Takeoff and Landing Performance Optimization

Development of a Computational Methodology

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Abstract

During the past decades the global aviation industry has been experiencing a precarious balance between revenue and costs. Besides, the modern world is living an economic recession and so crude prices are now higher than ever. Therefore, all over the world, airlines need to adapt and evolve, finding new ways of struggling through the competitive world of commercial aviation. Optimization is currently the key to succeed.

Aircraft performance data calculation and optimization reflects through the whole airline operation. Besides having flight safety as its ultimate concern, data availability and easy recalculation makes airlines' operation more safeguarded to operation disruptions due to external agents. Also, the quality of this data reflects in the airlines' balance sheets at the end of the year as the result of possible savings in different areas of operation [1].

The present work focuses in the development of a computational application for takeoff and landing performance data generation and optimization. The takeoff performance optimization entails the maximization of the Regulatory TakeOff Weight (RTOW) and the respective operational speeds (V_1, V_R and V_2). In a similar way, the Regulatory Landing Weight (RLW), the final approach speed (V_{FA}) and the landing distances (actual and required) are computed during the landing optimization. The results are to be automatically published in the form of RTOW and RLW charts. The actual calculations are processed by Airbus' Operational and Certified TakeOff and landing Performance Universal Software (OCTOPUS).

The developed application is more than a simple program; it handles a set of TAP's databases and external programs with the single objective of providing customized aircraft performance optimization capabilities, at the distance of one click, to TAP's personnel. This project is borne alongside TAP's in-house project for an Electronic Flight Bag (EFB) – an electronic system that displays a variety of aircraft data and executes performance calculations [2].

Keywords: Aircraft Performance; Performance Software; Takeoff Optimization; Landing Optimization; OCTOPUS.

1. Introduction

Operating almost 2,000 weekly flights through a route network that comprises 77 destinations in 34 countries worldwide, TAP is a large European airline [3]. Just recently, in 2010, TAP has achieved a profit of roughly 62.3 million euros, an increase of 8.7% against the previous year, and this way a positive balance which had not happen since 2008 – one of the worst years for the commercial aviation in history [4]. TAP is clearly a winner in the vast sea of airlines that nowadays struggle to remain afloat with only marginal profits.

In commercial aviation, profit demands cargo and passengers, which from an engineer's point of view translates as weight. To maximize aircraft's weight at takeoff, aircraft performance optimizations must take place.

Although takeoff and landing represent only a small portion of the total operation of an aircraft, performance of these two phases is considered very important due to entirely different reasons [5]. First, a great majority of accidents (mostly attributed to pilot error) occur during landing or take-off. Second, it is the take-off portion that establishes the engine sizing (in conjunction with air worthiness requirements) for design of civil aircraft. More importantly, civil airlines more than ever, need to optimize the weight of their aircraft to become more competitive.

This way, it is not a surprise that "takeoff and landing are the most strictly regulated segments of a flight" [6, pp. 16-2]. For safety reasons, authorities such as the JAA (Joint Aviation Authority) and the FAA (Federal Aviation Administration) have laid down operational procedures to ensure a safe practice during the takeoff and landing stages.

Performance data calculation and optimization reflect through the whole airline operation. Besides having flight safety as its ultimate concern, data availability and easy recalculation makes airline's operation more safeguarded to operation disruptions due to external agents. Also, the quality of this data reflects in the airline's balance sheets at the end of the year as the result of possible savings in different areas of operation [1].

Nowadays, airlines either subcontract or calculate takeoff performance by themselves. This data is presented in the form of tables such as the Regulatory TakeOff Weight (RTOW) and Regulatory Landing Weight (RLW) charts. Generally speaking, they consist in a list of weights (RTOW) and operational speeds as a function of specific parameters (such as aircraft model, runway characteristics and weather conditions). Besides providing utmost important data to airliner pilots, RTOW charts also provide important information for several ground operations, especially for the flight dispatcher who uses these documents during the planning and monitoring processes of aircraft's activities. In a similar way, to dispatch an aircraft, an operator has to verify landing requirements based on aircraft certification and on operational constraints defined in regulation, which is usually achieved by interpretation of RLW charts.

2. TAP's case study

There are two main target groups at TAP Portugal that currently handle RTOW charts in their daily activities and that will benefit directly from the present work: the flight dispatchers and the flight operations engineering department. Pilots will also benefit from this software since they will be allowed to perform calculations for training purposes, outside their schedule flights.

2.1. Fight dispatch

The flight dispatcher is responsible for planning and monitoring the aircraft's activities. They receive the expected payload for each flight from Load Control and use TAP's flight plan calculation program to calculate the ICAO flight plan which they must submit to EUROCONTROL. Furthermore, the required fuel is also computed and an automated message is sent to the fuel suppliers.

Simply put, he must check the weather conditions by consulting the newest Aviation Routine Weather Report (METAR) or Terminal Aerodrome Forecast (TAF), which he can retrieve through TAP's intranet system. Depending on the weather conditions he will know (or at least predict) which runway will be in operation at takeoff (headwind improves aircraft performance). Then, he must access TAP's RTOW chart repository and find the chart that matches the aircraft (for which he is planning the flight) and runway (that he identified by reading the weather conditions).

However, it is a common practice to have several charts for the same aircraft and runway, each one corresponding to different conditions (such as different aircraft configurations, or different runway conditions or intersections). Many times this process requires the flight dispatcher to interpolate between different lines of the same chart (e.g. temperature value between two lines), or to perform additional performance calculations to contemplate conditions that are not present in any chart in the repository (e.g., slush on the runway).

2.2. Fight operations engineering department

The Flight Operations Engineering Department is without a doubt in need of a new and more dynamic aircraft performance calculation tool.

One example of a task performed by TAP's engineers is the calculation of aircraft maximum payloads; currently, to accomplish this task the engineer needs to gather several data that is spread across the innumerous RTOW charts. First, he must identify which aircraft configuration results in a higher Maximum TakeOff Weight (MTOW) for the airport's reference temperature. Since each chart only displays information related to two of the possible configurations, he must handle different charts at the same time. Additionally, it may be necessary to perform interpolations since the airport reference temperature might not be strictly specified in those tables. The whole process can be extremely time-consuming and give way to possible mistakes. Besides, since the current tables are stored as PDF files, the engineer may find himself copy-pasting the values from the charts to another work tool such as Microsoft Excel or Matlab.

Code	Limitation
1	1^{st} Segment
2	2^{nd} Segment
3	Runway
4	Obstacle
5	Tire Speed
6	Brake Energy
7	Maximum Weight
8	Final Takeoff
9	V_{MU}
-	V_{MCG}
-	V_{MCA}
-	V_1/V_R
-	Acceleration 3^{rd} Segment
-	Gross Level-off Height
-	Turn Height

Table 1 - TAP's takeoff limitations.

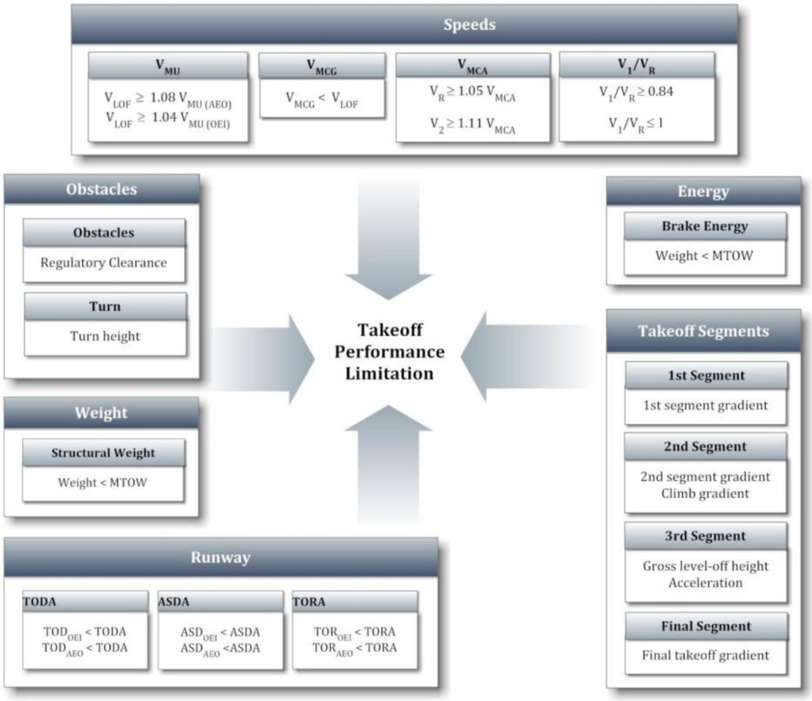

Figure 1 - Takeoff Performance Limitations.

2.3. Remarks

Summing up, it would appear that in both cases the performance considerations can be very time-consuming. Also, when they demand delicate performance calculations, they leave room for human error. Furthermore, most times, hand-made performance optimizations tend to use more conservative approaches than the computational methods and consequently it is evident that there is room for optimization. Also, it seems that the engineers are lacking of a more dynamic tool, one that could, for instance, export optimization results as an Excel file so that the data could be handled without requiring to be manually processed.

3. Takeoff Performance

The optimization objective is to obtain the highest possible performance-limited takeoff weight – Maximum Takeoff Weight (MTOW), while fulfilling all the airworthiness requirements and, consequently, respecting all the limitations enumerated in Table 1.

The first nine rows correspond to the original limitations set by Airbus' official documentation, while the remaining five are in agreement with the new TAP's takeoff performance limitations table (currently implemented in TAP's EFB project).

These takeoff limitations, result from constraints imposed either by regulatory or the aircraft manufacturer, as displayed in Figure 1.

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3.1. Takeoff performance optimization

It is necessary to determine which parameters influencing the takeoff (influencing the limitations) are fixed – Sustained Parameters (cannot be changed) and which offer freedom of choice – Free Parameters. For instance, the current wind condition cannot be changed or chosen – this is a sustained parameter. The influencing parameters are enumerated in Table 2.

Both the chosen flap setting and the engine bleeds condition take major impact in the aircraft performance, and consequently in the takeoff performance. Nevertheless the takeoff speeds represent the most important source of optimization and MTOW gain [7] [8]. This way, "at a given configuration (and all sustained parameters), takeoff weight limitations are set as functions of V_1/V_R and V_2/V_S" [9].

Sustained Parameters		Free Parameters
Runway	TORA TODA ASDA Lineup Adjustments Slope Condition	**Flaps Setting** **Air Conditioning** **V1/VR Ratio** **V2/VS Ratio**
Outside Elements	Wind Pressure OAT	
Obstacles and Takeoff Trajectory		
Anti-Ice		
Aircraft Status (MEL/CDL)		

Table 2 - Influencing Parameters (adapted from [7] and [9]).

3.2. Optimization range

Assuming a given aircraft condition, the takeoff optimization process will take place inside a well delimited range defined by the maximum and minimum allowed values for both speed ratios.

3.2.1. V_1/V_R Range: the decision speed, V_1, must always be less than the rotation speed, V_R. Although V_R depends on the weight and the value of V_1 is not fixed, the maximum V_1/V_R ratio is equal to one ($V_1/V_R \leq 1$) [7]. Also, the minimum V_1/V_R ratio is equal to 0.84 (manufacturer value [7]). This way, one can say that the V_1/V_R ratio has a well-defined range:

$$0.84 \leq V_1/V_R \leq 1 \tag{1}$$

This proves to be particularly useful since it also grants a well-defined range for the takeoff optimization process.

3.2.2. V_2/V_S Range: the minimum value for V_2 imposed for Airbus' Fly-By-Wire aircraft (all of TAP's fleet) is $1.13V_{S1g}$. Although V_2 does not have a fixed value (since the stall speed depends on the aircraft weight), the V_2/V_S ratio is known for a given aircraft type.

This way, having a well-known range, the V_2/V_S ratio proves to be very helpful for the takeoff optimization process:

$$1.13 \leq V_2/V_S \leq (V_2/V_S)_{MAX} \tag{2}$$

A maximum value for V_2 (and consequently, a maximum V_2/V_S) is specified by the manufacturer (see Table 3).

Aircraft Family	$(V_2/V_S)_{MAX}$
A320	1.35
A330	1.40
A340	1.45

Table 3 - V_2/V_S maximum values for the Airbus family (data retrieved from [7]).

3.3. Free parameters influence

3.3.1. Aircraft configurations are associated with a set of certified performance, making it suitable for one specific situation but inappropriate for another (e.g. shorter/longer runway). On account of this, "the optimum configuration is the one that provides the highest MTOW" [7]. As a general rule, this is the chosen configuration.

As a general rule, Configuration 1+F offers better aircraft performance on long runways (better climb gradients), whereas Configuration 3 provides better performance on short runways (smaller takeoff distances). Sometimes, other parameters, such as obstacles, can interfere. In this case, a compromise between climb and runway performance is required, making Configuration 2 the optimum configuration during takeoff [7].

3.3.2. Air Conditioning switched on during takeoff results in a loss of power and consequently degrades the takeoff performance.

3.3.3. V_1/V_R ratio: it is possible to find the optimal V_1/V_R value taking into account the takeoff limitations for a fixed V_2/V_S ratio (see Figure 2).

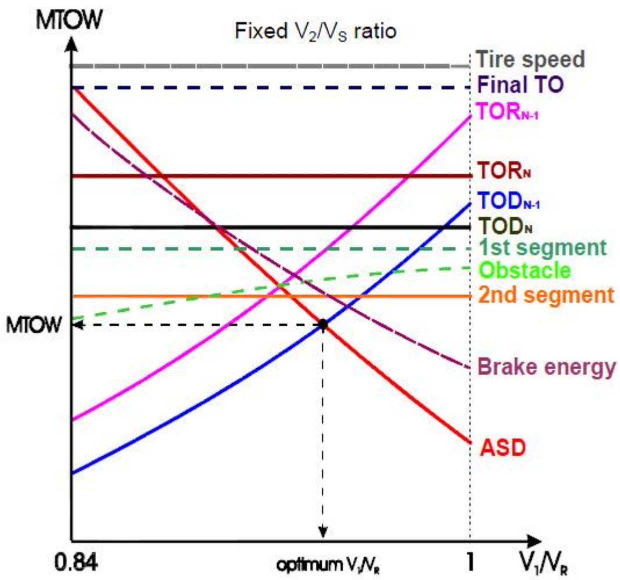

Figure 2 - Optimum V_1/V_R for a given V_2/V [7]$_S$.

This optimum V_1/V_R ratio corresponds to the MTOW for the given V_2/V_S ratio.

V_2/V_S ratio: In a similar way to the previous paragraph, it is possible to study the behavior of V_2/V_S and find its optimum value for a fixed V_1/V_R ratio [10].

3.4. Optimization process

"The Regulatory Take-Off Weight and associated takeoff speeds (...) are determined through an iterative process which looks for the optimum V_1/V_R for a given V_2/V_S and then for the optimum V_2/V_S for that V_1/V_R" [10]. The process continues until the difference between two subsequent iterations is less than, or equal to, the specified precision.

Figure 3 shows a spatial representation of the variation of MTOW with both speed ratios, for a given set of sustained parameters and aircraft configuration.

It is possible that under certain conditions the optimization results in a range of optimum solutions, instead of a single maximum (see Figure 4).

Once the optimum speed ratios (V_1/V_R and V_2/V_S) are obtained, the takeoff speeds are obtained as in Figure 5.

AFM means that the information is obtained from the Aircraft Flight Manual (AFM).

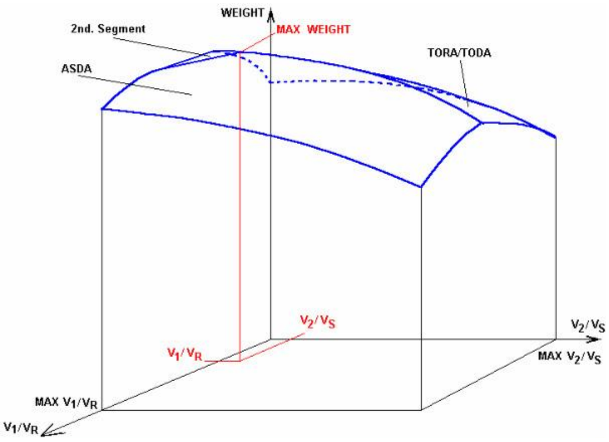

Figure 3 - MTOW as function of V_1/V_R and V_2/V_S [10].

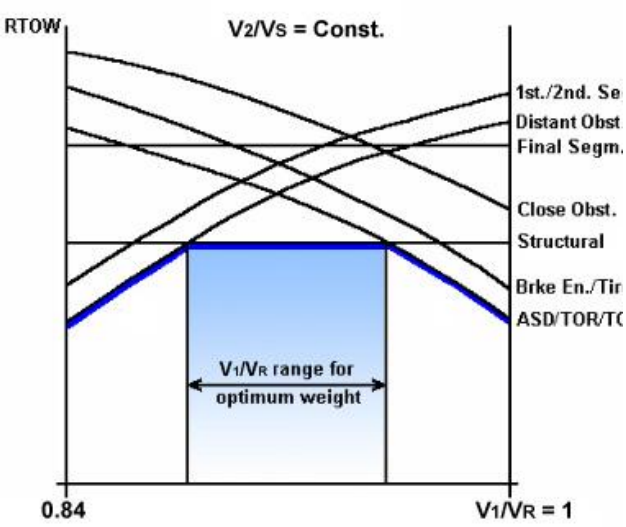

Figure 4 - Range of solutions that maximize MTOW (adapted from [10]).

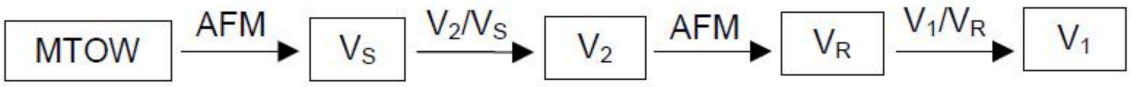

Figure 5 - Takeoff speeds calculation [11].

3.5. Flexible takeoff

Although flexible temperature calculation is beyond the scope of the current work since it can only occur moments before an aircraft takes-off, there are some flex related parameters that should be provided in the RTOW chart such as the maximum flexible temperature ($T_{Flex\ Max}$) and the reference temperature (T_{REF}).

Since engine thrust drops when OAT increases, if ATOW is less than MTOW it is possible to determine the temperature at which the needed thrust would be the maximum thrust for this temperature – see Figure 6. "This temperature is called flexible temperature (T_{Flex}) or assumed temperature" [7, p. 87].

Performing the thrust reduction resulting from a flexible takeoff will save engine life [12], reduce maintenance costs and improve engine reliability [9] [8]. As a result it improves both safety and reduces operational costs.

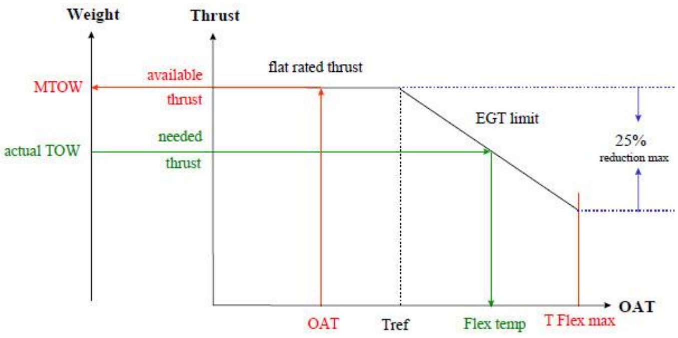

Figure 6 - Flexible temperature principle [7].

4. Landing performance

To dispatch an aircraft, an operator has to verify landing requirements based on aircraft certification (JAR 25) and on operational constraints defined in JAR-OPS [7]. In normal conditions, these requirements are not very restrictive and most times aircraft are dispatched at their maximum structural landing weight. This leads to a minimization of importance of landing checks during dispatch. However, landing performance can be drastically affected when considering missing and/or inoperative aircraft items, under adverse external conditions and in the presence of a contaminated runway. This way, landing performance checks are of utmost importance and should always be taken into consideration to ensure a safe flight.

In a similar way to the takeoff situation, the landing performance optimization is always constrained by regulation on operational speeds, on runway parameters, go-around requirements and outside elements. The resulting limitations can be summarized in the following table:

Code	Limitation
1	Structural Weight
2	LDA
3	Approach Climb
4	Landing Climb
5	Tire Speed
6	Brake Energy

Table 4 - Landing limitations [11].

5. Takeoff and Landing Performance Program (TLP)

Figure 7 illustrates the relations between TLP and all the external agents (user, OCTOPUS program and databases).

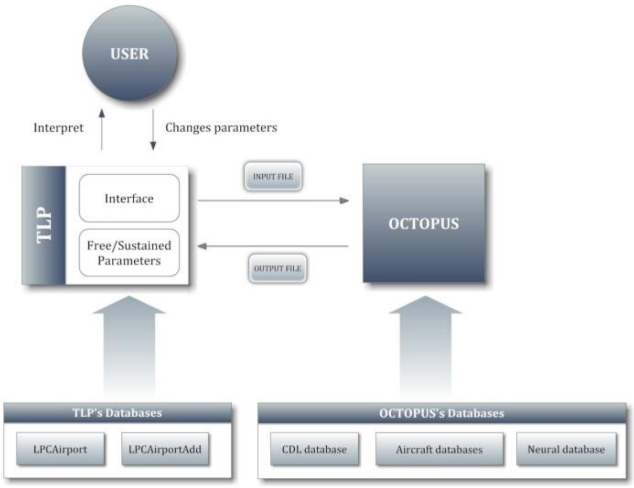

Figure 7 - TLP structure.

The TLP application uses two databases, the LPCAirport and LPCAirportAdd. The OCTOPUS program has its own set of databases which include aircraft data, CDL data, and neuronal networks.

The program executes in two different modes: Takeoff Optimization and Landing Optimization (Figure 8). The main purpose of the first mode is to optimize the takeoff weight (as a function of the sustained and the free parameters) and this way calculate MTOW and the resulting operational takeoff speeds (V_1, V_R and V_2). In a similar way, the objective of the Landing Optimization mode is to calculate the MLW, the landing distances (required and actual) and the approach speed.

Figure 8 - TLP on startup.

TLP's user interface consists in several visual basic forms that contain a series of controls (such as buttons, combo boxes, text inputs and check boxes) with which the user interacts, and this way configure the free and sustained parameters. The parameters are temporarily stored into visual basic classes and are later written to the OCTOPUS input file so that they can be used as input for the optimization process.

The OCTOPUS program is launched and ran in the background as an independent program through the windows shell function. In the meantime the TLP process stalls, launching a "Please Wait" message in a new thread, while waiting for the OCTOPUS program to successfully terminate its execution. The OCTOPUS program concludes its activity by writing an output file with the results of the optimization.

This output file is then loaded, parsed by the TLP program and presented to the user, which is able to export it as a real RTOW chart. The user can readjust the parameters and perform new optimizations at his will.

6. OCTOPUS

OCTOPUS stands for Operational and Certified TakeOff and landing Performance Universal Software. This is an Airbus program that is able to compute aircraft performance calculations under regulatory constraints, and this way is able to optimize takeoff and landing performance for given runways. OCTOPUS is used for computations related to A318, A319, A320, A321, A330, A340 and A380 aircraft [11]. It was delivered by Airbus in the form of Fortran 95 source code with roughly 230000 lines of code and later compiled during this work by the Compaq Visual Fortran 6 compiler.

6.1. Structure

OCTOPUS uses comprises a large group of files (sub-databases) that contain various aircraft data (such as speeds). These aircraft databases are called OCTOBASE. The Neural database consists of a set of neural files containing pre-computed data which can be used to initiate the calculation process. Performance penalties coming from CDL items are obtained from the CDL database.

6.2. Functions

OCTOPUS functions can be split in three categories: Aircraft data file consultations, Flight manual calculations, and Optimizations (takeoff and landing). The first two groups are certified while Optimizations use regulatory calculation but are not certified [11].

TLP only uses functions from the third group, specifically the Takeoff Optimizations and the Landing Optimizations functions. The Takeoff Optimizations may be performed in the point, curve, network or chart modes, while the Landing Optimizations can only be executed in point and chart.

In the point computation mode, OCTOPUS optimizes the takeoff weight for a specific set of conditions. For curve and network modes, however, it is possible to set a group, or two, of additional conditions to be optimized (such as a temperature vector, and/or different wind conditions). The aim of the chart computation mode is to build a complete RTOW chart, and in the same way as the curve and network modes, also allows specifying additional groups of conditions [11].

Since TLP's goal is to optimize the aircraft performance under a specific set of conditions, and for a certain temperature vector: for the takeoff optimization mode the curve computation is adequate, while for the landing optimization it was necessary to implement a chart computation.

7. Conclusion

Motivated by the opportunity to provide real contribution to the aviation industry, and particularly to TAP, it was with great enthusiasm that the author overcame the different stages of this project.

Although the current work consisted in the development of a computational application, a large initial effort was invested in the interpretation of the OCTOPUS program, namely its internal procedures, functions, databases and specially its input and output files. Undoubtedly, this was one of the most important and time-consuming stages of the dissertation; OCTOPUS is after all the backbone of the TLP program.

Simultaneously, the author attended one of TAP's internal Aircraft Performance courses which proved to be of great value. It has provided not only valuable theoretical knowledge but also in loco know-how on TAP's own policy on takeoff and landing procedures.

Only later, when the program's lifecycle, and consequent flowchart, became a comfort area to the author, it took place the computational development. The user interface is the outcome of an interactive process based on the experience and sensibility acquired from Airbus' official performance programs (PEP) of both TAP engineers and future users of this application.

The Takeoff and Landing Performance Program (TLP) is TAP's new technological solution for on-ground performance calculation. Besides providing valuable benefits for the dispatch procedures, with its dynamic and prompt reaction user interface, it will prove to be a helpful working tool for TAP's performance engineers with its vast configurable inputs and editable Excel worksheet outputs. One process that could take a couple of hours, before, can now be accomplished within seconds, providing safe and always optimal values.

All in all, the author believes that the present project will prove its benefit to TAP Portugal, either by simplifying the daily activity of its engineers or by serving as a new training tool for pilots. This way, TLP places TAP one step further in the never-ending optimization process.

Computer performance data calculation in cockpits is the next step in airline industry [1]. Major commercial companies have investigated the advantages of electronic computing devices in the cockpit. In 2001 UAL (United Airlines) tested an EFB device incorporating a Fujitsu Pentablet computer on an Airbus 319 aircraft with specially trained crewmembers. Since receiving a grant from the FAA in September of 2001, UAL has been developing an EFB that may become a standard for the industry [13]. Projects such as this and TAP's Electronic Flight Bag are currently pioneers in the struggle to develop certified EFBs.

Primarily, EFBs are used by commercial transport pilots for the performance of flight management tasks, both during flight and in the aircraft turnaround. Currently, the range of functionality supported includes aircraft performance calculations, weather and situation displays, flight log reporting, aircraft defect reporting, communications and document viewing (checklists, aeronautical charts and maintenance manuals) [14].

There are two distinct steps proposed by Airbus for implementing this idea into life [1]. The first involves the implementation of out of the box technology low cost solutions, such as TAP's EFB. These take advantage of commercially available laptops, which can be plugged-in to the aircraft's cockpit. The next step would be server linking aircraft avionics and EFB systems, allowing aircraft manual update, enhanced flight functions, and maintenance data transfer through wireless gate-links at speeds 100 times faster than today's Aircraft Communication and Reporting System (ACARS)[14].

8. List of acronyms

ACARS – Aircraft Communication and Reporting System
AFM – Aircraft Flight Manual
ASDA – Accelerate Stop Distance Available
ATOW – Actual Takeoff Weight
CDL – Configuration Deviation List
EFB – Electronic Flight Bag
EGT – Exhaust Gas Temperature
FAA – Federal Aviation Administration
ICAO – International Civil Aviation Organization
JAA – Joint Aviation Authority
LDA – Landing Distance Availabe
MCT – Maximum Continuous Thrust
MEL – Minimum Equipment List
MLW – Maximum Structural Landing Weight
MTOW – Maximum Structural Takeoff Weight
OAT – Outside Air Temperature
OCTOPUS – Operational and Certified TakeOff and landing Performance Universal Software
OEI – One Engine Inoperative
PEP – Performance Engineer's Programs
RLW – Regulatory Landing Weight
RTOW – Regulatory Takeoff Weight
TLP – Takeoff and Landing Performance Program
TOD – Takeoff Distance
TODA – Takeoff Distance Available
TOR – Takeoff Run
TORA – Takeoff Runway Available
T_{Flex} – Flexible Temperature
$T_{Flex\ Max}$ – Maximum Flexible Temperature
T_{MAX} – Maximum Operational Temperature
T_{REF} – Reference Temperature
V_1 – Decision Speed
V_2 – Takeoff Climb Speed
V_{LOF} – Lift-off Speed
V_{MCA} – Minimum Control Speed in the Air
V_{MCG} – Minimum Control Speed on the Ground
V_{MU} – Minimum Unstick Speed
V_R – Rotation Speed
V_S – Stall Speed
V_{TIRE} – Maximum Tire Speed

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