg</td>
<td>13,995,498 kg</td>
</tr>
<tr>
<td>Consumption (kg)</td>
<td>18,392,981 kg</td>
<td>17,100,501 kg</td>
</tr>
<tr>
<td>CO2 emission (tonnes)</td>
<td>51,865.7 T</td>
<td>44,085.8 T</td>
</tr>
<tr>
<td></td>
<td>57,937.8 T</td>
<td>53,866.6 T</td>
</tr>
<tr>
<td>Save</td>
<td>≈7,780 Tonnes of CO2</td>
<td>≈4,070 Tonnes of CO2</td>
</tr>
</tbody>
</table>

In the year 2010, the reduction of CO2 emissions from aviation in European airspace went down by almost 2% (2.2 Million tonne of CO2). In the addition, the emission calculation method should preferably take clear and precise values, based on officially accepted documents and to ensure that the data used for flight emissions is in closest possible agreement with real emissions. Generally, flight emissions depend on engine, airframe, flight path, flight distance and load factor, which can be taken from aircraft manuals, ICAO database and other documentations.

Furthermore, some of the projects are also taking advantage of and complementing results achieved by other European activities, such as Clean Sky programme. Clean Sky is a Public Private Partnership between the European Commission and the Aeronautical Industry, that was set up to bring significant step changes regarding the environmental impact of aviation. Clean Sky is working on speeding up the technological breakthrough developments for new and cleaner solutions, to significantly contribute the environmental footprint of aviation, green life cycle for our future generations.

Clean sky states, that flights produce on average 628 Million tonnes of CO2 yearly (1.7 MTonn/day). Based on the current state of the art available, Clean Sky with support from European Union are looking at enabling at least 20 to 30 % CO2 reduction, compared to the current state of the art, to meet the society’s needs in the aeronautics industry. It will accelerate the development of smart, environmentally friendly and energy efficient aircrafts that operate worldwide and thereby meet environmental and social targets for a more efficient, safer and more environmentally friendly air transport [29].
Chapter 6

CONCLUSION

6.1 Overview

SESAR defines and proposes changes on the development and when to deploy the new ATM system supporting all the required ATM concepts with respect to significant contribution to the overall Single European Sky objectives. Its contribution to the overall operational objectives will come as a result from a completely new approach to air traffic management. It aims to increase airspace efficiency, optimise the use of existing airborne system, enhance flexibility, bring financial and operational benefits to airspace users, as well as providing the environmental benefits to its full extent.

The today’s airspace is made up from predefined paths and altitudes, speed constraints and fixed routes regardless of weather conditions. In the future we will be looking at shorted and direct routes with better vertical profiles i.e. flying at optimum altitude and speed.

The final goal is to remove all routes and allow unrestricted direct routing between any points. This will be long term strategy to be established. While this is the endgoal, currently there are technical limitations with flight plan processing system, traffic controller tools, which make it impossible to allow such implementations for a full-scale. Once the operational systems will be upgraded the goal for unrestricted flying will able to be realised.

The new SESAR proposed features are the key element for implementation in Single European Sky. Its recommendation will accelerate the urgently required technological evolution of the present ATM system to support the new SESAR ATM concept and its key contributions to the societal goals of SES.

Some air navigation services in Europe have already deployed the free routing airspace at their local level and neighbouring countries, as it can be seen from an example of Maastricht airspace, which we have mentioned earlier.

SESAR research and development deployments are providing benefits to the real-life environment solutions. Stakeholders from airlines, air navigation service providers, the manufacturing industry and airports work together on projects, in order to demonstrate SESAR concepts and technologies. Performance gains cover a wide range of key performance areas, including better customer satisfaction, environmental efficiency, air navigation service provision productivity, safety and capacity. Furthermore, some of the projects are also taking advantage of and achieving results realised by other European initiatives, such as Clean Sky.
6.2 Description of Results

In our work we have covered a wide area and aspects of airspace and the current aeronautical procedures. Further, we took a look on how the possible improvements to the airspace situation could be enhanced and what benefits could be obtained.

First of all we took a look at the distance the aircraft is travelling by fixed routes and compared the distance for the aircrafts initial flight path to the actual one travelled. The results indicated that actual route taken by the aircraft is shorter than the initially proposed one. It says that pilots usually take deviations from the initial flight trajectory to reduce distance and shorten flight time.

The second comparing took a look at the distance the aircraft is travelling by fixed routes and knowing the distance between its departure and arrival points, we applied the shortest route – great circle distance, to obtain the future possible route savings. Obtained values showed us that on average a reduction of 1.4 million Nautical miles in distance from all flights in one operational day could be obtained, 44.3 NM per flight. From this, it is obvious to state that shorter flight distance would result in shorter flight time, which in future would result in greater fuel consumption savings and fewer emissions.

One of the SESAR proposals is the drive towards a more sustainable air travel, with a possibility of 10% reduction fuel consumption and in CO2 emissions. It proposes to reduce carbon emission by an amount of 50 million tons over the period from 2013-2030. Despite the additional air traffic created SESAR will have a positive overall net effect on CO2 emissions in this period, and with an on-time scenario an approximate reduction in fuel consumption of 10% of the total.

In our estimations we have used the simplified model for just an average estimation of the fuel consumption provided from BADA documentation, to assume a possible reduction in fuel consumption and CO2 emissions. The results comparing the fuel consumption flying by direct routing showed us that a possible decrease in fuel consumption could result approximately to 20% of the total fuel (in one day).

Fuel consumption is directly related to the CO2 emissions. Clean Sky states that the average yearly CO2 emissions from air activity result in 628 Million of tonnes (1.7 Million Ton/day) and with support from European Union in the next several decades are looking at enabling at least 20% CO2 reductions. Our results showed that an estimated daily CO2 emission result in 0.67 Million Ton/day (only in European airspace), which is relatively close to the actual value, and with proposed initiative of direct routing would result on average of 19% reduction in CO2 emissions and with additional aircraft improvements a further 9% reduction in emissions could be obtained.
The achieved results show that by applying method of Direct routing would result in substantial improvements to the airspace situation and bring the necessary sustainable advances in the airspace community.

6.3 Future Work

With the results provided, we can make the assumption that SESAR proposal are possible for execution, however future advances should be made. One of the suggestions for the future assumption is to, extend the data for flights i.e. take a range of days, months or a full year for future estimates. The extension of measured data with different periods of time could provide better approximation of the results. Another proposal to improve estimated results for fuel consumption is to improve the aircraft performance model. By taking into account weather conditions and more precise aircraft performance data, it is possible to obtain more accurate values for the fuel consumption at any given point, therefore supplying much more realistic results.

Supporting the entire ATM system and efficient operation, System Wide Information Management (SWIM) environment must include aircrafts as well as ground facilities, where terminal and en-route functions will be integrated to provide smooth traffic flows into and out of terminal areas as well as supporting the continuous descent approaches. Continuous descent approaches have potential environmental benefits including emissions and fuel burn and can show additional savings to be done consumption with a more sustainable approach.

In the next several decades we will be looking at global transformation of the air transport system with support of SESAR and NextGen that are being developed in the new era. Both programs deal with the current ATC procedures and technologies that are not able to accommodate the increased traffic demand while maintaining the same levels of safety. So another advance in technology will be to use 4D trajectories and technology of FMS that will come with it. The controllers will no longer be surprised by unexpected turns, and will have a clear view on their screens the aircraft trajectories and systematically share their trajectories between various ATM participants to ensure that all partners have a common view of flight and have access to the most up-to-date data available. Predicting demand with minimum distortions to the aircraft trajectories; such technological modifications will enable staff to verify during real-time simulations for the system to fully support the required operations.

Air traffic service is a system of agreed actions to ensure the safety of flying aircrafts, aiming at preventing collision between them. To keep them safe different organisations work continuously to improve system by incorporating new equipment and facilities as well as determining where that equipment and facilities will be most
The technology is catching up with traffic volumes that enable to navigate and predict aircraft performance. Most air traffic controllers monitor radar screens to track aircraft as it passes over the radar sites and that data is communicated back to the controller miles away. Currently European Union is developing a complimentary positioning system to better meet the needs of airspace users - Galileo, so for the next generation of air transportation system, it will transform from the ground-based radars to one that will use satellite technology.

Most advanced ATC systems continue to work on the basis of data representing the aircraft performance and environment conditions, which in result poorly approximate reality. Therefore, only limited accommodation of optimised flight profile is achieved. At this time, Eurocontrol is working at BADA 4.x family of documentation that will provide increased levels of precision in aircraft performance parameters over the entire flight.

In particular there should be established an integrated European air traffic management system, a true network with a single control structure and a stronger supervision potential. By working together on SESAR projects, the European aviation community is proving that the first SESAR solutions for the future air traffic management system are both operational and ready for industrialisation.
BIBLIOGRAPHY


[17] Eurocontrol, Maastricht Upper Area Control Centre."As the crow flies Free, Route Airspace Maastricht (2011) member of FABEC-Eurocontrol www.eurocontrol.int/muac


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APPENDIX B .OPF file structure

File_name: A320__.OPF
Creation_date: Apr 30 2002
Modification_date: May 14 2004

Aircraft Performance Operational File

Actype
A320__ 2 engines Jet
Airbus A320-212 with CFM56_5_A3 engines wake

Mass (t)
reference minimum maximum max payload mass grad
.64000E+02 .39000E+02 .77000E+02 .21500E+02 .28000E+00

Flight envelope
VMO(KCAS) MMO Max.Alt Hmax temp grad
.35000E+03 .82000E+00 .39000E+05 .34354E+05 .13000E+03

Aerodynamics
Wing Area and Buffet coefficients (SIM)
Crossr Surf(m2) Clbo(M=0) k CM16
5 .12260E+03 .10400E+01 .22700E+00 .00000E+00

Configuration characteristics
Phase  Name  Vstall(KCAS) CD0 CD2 unused
1 CR  Clean .14500E+03 .24000E-01 .37500E-01 .00000E+00
2 IC  1 .12000E+03 .24200E-01 .46900E-01 .00000E+00
3 TO  1+F .11400E+03 .39300E-01 .39600E-01 .00000E+00
4 AP  2 .10700E+03 .45600E-01 .38100E-01 .00000E+00
5 LD  FULL .10100E+03 .83800E-01 .37100E-01 .00000E+00

Spoiler
1 RET
2 EXT .00000E+00 .00000E+00

Gear
1 UP
2 DOWN .31200E-01 .00000E+00 .00000E+00

Brakes
1 OFF
2 ON .00000E+00 .00000E+00

Engine Thrust
Max climb thrust coefficients (SIM)
.13605E+06 .52238E+05 .26637E-10 .10290E+02 .58453E-02

Desc(low) Desc(high) Desc level Desc(app) Desc(ld)
.94370E-02 .31014E-01 .15000E+05 .13000E+00 .34000E+00

Desc CAS Desc Mach unused unused unused
.31000E+03 .78000E+00 .00000E+00 .00000E+00 .00000E+00

Fuel Consumption
Thrust Specific Fuel Consumption Coefficients
.94000E+00 .10000E+06

Descent Fuel Flow Coefficients
.88900E+01 .81926E+05

Cruise Corr. unused unused unused unused unused
.18600E+01 .00000E+00 .00000E+00 .00000E+00 .00000E+00

Ground
TOL LDL span length unused
.21900E+04 .14400E+04 .34100E+02 .37570E+02 .00000E+00


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### APPENDIX B .PTF file structure

**Speeds:**
- **Climb:** CAS (LO/HI) 0.78 low - 46800
- **Cruise:** CAS (LO/HI) 0.78 nominal - 64000 Max Alt. [ft]: 39000
- **Descent:** CAS (LO/HI) 0.78 high - 77000

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APPENDIX B .APF file structure

File_name: A320__.APF
Creation_date: Apr 30 2002
Modification_date: May 14 2004
LO= 39.00 to --.-- / AV= --.-- to --.-- / HI= --.-- to 77.00

LO= 39.00 to --.-- / AV= --.-- to --.-- / HI= --.-- to 77.00

Company name ----climb------- --cruise-- -----descent------- --approach- model- /
version engines  ma  cas cas mc xxxx xx  cas cas mc  cas cas xxxx xx  xxx xxx xxx  opf__ /

Default Company /

Default Company /

THE END

THE END
APPENDIX C
El Prat aerodrome chart- LEBL Barcelona Approach
## APPENDIX D

Fuel consumption for new aircraft estimates

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<th>#</th>
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<th>Quantity of Flights</th>
<th>Min Fuel Consumption for Optimum Flight Level (kg/min)</th>
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<th>New aircraft model consumption (kg/min)</th>
<th>(G)Direct Route Fuel Consumption (kg)</th>
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<td>Total 154,747,408.7 (kg)</td>
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APPENDIX E
Solution code from mathematical software:

Part 1 – Bigmain.cs

```csharp
namespace Calc_flight
{
    public class BigFile
    {
        public string[,] Bigmain(string file, char sep, int[] a)
        {
            int i, j, k; // Counting integers
            string[] line = System.IO.File.ReadAllLines(file);
            string oneline; // Declaring -oneline- is a string
            string[] splitting;
            i = line.Length; // i- size of -line- of the file in Rows
            j = a.Length;
            string[,] temp = new string[i, j]; //Temporary string array, used to initialze -alldata- j columns, i numeber of rows
            for (i = 0; i <= line.Length - 1; i++)
            {
                oneline = line[i]; //Storing first line on -oneline- string
                splitting = oneline.Split(sep); //Spliting
                for (k = 0; k < j; k++)
                {
                    temp[i, k] = splitting[a[k]];
                }
            }
            return temp; //stores data in temp
        }
    }
}
```

Part 2 – Main.cs

```csharp
namespace Calc_flight
{
    public class Program
    {
        public static void Main(string[] args)
        {
            Calc_flight.BigFile so6 = new BigFile();
            string[,] so6data;
            string file= @"C:\Users\*****\*****\******\20120810_m3_Initiall_flights.so6";
            char space = ' ';
                // providing with a separator
            int[] columns={1,2,3,4,5,8,10,11,17,18};
            so6data=so6.Bigmain(file,space,columns);
            string[,] lengths; //previous txt file
            file= @"C:\Users\*****\******\*******Detailed_all.csv"; //previous txt file
```

```csharp
Calc_flight.Program A = new Program();
A.Cruise(so6data,lengths);
A.Best(so6data,lengths,aircrafts);
A.Total(so6data,lengths,aircrafts);
A.tracker(so6data,lengths,aircrafts);
A.abc(fullaclist,originalfl);
}
public void Cruise(string[,] s6 , string[,] txt)
{
    System.IO.StreamWriter first = new System.IO.StreamWriter(@"C:\Users\****\******\*******\output\orig_dest_length_A_G.csv");
    int i,j;
    double distance, actual, gcd, difference, fil;

    actual=0;
    distance=0;
    gcd=0;
    fil=0;
    first.WriteLine("Or,Des,cruise,actual,GC,ncruise,Filled");
    for(i=0;i<s6.GetLength(0);i++)
    {
```
if(s6[i,5]=="2") {distance=distance+Convert.ToDouble(s6[i,9]);}
if (s6[i,8] == "1" && i != 0)
{
for (j=0; j<txt.GetLength(0); j++)
{
if (txt[j,0]==s6[i-1,0] && txt[j,1]==s6[i-1,1])
{actual=Convert.ToDouble(txt[j,4]);
gcd=Convert.ToDouble(txt[j,2]);
fil=Convert.ToDouble(txt[j,3]);}

difference=actual-distance;
first.WriteLine(s6[i-1,0] + "," + s6[i-1,1] + "," + distance + "," + actual + "," + gcd + "," + difference + "," + fil );

distance=0;
gcd=0;
actual=0;
fil=0; }
}
first.Close(); }

public void Best(string[,] s5 , string[,] txt_temp , string[,] csv)
{
System.IO.StreamWriter first = new System.IO.StreamWriter(@"C:\output\consumption.csv");

int i,j,k;
double fc, tas, time_act, time_fil, time_gcd; //together with f_c
fc=0;
tas=0;
time_act=0;
time_fil=0;
time_gcd=0;
first.WriteLine("origin,destination,type,GC, actual,initial");
for(i=0; i<s5.GetLength(0); i++)
{
if (s5[i,8] == "1")
{
for (j=0; j<csv.GetLength(0); j++)
{
if (csv[j,0]==s5[i,2]) //s5[i,2] is AC type
{fc=Convert.ToDouble(csv[j,1]);
tas=Convert.ToDouble(csv[j,2]);}

if(fc!=0)
{
for(j=0; j<txt_temp.GetLength(0); j++)
{
if(txt_temp[j,0]==s5[i,0] && txt_temp[j,1]==s5[i,1])
{ time_gcd=(Convert.ToDouble(txt_temp[j,2])/tas)*(fc*60);
time_act=(Convert.ToDouble(txt_temp[j,4])/tas)*(fc*60);
time_fil=(Convert.ToDouble(txt_temp[j,3])/tas)*(fc*60); }
first.WriteLine(s5[i,0] + "," + s5[i,1] + "," + s5[i,2] + "," + time_gcd + "," + time_act + "," + time_fil );
fc=0;
tas=0;
time_act=0;
}
public void Total(string[,] s5 , string[,] txt_temp , string[,] csv)
{
    System.IO.StreamWriter first = new System.IO.StreamWriter(@"C:\**\******\output\type_qty_fuel_.csv");
    int i,j,k;
    double fc, tas, time_act, time_fil, time_gcd;         //together with f_c
    string[] actype= new string[csv.GetLength(0)];
    int[] number= new int[csv.GetLength(0)];
    double[,] fuel = new Double[csv.GetLength(0),3];
    for(i=0;i<csv.GetLength(0);i++)
    {
        actype[i]=csv[i,0];
        number[i]=0;
        fuel[i,0]=0;
        fuel[i,1]=0;
        fuel[i,2]=0; }
    fc=0;
    tas=0;
    time_act=0;
    time_fil=0;
    time_gcd=0;
    first.WriteLine("Type,Qty,fuelGC,fuelActual,fuelInitial");
    for(i=0; i<s5.GetLength(0); i++)
    {
        if (s5[i,8]== "1")
        {
            for(j=0; j<csv.GetLength(0); j++)
            {
                if (csv[j,0]==s5[i,2])  //s5[i,2] is AC type
                    {
                        number[j]=number[j]+1;
                        fc=Convert.ToDouble(csv[j,1]);
                        tas=Convert.ToDouble(csv[j,2]);
                    }
            } if(fc!=0)
            {
                for(j=0; j<txt_temp.GetLength(0); j++)
                {
                    if(txt_temp[j,0]==s5[i,0] && txt_temp[j,1]==s5[i,1])
                        {
                            time_gcd=(Convert.ToDouble(txt_temp[j,2])/tas)*(fc*60);  //fuel consumption
                            time_act=(Convert.ToDouble(txt_temp[j,4])/tas)*(fc*60);  //fuel consumption
                            time_fil=(Convert.ToDouble(txt_temp[j,4])/tas)*(fc*60);  //fuel consumption
                        }
                } fuel[j,0]=fuel[j,0]+time_gcd;
            }
        }
    } first.Close(); }
fuel[j, 1]=fuel[j, 1]+time_act;
fuel[j, 2]=fuel[j, 2]+time_fil;  }  }
fc=0;
tas=0;
time_act=0;
time_fil=0;
time_gcd=0;
}  }
for(i=0;i<csv.GetLength(0);i++)
{
  first.WriteLine(actype[i]+ ','+number[i]+ ','+fuel[i,0]+ ','+fuel[i,1]+ ','+fuel[i,2]);
} first.Close();

public void tracker(string[,] s5, string[,] txt_temp, string[,] csv)
{
  System.IO.StreamWriter first = new System.IO.StreamWriter(@"C:\output\type_qty_fuel_Cruise.csv");

  int i,j,k;
  double fc, tas, time_act, time_fil, time_gcd, time_crus;   //together with f_c
  double dist;
  string[] actype= new string[csv.GetLength(0)];
  int[] number= new int[csv.GetLength(0)];
  double[,] fuel = new Double[csv.GetLength(0),4];
  for(i=0;i<s5.GetLength(0);i++)
  { actype[i]=csv[i,0];
    number[i]=0;
    fuel[i,0]=0;
    fuel[i,1]=0;
    fuel[i,2]=0;
    fuel[i,3]=0;  }
  dist=0;
  fc=0;
  tas=0;
  time_act=0;
  time_fil=0;
  time_gcd=0;
  time_crus=0;

  for(i=0; i<s5.GetLength(0); i++)
  {
    if(s5[i,5]=="2"){
      dist=dist+Convert.ToDouble(s5[i,9]);
    }
if (s5[i, 8] == "1" && i != 0)
{
    for (j = 0; j < csv.GetLength(0); j++)
    {
        if (csv[j, 0] == s5[i - 1, 2])
        {
            number[j] = number[j] + 1;
            fc = Convert.ToDouble(csv[j, 1]);
            tas = Convert.ToDouble(csv[j, 2]);
        }
    }
    if (fc != 0)
    {
        for (j = 0; j < txt_temp.GetLength(0); j++)
        {
            if (txt_temp[j, 0] == s5[i - 1, 0] && txt_temp[j, 1] == s5[i - 1, 1])
            {
                time_gcd = (Convert.ToDouble(txt_temp[j, 2]) / tas) * (fc * 60); //
                time_act = (Convert.ToDouble(txt_temp[j, 4]) / tas) * (fc * 60); //
                time_fil = (Convert.ToDouble(txt_temp[j, 3]) / tas) * (fc * 60); //
                time_crus = (dist / tas) * (fc * 60);
            }
        }
        for (j = 0; j < csv.GetLength(0); j++)
        {
            if (csv[j, 0] == s5[i - 1, 2])
            {
                fuel[j, 0] = fuel[j, 0] + time_gcd;
                fuel[j, 1] = fuel[j, 1] + time_act;
                fuel[j, 2] = fuel[j, 2] + time_fil;
                fuel[j, 3] = fuel[j, 3] + time_crus;
            }
        }
    }
}
for (i = 0; i < csv.GetLength(0); i++)
{
    first.WriteLine(actype[i] + ',' + number[i] + ',' + fuel[i, 0] + ',' + fuel[i, 1] + ',' + fuel[i, 2] + ',' + fuel[i, 3]);
}
first.Close();

public void abc (string[,] allone , string[,] rfl)
{
    System.IO.StreamWriter first = new System.IO.StreamWriter("C:\Users\****\*****\******\output\abc_initial.csv");
    int i, j, k;
    int timeStart, timeFinish, minStr, hStr, minFin, hFin;
    int timeDiff;
    double fuel;
    string[] splitting;
for(i=0; i<rfl.GetLength(0); i++)
    for(j=0; j<allone.GetLength(1); j++)
        if(rfl[i, 5]==allone[0,j])
            timeDiff=0;
            splitting = rfl[i,2].Split(":");

            minStr= Convert.ToInt32(splittng[1]); // minutes
            hStr= Convert.ToInt32(splittng[0]); // hours

            splitting = rfl[i,3].Split(":");
            minFin=Convert.ToInt32(splittng[1]); // minutes
            hFin=Convert.ToInt32(splittng[0]); // hours

            timeStart=minStr+60*hStr;
            timeFinish=minFin+60*hFin;

            if(timeFinish<timeStart)
                { timeFinish=timeFinish + 1440; }

            timeDiff=timeFinish-timeStart;

        for(k=0;k<allone.GetLength(0); k++)
            { fuel=0;
                if(rfl[i,4]==allone[k,0])
                    {fuel=Convert.ToDouble(allone[k,j]);
                        fuel=fuel*(timeDiff);
                        first.WriteLine(rfl[i,0] +',' + rfl[i,1] + ',' + fuel);
                }}}
            first.Close();