Towards a robust multidisciplinary design optimization model for the airplane in the air transport system

Nicolas Peteilh

MAIAA and Air Transport Department, ENAC

KEYWORDS: Airplane conceptual design, Airplane operations

ABSTRACT:

In an airplane preliminary design phase, the optimization for costs and fuel consumption is based on anticipating the future operations of the airplane by defining one representative mission. How effective is this process? In this study, based on data exploration and statistical analysis, we identify and represent the operational parameters impacting the variability of the actual missions of an airplane. These parameters include the airline route network and flight optimization, Air Traffic Management (ATM) considerations, and the atmospheric and meteorological phenomena. Our results show how significant some impacts are, mainly on actual flight distances but also on flying conditions. A conclusion of our study is that airplanes are operated on missions different from the reference mission considered during the preliminary design phase and this has a significant impact on operating costs and fuel burn efficiency.

1. INTRODUCTION

In its Strategic Research and Innovation Agenda [1] (SRIA), the Advisory Council for Aeronautics Research in Europe (ACARE) has identified the protection of the environment and the energy supply as a challenge for the future and the definition of the air vehicles of the future as a key action area. It also emphasizes the need for developing an integrated resilient air transport system, where the airplane, together with the other actors of the civil aviation world such as the airports, the airlines, the air navigation service providers, the authorities, etc. interact one with each other and influence each other's design. In this perspective, considering the airplane within its real operational environment appears to be a way of improvement, even in its early preliminary design phase, when decisions have a great impact on future operational efficiency and on costs.

Focusing on the early design phase of an airplane, the benefits of multidisciplinary design process and the limits of airplane design optimization based on a reduced number of reference flight conditions have already been described in the literature. See for instance [2], where ways forward are proposed through multi-mission and multipoint approaches. Reference [2] describes a method in order to obtain a set of representative missions from in-service data and demonstrates the interest of considering real operational conditions in improving the results of multidisciplinary design optimization (MDO). However, it relies mainly on the BTS flight database [3], which features aggregation of operational data, the atmosphere is considered as standard, and the mission profile is determined by performing theoretical-mission analysis.

In this paper, we shall demonstrate the benefits of taking into account more details in describing the conditions in which the airplane is operated in the real world, in order to capture the potential effects of airlines routes network, operational flight optimization, Air Traffic Management (ATM) considerations, and the atmospheric and meteorological conditions.

One key challenge here is to find reliable and detailed operational data that enable one to have a deeper insight of the real conditions in which airplanes operate. Another objective is to extract from these data the relevant information.

This paper is organized as follows. Section 2 describes the main identified operational uncertainty parameters. Section 3 addresses the data processing from the selection of sources to the methods used. Section 4 presents the analysis of the statistical results. Section 5 concludes the paper.

2. MAIN UNCERTAINTY PARAMETERS

In order to capture the potential effects of airline route network, operational flight optimization, Air Traffic Management (ATM) considerations and atmospheric and meteorological conditions, we first investigated how each of these conditions affects the airplane operations. This investigation is made by engineering judgement, at the best knowledge of the actual operational world. The parameters identified are those the most exposed to uncertainties.

2.1. The payload

The very first parameter that affects the airplane is the payload. It changes at every flight the mass of passengers and fret.

Airlines aim at optimizing their revenue and improving their load factor. Nevertheless, they must sometimes operate empty or half empty airplanes. The first data of interest is therefore the actual weight of the airplane at take-off.

2.2. Route network

The route network has a direct impact on the ranges the airplanes fly. Indeed, even though the use of a new type of airplane may allow an airline to modify its route network, the localization of the airports to be operated and the flight schedule to meet passenger demand will determine the ranges flown by airplanes.

Therefore, the second set of data needed includes the departures, destinations and frequencies of flights performed by the type of airplane under study.

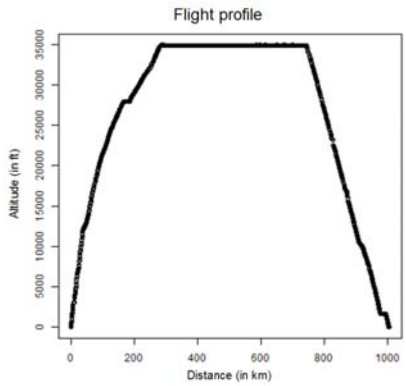

Figure 1. Short-range flight profile

2.3. Operational flight optimization

When preparing their flight, airlines choose the ground track to be followed as well as the flight path profile. This analysis depends on the payload and ensures that all operational limitations of the airplane are met, the safety requirements are addressed, and the operational costs are minimized. As a result, the chosen path from one airport to another might well not be the direct route.

The third data set needed is the actual ground track chosen by the airlines, which corresponds to the latitude and longitude coordinates all along the airplane trajectory.

Remark also that airlines might choose longer ground tracks in order to obtain shorter air distances. The fourth parameter that matters is therefore either the wind data or the airplane true airspeed.

2.4. ATM considerations

Once the airline has defined its optimized mission, it submits the flight plan for approval. After being processed together with the other airline flight plans, for instance in Europe by the NMOC (Network Manager Operations Centre), the final approved flight plan may be different from the one requested. The modifications may impact departure time, flight levels, or even the ground track. Furthermore, the ground trajectory may also be impacted by ATC (Air Traffic Control).

The fifth parameter of importance is therefore the altitude of the flight. As shown in Fig.1 and Fig.2, range and ATC can have an impact on altitude. As airplanes consider barometric altitude, it is even more important to get the atmospheric pressure all along the flight track.

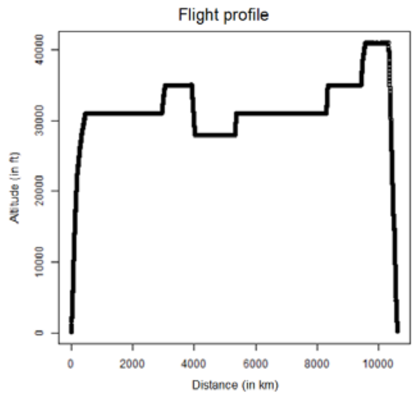

Figure 2. Long-range flight profile

2.5. The atmospheric and meteorological conditions

The atmospheric conditions are the last effect to be investigated. As atmospheric pressure is already considered, the sixth parameter that is needed is the air temperature all along the flight path.

There are also local specific phenomena, like storms, that require real-time flight path modification by the pilot, and will impact the flight conditions. However, studying such phenomena goes beyond the scope of this paper.

2.6. Synthesis

The main identified uncertainty parameters considered in this study are the following:

1. Airplane type
2. Route information (departure, destination and frequency)
3. All along the trajectory: latitude and longitude coordinates, wind data (or true airspeed), barometric altitude, and air temperature
4. Payload

The data investigation was done in order to observe and quantify the variability encountered in service.

3. DATA PROCESSING

Researching data, we identify two sources of particular interest. We then collect data and after exploring them, we can represent the operational variability with respect to the main identified uncertainty parameters. We focus our analysis on Airbus long range airplanes and more precisely on A340 types.

3.1. Data sources

It was not possible to find any set of data including all the relevant parameters we wanted to explore. As a result, our approach is to get sufficient data to explore independently each parameter. Here are the sources on which we base our analysis.

Reference [3] includes data related to payload (passengers and freight) carried per month, airline, airplane type, and route (departure and destination). Direct route distances are also included. This database contains only U.S. domestic and international air traffic data. The main drawback of this first database is that it does not contains the trajectory detail (latitude, etc.) described at the end of section 2.

Reference [4] provides the all-along-the-flight-path data that we need. Nevertheless, payload and mass information is missing.

3.2. Data processing

The approach used for data processing followed five steps. Data are extracted from [4], for one specific airplane during one year. More than 400 trajectories were analysed. Fig.1 and Fig.2 show two examples of vertical flight path.

Fig.3 displays the direct route distance distribution over one year for one specific airplane. It shows the variability of the airlines' route networks. It also sets a reference for the remaining of the study.

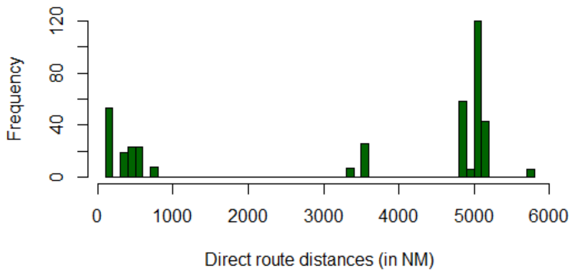

Figure 3. Direct route distance distribution

Fig.4 compares the actual ground path with the direct route distance.

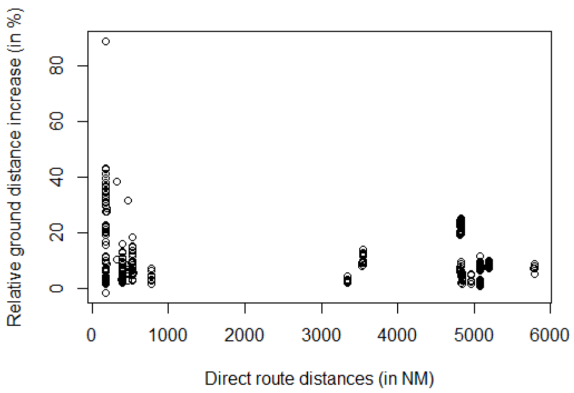

Figure 4. Relative increase of ground distance

In order to take into account the effect of the wind, we plot the difference between air distance and ground distance on Fig.5.

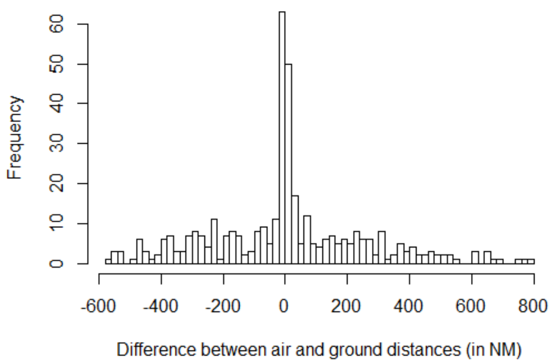

Figure 5. Air-to-ground distance distribution

Fig.6 illustrates difference between air and ground distances.

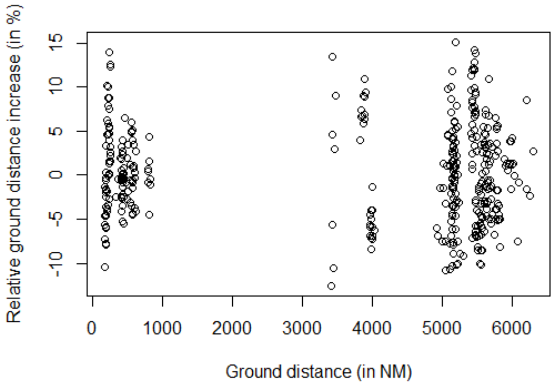

Figure 6. Relative increase of air vs. ground distances

Fig.7 illustrates the variability related to cruise altitude by plotting the total air distance flown by the airplane during one year (Fig. 7) for each cruising altitude. As it is calculated based on atmospheric pressure along the flight path, this plot provides also information on the pressure variability.

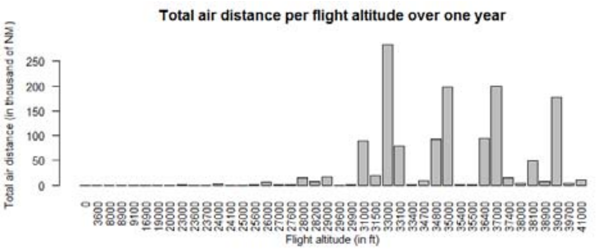

Figure 7. Total air distance per flight altitude

We then focus on the variability related to air temperature. Fig. 8 shows the difference between the air temperature actually measured on the flight path, and the International Standard Atmosphere temperature at the altitude considered.

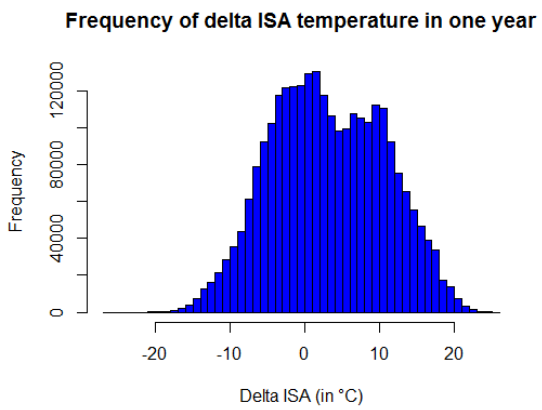

Figure 8. Delta ISA Temperature (in °C)

Finally, in order to represent the uncertainty related to payload and range, we select from [3] the data covering one year of operation of a specific type of airplane (A340) operated by one particular airline to and from the U.S.A. Fig.9 displays these results.

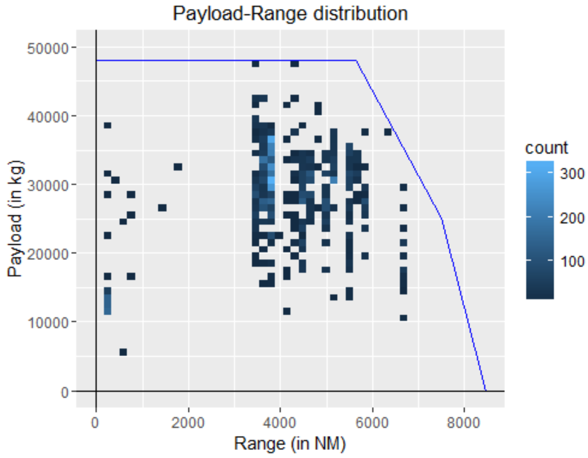

Figure 9. Payload-Range distribution

4. ANALYSIS OF THE STATISTICAL RESULTS

The results presented illustrate the variability related to the main identified uncertainty parameters.

4.1. Variability and operational parameters

The direct route distance distribution (Fig.3) shows that even long-range type airplanes can be operated on very short-range trips. This is not specifically related to the airplane analysed in this study but is rather a more general observation, as shown in Fig.9. This situation cannot be improved by the airlines as there is no conventional distance between the airports to be flown into.

The distance that the airplane actually flies is the air distance. From the analysis of Fig.4, Fig.5 and Fig.6, we identify the operational conditions and parameters that affect the air distance flown.

When optimizing the ground trajectory, the airlines take into account costs, landscape, payload, atmospheric conditions, ATM, airports constraints, airplanes limits and safety considerations. This study shows that these parameters can result in significant increase of the actual ground distances flown by the airplane under consideration in this paper. Fig.4 shows that, even for long-haul flights, the actual ground distance can be more that 20% longer than the direct route distance.

Fig.5 and Fig.6 illustrate the differences between ground and air distances. The main parameter that explains these differences is the wind. The distribution presented appears mainly symmetrical, which means that the wind has both positive and negative impacts and almost in the same proportion. It appears consistent with operational conditions. However, one might have expected to observe more drawbacks than benefits from the wind. Indeed, if head wind could explain this symmetry, side wind would induce a shift towards longer air distances. The balance between positive and negative impacts observed in Fig.5 can however be explained by the strategy of the airlines to modify the flight track to reduce the negative impact and maximise the benefits of the wind.

The variability related to altitude (Fig.7) is mainly related to ATM. The cruise altitudes are aligned with the available flight levels defined to ensure vertical separation between the airplanes. However, there are some cruise altitudes that are different from the ATM predefined flight levels. We have not identified the operational parameter related to this variability yet.

The temperature shows variability too (Fig.8). The airplane can operate on colder or warmer environment. The specific airplane considered in this study mainly operated in the northern hemisphere. The shape of the distribution shows two peaks. Our first hypothesis to explain this is the seasonal variation of the temperature. The left peak would correspond to winter and the right one to summer.

Finally, Fig.9 reveals the variability related to the payload is very large. Our analysis is that the uncertainty on payload depends on the routes, the day of the week, the period of the year and the efficiency of the airline to sell flight tickets. It could also be explained by operational limitations at the airport for instance. The correlation has not been investigated yet.

4.2. Variability for the airplane design

During the preliminary phases of an airplane design, this one is usually optimized with respect to one referenced mission. Aerodynamics, structures, systems and engines are then optimized to minimize the weight, the fuel consumption and the operating costs or to maximize the range and the payload. Based on these analyses, decisions are made to define the specific features of the future airplane. Reference [2] underlines the risks related to optimising an airplane based on one mission only.

The representations we obtained of the operational variability during the work presented here can be the basis for developing models that will be adequate for airplane preliminary design and for proposing robust methods to cope with the described uncertainty parameters.

5. CONCLUSION

The main identified uncertainty parameters related to airplane operations and real civil aviation world activity have been listed and described. Using databases and statistical data processing, the related variability was plotted and analysed to make a link between its statistical distribution and various operational parameters.

The benefit demonstrated by this study is that it seems possible to correlate the observed variability to operational parameters, such as airlines routes network, operational flight optimization, ATM, and the atmospheric and meteorological conditions. Based on this work, the next step will be to elaborate models that will capture and represent this variability so that it can be taken into account in the preliminary design process of an airplane, where the decisions taken are of great importance for the future efficiency of the designed airplane.

6. REFERENCES

1. Advisory Council for Aeronautics Research in Europe, Strategic Research and Innovation Agenda, 2012

2. R. P. Liem, G. K. W. Kenway, and J. R. R. A. Martins. Multimission Aircarft Fuel-Burn Minimization via Multipoint Aerostructural Optimization. *AIAA Journal*, Vol. 53, No. 1 (2015), pp. 104-122. doi:10.2514/1.J052940

3. Database, http://www.transtats.bts.gov, United States Department of Transportation, Bureau of Transportation Statistics.

4. MOZAIC IAGOS Database, http://www.iagos.org/, European Research Infrastructure IAGOS (In-service Aircraft of a Global Observing System)