Study and development of an algorithm to detect stability points for aircraft performance analysis

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Abstract

The financial difficulties that airlines are facing following the financial crisis and the oil prices fluctuation are very hot subjects nowadays. On top of this, in a very competitive market where profit margins are constantly shrinking, it becomes mandatory for airlines to monitor the fuel consumption which is its main operating cost and to increase the energetic efficiency. The aircraft performance analysis is directly linked with the fuel consumption.
In the present work a software tool in C programming language was developed to identify the stability points that are required to determine the degradation factor, based on the flight parameters recorded by the aircraft. The tool contains stability criteria that filter the flight parameters to ensure consistent and reliable data acquisition. A procedure to identify the best stability point based on the quality number was introduced.
The obtained results show that it is possible to use more stringent stability criteria than the ones currently in use. Differences between the performance degradation values obtained by the tool and the currently considered values were found. These differences appear to be due to divergences in the source data acquisition procedures in each of the methods considered, which leads to the extraction of less accurate data that will need to be corrected in the future.

Key-words: stability points, specific range degradation, quality number

1. Introduction

The aeronautical industry is one that has suffered most from the variation in the fuel price that has been increasing significantly since 2000, achieving maximum values in 2008. Given the volume of fuel costs, airlines, more than ever, begin to invest in preventive and corrective measures that lead to a reduction in fuel consumption. Additionally, the environmental impact of greenhouse gas emissions is a growing concern in commercial aviation. In an airline, to observe the impact that the reduction of fuel consumption has environmentally and economically, the performance degradation of the fleet needs to be maintained monitored and controlled to optimize fuel consumption for each flight. The aircraft performance analysis is closely linked to fuel consumption.
We have assisted to the increment of actions and measures to increase energy efficiency and consequent fuel consumption reduction in the sector. Since the augmentation in fuel prices in the 1970s, airlines and aircraft and engine manufacturers have made efforts to find solutions that increase the level of efficiency of aircraft and operations by reducing fuel consumption. Efficiency augmentation has been tremendous over the past decades. The current aircrafts consume 70% less fuel per passenger-mile than 40 years ago. To reduce the impact of fuel costs, the airlines have been considering many strategies in different areas particularly in flight operations, aircraft maintenance, ground-handling, marketing, planning routes and aircrafts and also the selection of more efficient aircraft.
In addition to what was mentioned above there is an increment in systems and procedures for monitoring fuel consumption of aircraft. These systems allow airlines to follow the evolution of fuel consumption and evaluate the effectiveness of their measures in projects to reduce fuel consumption. Monitoring the aircraft and engine performance is a horizontal task to airlines and consists in the permanent collection of flight data that will be analyzed to determine the level of aircraft performance degradation at each moment. This procedure appears as a fundamental requirement for any project to reduce the fuel consumption or for flight planning. The monitoring of aircraft performance is focused on two main objectives: the reduction of fuel consumption (and/or monitor the consumption so that there is no unnecessary use) and to evaluate the aerodynamic drag degradation of the aircraft.
The performance monitoring is currently carried out through a flight data analysis from which the performance degradation level of each airplane can be determined against a benchmark set by the manufacturer. To do this analysis a performance software is used - PEP (Performance Engineer's Program) - developed by the manufacturer of the aircraft - in this case, Airbus - which contains several modules, among which is the APM (Aircraft Performance Monitoring). This module is responsible for determining the performance factor and requires the input of data recorded during flights. The data used in this program may have two different origins: the Cruise Performance Reports and AGS (Analysis Ground Station). The Cruise Reports are generated in flight and saved in the airplane and later are recovered in floppy discs or can be sent to the ground by wireless and this data is then processed. The second source contains data for a significant number of parameters that are constantly recorded throughout the flight. The analysis method using Cruise Performance Reports is what is currently done by TAP Portugal, but has limitations in terms of the amount of data that is available and of the representativeness of flights for which there is this data. To overcome these limitations and increase the amount of data available, the AGS comes as a solution of greater potential. This work consists mainly in the development of a tool that, based on the plane parameters properly processed by the AGS, determines points of stability and builds data files in a format that can be used directly by the

APM, which is to be an alternative to the current process.

2. Performance Analysis

Aircraft performance analysis can be accomplished using several alternative methods, such as comparing the instantaneous fuel consumption with the amount specified in FCOM (Flight Crew Operating Manual), the comparison of fuel consumption during a flight with the expected value given by the flight plan, which allows the correction of aircraft performance, taking into account the differences between the current values and those in the flight plan, or by examining the specific range. The specific range, as shown in equation 1, can be taken as an indicator of the aircraft performance when it is at a steady speed. This work is based on the method of the specific range

$$SD=\frac{\text{Distance (NM)}}{\text{Consumed Fuel (kg or ton)}} \qquad 1$$

The specific range is obtained by analyzing the flight data recorded during the flight phase that has more stable conditions. This analysis can be done using the software of the Airbus, the APM, which is a PEP module.

The APM calculates the flight performance by using mathematical methods (probabilistic and statistical calculations), the equations of aerodynamics, such as lift and drag equations and data related to the engine power. The input file for this program contains data such as the Mach number, total air temperature, altitude, weight, inertial vertical velocity, pack flow and center of gravity position. After this calculation, the program determines the deviation of the SR - DSR (Delta Specific Range or Specific Range Deviation), ie the difference between the specific range obtained and the reference value of the specific range that is indicated by the manufacturer in the testing phase of the aircraft. The APM also allows a distinction between the influence of the aircraft structure (DFFA) and engines (DFFB) for the observed deviation of this factor in the equation 2.

$$DSR=DFFB-DFFA \qquad 2$$

Figure 1 illustrates the principle of the APM program.

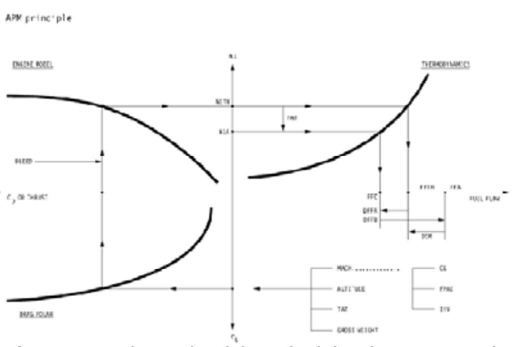

Figure 1 - Schematic of the principle of APM operation

Among the most important outputs of the APM there is the DSR and its standard deviation, DFFA and DFFB. A negative value of DSR means degradation due to engines and/or due to aerodynamic performance, depending on the values of DFFA and DFFB, which causes a reduction in the specific range and translates into a value worse than expected by the FCOM.

3. Stability points

The subject of this work is the determination of the stability point which is the average of parameters calculated for the central period of 20 seconds from a longer period of time identified as being a stability period. The stability period has 100 or 120 seconds, at which the differences between the maximum and minimum values of various parameters used, do not exceed the pre-defined tolerances meaning that the stability criterion was satisfied.

When identifying stability periods it should be taken into account a number of parameters from the flight data, including the Mach number (MN), total air temperature (TAT), altitude (ALT), engine rotation speed (N1 and N2) which is given in percentage, ground speed (GS), roll angle (ROLL), vertical acceleration (VRTG), the exhaust gas temperature (EGT), fuel flow (FF) and vertical speed (IVV).

Another important issue relates to the progress of the observation window. There are two distinct methods of observation: the individual observation windows with no common data or by a gliding observation window. With the first method, the parameters from the individual windows of 100 or 120 seconds are analyzed and when the examination is completed, it starts a new analysis to the data of the next window with no data in common with the previous one. The second method, the gliding window, has an operating principle based on the concept of do not reject any data from any period of 100 or 120 seconds. The aircraft system that generates the Cruise Performance Report uses the gliding window method which will also be implemented in the current work. While the gliding window used in the aircraft algorithm has 100 seconds and the advancements 20 seconds, in the current algorithm an observation window of 100 seconds will be used but with an advancement of 1 second.

The stability point is generated with the data of the period considered to be stable. The identification of the stability point is based on the analysis of the parameters values in the central 20 seconds of the corresponding stability period and the calculation of their average for this central period.

If various stability periods are identified and consequently several stability points are determined, it must be determined the optimal point for input on an analysis of APM. To do so it is quantified the quality of stability periods through the quality number. The quality number for a certain observation period is the sum of the individual parameters quality considered to obtain the stability point (equation 3). In turn, the parameter individual quality number is a factor that measures the variation that a parameter has during the time period under study.

$$QA = W_A \frac{VAR_A}{(TOL_A)^2} + W_B \frac{VAR_B}{(TOL_B)^2} + \cdots + W_N \frac{VAR_N}{(TOL_N)^2} \qquad 3$$

4. Tolerances and data filter

FDIMU (Flight Data Interface Management Unit) is an airborne unit which records and filters the flight data that is subsequently read and decoded by the AGS. In this unit is established a maximum variation window (tolerance) for each parameter.

In this work we considered two alternative tolerance systems: the one used in the programming language that generates the Cruise Performance Report and a system of tighter tolerances, more restrictive. The restrictive tolerances have been identified through an iterative process since it is necessary to establish a compromise between the tolerances applied and the number of stability periods found. This was the first approach to improve the existing system for determination of the best stability point. The two tolerance systems mentioned above are shown in Tables 1 and 2.

Parameter	Tolerance
MN	0,008
TAT	1,1°C
ALT	150ft
N1	1,6%
N2	0,9%

Parameter	Tolerance
GS	6,0kt
ROLL	0,8°
EGT	18°C
VRTG	0,03g
FF	100kg/h

Table 1 – Tolerance system used in the aircraft

Parameter	Tolerance
MN	0,003
TAT	0,5°C
ALT	30ft
N1	0,9%
N2	0,7%

Parameter	Tolerance
GS	2,0kt
ROLL	2°
EGT	18°C
VRTG	0,03g
FF	100kg/h
IVV	100ft/min

Table 2 – Final restrictive criteria

These tolerance systems can be adjusted depending on the amount of stability points that will be identified and optimized by reducing the tolerances to fit the results against objectives. This was done later in the initial test phase of the algorithm and therefore it was adopted a more demanding tolerance system as it shall be seen later.

In addition to the tolerance system, the airborne algorithm also uses a data filter to mitigate the noise effect on the measurements made. The filter works as a correction of read data and is does not eliminate any reading but adapts it to the previous reading. For this, it is used the following equation:

$$FO = OFV + \frac{t}{T}(NRV - OFV) \qquad 4$$

In equation 4, FO (filter output) represents the value already filtered, OFV (old filtered value) is the previous value of the same parameter already been altered by the filter, t is the number of samples per second, which in this case is 1 sample per second (t = 1), T is a filtering constant - in this case the value 3 will be considered, since it is the same constant used by the aircraft system to establish the Cruise Performance Report - and finally the variable NRV is the reading done without the filter (new raw value) which becomes the FO value after applying the filter. After replacing the values of t and T in equation 4, the previous equation degenerates into equation 5:

$$FO = OFV + \frac{1}{3}(NRV - OFV) \qquad 5$$

5. Algorithm

In order to detect stability points with good quality it was developed a C code which has an input data file obtained by the AGS. After setting the tolerances to be used as a stability criterion, the algorithm parses the parameters recorded in the input file, determines the maximum variation of each parameter in the observation period and verifies if the stability criterion is met and if so the current period is identified has being a stability period. This process is repeated using the gliding window method. When a stability period is identified, it is calculated the corresponding stability point. For each stability point is calculated the corresponding quality number which will be used to determine the best stability point encountered for the current flight under analysis. Figure 2 illustrates the procedures performed by the developed algorithm.

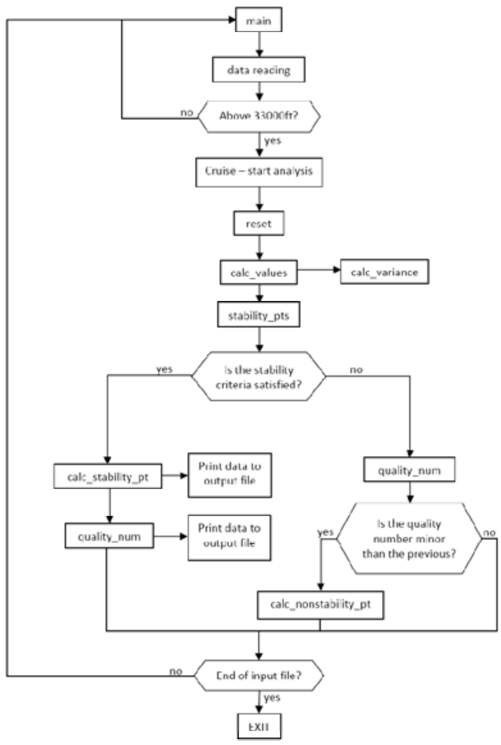

Figure 2 - Flowchart of algorithm for detecting stability points

6. Results

The algorithm described in the previous section was initially used to test the lower tolerances to be implemented. The stability criterion established by the tolerances described in Table 2 was tested. After the algorithm implementation and after testing it for several flights, it was observed that the tolerances could be further reduced compared to the ones that were initially imposed (Table 2). This process was repeated for several flights with the same aircraft with the intention of getting to a compromise between the number of flights that originated stability points and the amount of stability points identified for each flight. This compromise was achieved by reducing the tolerances of all parameters except for fuel flow which was maintained with the same value. With this iterative process it could be established the stability criterion considered in this work and shown in Table 3.

Parameter	Tolerance	Parameter	Tolerance
MN	0,002	GS	1,0kt
TAT	0,3°C	ROLL	0,5°
ALT	20ft	EGT	4°C
N1	0,6%	VRTG	0,02g
N2	0,4%	FF	100kg/h
		IVV	50ft/min

Table 3 – Stability criterion used

The tolerances shown in Table 3 were also used to test the algorithm at study. With these tolerances only one out of 10 flights analyzed (on average) did not generate a stability point, concluding that these tolerances are a good stability criterion to find stability points in order to carry out an APM analysis. The results shown hereafter were obtained using the tolerances in Table 3, except when said.

As mentioned above, in order to find the aircraft degradation it is currently used the APM for which the input file is the report taken from the plane (Cruise Performance Report).

In the Airbus A320-211 the systems that originate the Cruise Performance Report are less sophisticated than those currently existing and one disadvantage in that report is the fact that it only reports the first stability point and not necessarily the better stability point in flight during the cruise phase. This process makes data to be less consistent than the expected to be obtained by the algorithm now developed as it follows the methodology of [3], where it becomes clear that it is an optimized methodology and able to produce input data to the APM with a superior quality.

In the analysis performed it was used the data from a flight from Lisbon to Praia with an Airbus A320 - 211 and the procedures that will be made can be extrapolated to all aircraft under the same conditions. For this flight, it was obtained a stability point at 21h37m41s by the Cruise Performance Report. Figure 3 shows a graph with the most relevant parameters (MN, IAS, ALT, TAT, N11, N12, FF1, FF2, VRTG and IVV) for the entire cruise phase. In the abscissa, it is represented the time in seconds, the instant 21h35m corresponding to 0s.

This figure depicts the variation in time of certain parameters of this flight from 21h35m till 00h44m. As it can be seen, the initial parameters evolution appears to be very unstable compared with the periods following the change in flight level, visible in the curve on the altitude. From direct observation of the figure it is possible to identify a period with characteristics of a potential stability period between the seconds 4500 and 5100. However, the period corresponding to the one presented by the Cruise Performance Report stays between 0s and 300s.

To make an analysis of this flight with the algorithm it was used a data file extracted from AGS. A brief observation of this file revealed that it contained data that did not meet the desired quality of input data for the algorithm developed. This was observed for the gross weight, for example.

When trying to understand if what was revealed with the previous data file was just a coincidence other files from different flights of the same type of aircraft (Airbus A320-211) were observed too and it was concluded that it is not a coincidence but instead a choice of a lower sampling frequency. This means that the weight, as a few other parameters (for example, for the latitude it was observed the same) have a sampling frequency of one reading every 4 seconds. This causes some instability in data reading and that weight for example is a parameter that is zero in certain periods of time and alternately it is presented with values consistent with what was predicted. There are even parameters which for this work are not relevant, which are read every 64 seconds. In the case of weight it would be interesting in terms of future work to incorporate a routine in the algorithm developed to calculate the weight of the plane through the fuel used and knowing the initial weight of the aircraft. Since the weight and other parameters which showed some errors are not covered by the stability criterion used, the analysis of the flight with the algorithm under study was made.

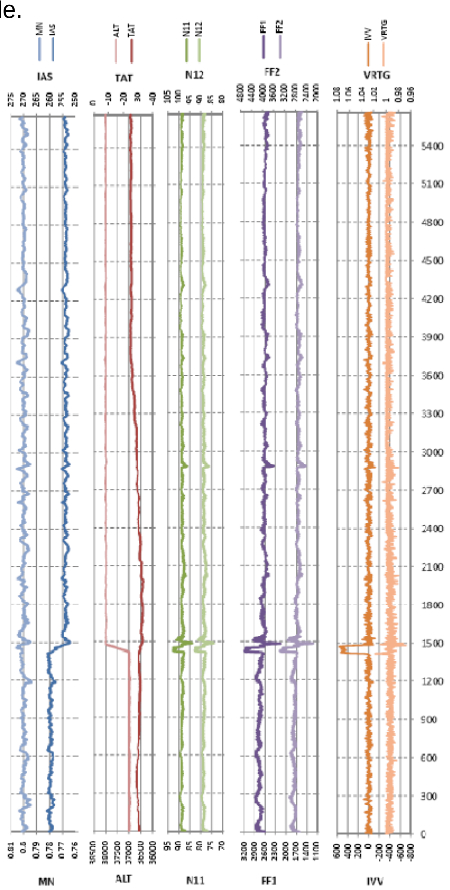

Figure 3 - Total cruise phase for a flight from Lisbon to Praia

In order to identify the stability periods in flight, it was used the two stability criteria described above in the algorithm which was developed, and it will be called Criterion 1 to the stability criterion given by the tolerances shown in Table 1 and Criterion 2 the stability criterion presented in Table 3. Table 4 summarizes these two criteria:

Criterion 1	
Parameter	**Tolerance**
MN	0,008
TAT	1,1°C
ALT	150 ft
N1	1,6%
N2	0,9%
GS	6,0 nós
ROLL	0,8°
EGT	18°C
VRTG	0,03g
FF	100kg/h

Criterion 2	
Parameter	**Tolerance**
MN	0,002
TAT	0,3°C
ALT	20ft
N1	0,6%
N2	0,4%
GS	1,0kt
ROLL	0,5°
EGT	4°C
VRTG	0,02g
FF	100kg/h
IVV	50ft/min

Table 4 - Stability criteria used

The analysis of this flight was made using the unfiltered data file and Criterion 2 because it is the most restrictive. However, no stability points were obtained with this criterion. When changing the criterion the result was the same. Thus, it was made the same procedure using filtered data. With Criterion 2 the result was the same, meaning that even with the filtered data it could not identify periods of time in which the parameters variations were within the limits imposed by tolerances. Changing the analysis and using the criterion 1 the results were different.

Analyzing the flight from Lisbon to Praia mentioned above with Criterion 1 it proved to be curious. 711 stability points were obtained and the first point occurred at 21h52m, ie well after the point where Cruise Performance Report was generated. A first study to be made after observing the results of the algorithm was trying to figure out why the stability period was not obtained at the same instant as the Cruise Performance Report. Making an observation to the data file of this flight it was found that for the period reported by the aircraft (21h37m41s) the parameters variations exceeded those allowed by Criterion 1. One question emerges now: if the variations are greater than the tolerances of Criterion 1 - which are currently used in aircraft system - so how did it generate the point of the Cruise Performance Report? One possible explanation is that the aircraft system for the plane under consideration is already old and therefore may eventually allow a system of tolerances less stringent than the system of the latest aircraft.

The second and final study done for this plane was to find the stability period among the 711 obtained which had the best quality number. The stability point with the best quality occurred at 00h20m. This moment is precisely the period of time between the seconds 4500 and 5100 that was considered previously as a time interval with potential for being a stability one. Figure 4 shows the evolution of parameters for the period with greater stability identified by the developed algorithm with filtered data. In this figure it is shown the interval between 00h16m (frame 0) and 00h22m (frame 180). Figure 5 shows a detail from the period generated by the Cruise Performance Report and the frame 90 corresponds to 21h37m (Greenwich Cruise Performance Report). This figure presents the evolution of 5 minutes from cruise phase, including the stability period. In the following figures, each 30 frames correspond to 1 minute.

Figure 4 shows that the period of greater stability is between frames 60 and 120, and the frame 120 corresponds to the instant 00h20m.

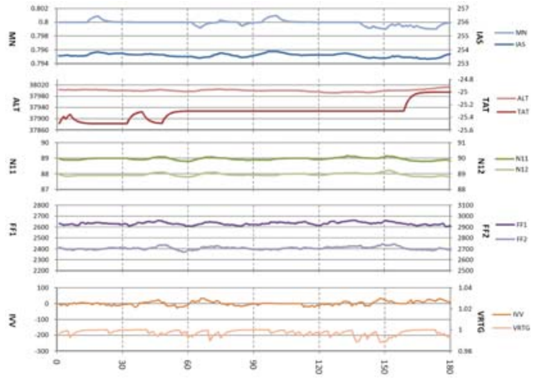

Figure 4 - Detail of stability period at 00h20m (algorithm)

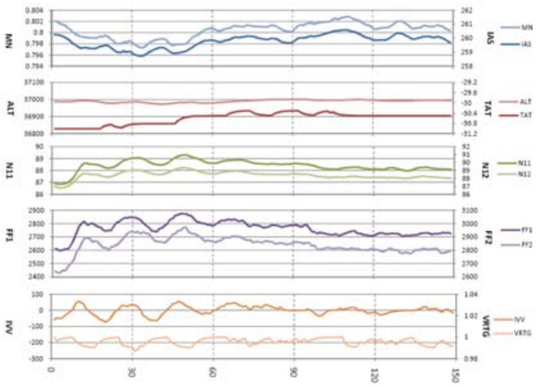

Figure 5 - Detail of stability period at 21h37m (Cruise Performance Report)

The stability period obtained by the developed algorithm has a much lower fluctuation of data than the period obtained by the aircraft system. Proof of this is that the point obtained by the Cruise Performance Report is not even a stability point when processing the data by the algorithm. This means that the period presented by the Cruise Performance Report has data variations high enough to disrespect the tolerances given by Criterion 1 which itself is a non restrictive criterion.

Looking at figure 4 it can be seen that there is a lower data variation in the stability period identified by the proposed algorithm, while observing Figure 5 there is a greater fluctuation in the data reported by the aircraft system and in adjacent periods.

For this flight it was not done any analysis using APM. One of the crucial parameters for an efficient APM analysis is the weight and, as mentioned, this parameter does not have the required quality in data file. A performance analysis using APM would be very helpful to find out about the consistency of the data obtained by the algorithm. Due to lack of data, alternatively it can be determined if there is consistency of data or not by the quality number for the 2 stability periods. Table 5 presents the results of this calculation for each previous stability period.

Quality number for 21h47m	Quality number for 00h20m
8,356297	0,12197

Table 5 – Quality number for the 2 stability periods

By observation of the table, the quality number of instant 21h47m obtained by the aircraft is a much higher number than that obtained for the stability period generated by the algorithm (00h20m). Since the quality number can be understood as a sample dispersion measure, then it is clear that the point reported by the Cruise Performance Report was achieved with a greater dispersion of parameters, thus suggesting a greater fluctuation of data in this period, as it was seen (figure 5). If there is flight data quality in the input file read by the algorithm, it is expected that a performance analysis is much more reliable with data produced by the developed algorithm than performing the same analysis using the points generated by the Cruise Performance Report. This superior input data quality of the algorithm is expected to be achieved if a subroutine is integrated to properly calculate the weight by making use, for example, of the fuel consumed.

The latest aircraft systems, excluding the Airbus A330, have already into account the entire flight meaning that they do not report the first stability point but the one that throughout the flight has the best quality number. In the case of the Airbus A330 these aircraft have a stability point's generation system different from that used by the family of Airbus A320. The Airbus A330 report all stability points obtained using the same algorithm that generates the Cruise Performance Reports and the choice of the best stability point is made later. Thus, there was a comparison study between the points generated by the aircraft system and the ones generated by the algorithm under study. The aircraft chosen for this analysis was an Airbus A321.

Before starting the analysis of these aircraft, the data files of some of the flights, were checked but not exhaustively. It was found that the longitudinal acceleration, FPAC (Flight Path Acceleration), showed a discrepancy regarding GS (Ground Speed), which was gradually presented. So, for all tests carried out subsequently, the FPAC value takes the analytically calculated value using the values of GS presented in the central 20 seconds of the considered stability period.

In order to discover the data consistency it was necessary to obtain multiple stability points on the same flight for each system. As the Cruise Performance Report consists of only one stability point that meets the stability criterion imposed by the aircraft systems, the conditions in which this report is produced were recreated by the algorithm. In order to achieve this, it was used the tolerances required by Criterion 1 and compared the points for this criterion to the points obtained by Criterion 2. For this first analysis it was used a flight of an Airbus A321 from Lisbon to Paris (Orly). In this first approach the first ten stability points that were obtained with both criteria were analyzed by the APM. With the stability points selected by the procedure described above the performance results presented in Table 6 were obtained.

APM DEVIATION DATA

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	0,278	1,531	3,235	3,696	-4,594
2	0,280	1,546	3,227	3,678	-4,600
3	0,286	1,580	3,216	3,668	-4,622
4	0,260	1,431	3,196	3,651	-4,464
5	0,263	1,447	3,184	3,633	-4,468
6	0,234	1,286	3,175	3,622	-4,308
7	0,238	1,311	3,160	3,605	-4,318
8	0,237	1,304	3,148	3,593	-4,300
9	0,236	1,299	3,136	3,576	-4,283
10	0,234	1,285	3,114	3,558	-4,250
MV	0,255	1,402	3,179	3,628	-4,421
SD	0,021	0,119	0,040	0,046	0,146

Table 6 – APM analysis with Criterion 1

Similarly, the same analysis was made for Criterion 2 with data from the same flight. The results of the APM analysis using the stability points obtained by Criterion 2 are present in table 7.

APM DEVIATION DATA

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	0,310	1,786	2,917	2,562	-4,540
2	0,342	1,970	2,913	2,568	-4,708
3	0,372	2,147	2,899	2,568	-4,859
4	0,372	2,150	2,894	2,568	-4,859
5	0,401	2,320	2,894	2,568	-5,016
6	0,424	2,458	2,889	2,567	-5,140
7	0,418	2,419	2,889	2,567	-5,104
8	0,439	2,548	2,894	2,573	-5,227
9	0,412	2,388	2,963	2,565	-5,143
10	0,432	2,505	2,968	2,565	-5,256
MV	0,392	2,269	2,912	2,566	-4,985
SD	0,042	0,249	0,030	0,002	0,236

Table 7 – APM analysis with Criterion 2

The most important parameters needed to check the aircraft performance are the DFFBM and DSR. For these two results the associated standard deviations were observed. The corresponding results are presented in table 8.

	Criterion 1	Criterion 2
DFFBM	0,04	0,03
DSR	0,146	0,236

Table 8 - Standard deviations of the results

Analyzing the standard deviations of each one of these parameters obtained for each one of the performed analysis, it can be seen that the global degradation standard deviation, given by the DSR value, is greater for Criterion 2 (most restrictive) than for Criterion 1 (least demanding). Even though the opposite was expected, this is in fact true given that the calculation of the parameters depends on a variety of flight characteristics, not only regarding the engines, but also regarding the aerodynamics, the gross weight (or fuel quantity), the wind speed and direction, when these factors are considered. Opposing these facts, the standard deviation associated with DFFBM is inferior when analyzing the points from Criterion 2 comparing with the standard deviation with the points from Criterion 1. The DFFBM is a parameter associated with engine degradation and is supposed to maintain a minimal fluctuation during the whole flight and consequently it should have low variations from one stability point to another. For this parameter, the standard deviation associated with it is inferior using the stability points obtained by the Criterion 2. This might be a testimony that there is a greater

consistency in the data obtained by Criterion 2, because the standard deviation for DFFBM is inferior to the one obtained with Criterion 1.
In order to understand the influence of this algorithm in the calculation of aircraft degradation three flights of the same A321 were analyzed with the studied algorithm and using the tolerances given in Criterion 2. To fortify the study of the algorithm, these flights were also tested without the data filtering application, and three stability points were obtained in the given condition. For better perception of the performed study, the following chart is presented (table 9).

Flight name	From	To	Departure time	Arraival time	Stability point time
Flight 1	Lisboa	Dakar	21h32m	01h10m	22h46mm
Flight 2	Dakar	Lisboa	02h41m	06h12m	05h01mm
Flight 3	Paris (Orly)	Lisboa	10h46m	13h01m	11h36mm

Table 9 – Studied flight information

For each flight presented in table 9, more than one stability point were obtained given that the stability point with the better quality (lower quality number) occurred in the instant shown in the last row of the right side of this table. For each analyzed flight two output files were obtained by the algorithm, one with unfiltered data stability points and the other containing stability points obtained applying the data filter. Also, the influence of gravitational correction being present or absent was also taken in consideration because it would imply the introduction of other parameters in the APM input data. The additional data for gravitational correction are the true heading, latitude, wind speed and wind direction. The data is presented without gravitational correction but in the end it is performed a result comparison.
In the following charts, the blue line corresponds to the stability point with the best quality number. For each one of the three flights three stability points were chosen, so they could be analyzed in the same APM analysis.
The results for the stability points from Flight 1 are presented in table 10:

Filtered dara

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	0,175	0,748	3,220	2,405	-3,839
2	-0,125	-0,535	3,336	2,528	-2,708
3	-0,037	-0,159	3,142	2,598	-2,893
MV	0,005	0,018	3,233	2,510	-3,146
SD	0,154	0,659	0,097	0,098	0,607

Non filtered data

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	-1,047	-4,499	8,088	2,380	-3,124
2	-0,208	-0,888	3,366	2,511	-2,390
3	0,077	0,334	3,253	2,633	-3,473
MV	-0,392	-1,684	4,902	2,508	-2,996
SD	0,584	2,513	2,759	0,127	0,553

Table 10 – APM results for Flight 1

The data retrieved from Flight 2 is shown in table 11.

Filtered data

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	-0,107	-0,568	2,769	2,567	-2,139
2	-0,154	-0,822	3,267	2,666	-2,361
3	0,589	3,306	3,303	2,943	-6,296
MV	0,109	0,639	3,113	2,725	-3,598
SD	0,416	2,314	0,299	0,194	2,339

Non filtered data

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	-0,093	-0,489	2,911	2,530	-2,351
2	-0,093	-0,492	2,568	2,542	-2,117
3	0,467	2,597	3,255	2,968	-5,603
MV	0,094	0,538	2,945	2,680	-3,357
SD	0,323	1,783	0,295	0,250	1,949

Table 11 – APM results for Flight 2

Finally, for Flight 3, the APM analysis results are presented in table 12.

Filtered data

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	-0,114	-0,505	3,146	2,838	-2,558
2	-0,329	-1,441	3,217	2,757	-1,700
3	-0,954	-4,082	3,130	2,983	1,092
MV	-0,466	-2,009	3,164	2,859	-1,055
SD	0,437	1,855	0,046	0,115	1,908

Non filtered data

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	-0,104	-0,462	3,099	2,841	-2,556
2	-0,199	-0,877	3,192	2,757	-2,236
3	-0,883	-3,783	3,095	2,972	0,811
MV	-0,395	-1,707	3,129	2,857	-1,327
SD	0,425	1,810	0,055	0,108	1,859

Table 12 – APM results for Flight 3

Presented in table 13 are the APM analysis results with gravitational correction.

	Flight 1		*Flight 2*		*Flight 3*	
	Filtered	Non filtered	Filtered	Non filtered	Filtered	Non filtered
	DSR %	DSR %	DSR %	DSR %	DSR %	DSR %
1	-4,122	-4,101	-2,694	-2,909	-2,728	-2,727
2	-2,996	-2,677	-2,902	-2,572	-1,875	-2,236
3	-3,182	-3,760	-6,776	-6,087	0,919	0,811
MV	-3,433	-3,513	-4,124	-3,889	-1,228	-1,384
SD	0,603	0,743	2,299	1,907	1,907	1,917

Table 13 – APM results with gravitational correction

By the results given above (table 13) it is verified that the standard deviations of the relevant parameters – DFFBM and DSR – do not have significant differences when moving from a filtered data analysis to an unfiltered one. It is though perceptible that the absence of filter causes a slight result change. Many of the parameters that are recorded in-flight are undergoing external disturbances and this can cause some sudden discrepancies in the recordings which are difficult to reduce even with the filter application.
As far as the gravitational correction is concerned, it does not make such a difference that would justify its use. Nevertheless, the obtained values for DSR are not equal in both situations which leads to the conclusion that the gravitational correction affects the result of the aircraft performance degradation, but not at a significant level. These different DSR values obtained with and without correction are shown in table 14.

	Flight 1		Flight 2		Flight 3	
	Filtered	Non filtered	Filtered	Non filtered	Filtered	Non Filtered
MV	-0,287	-0,517	-0,526	-0,532	-0,173	-0,057
SD	-0,004	0,190	-0,040	-0,042	-0,001	0,066

Table 14 – Gravitational correction influence

Besides the three studied flights, there were 7 more flights that were subject to analysis (which raises the total analyzed flights to 10) which were all performed between May and July 2009. It was verified that there is not a considerable discrepancy in the instant of the stability point in which the Cruise Performance Report is generated and the stability instant detected by the studied algorithm. The aircraft used to make this study already has a system that pre-selects the stability point by the best quality number.
To show this tendency the points generated by this aircraft system in the three flights were checked. In table 15 it is shown the results obtained by these stability points.

	DN1M %	DFFAM %	DFFBM %	DFFBM by algorithm %	DEGTM %	DSR %	DSR by algor %
Flight 1	-0,075	-0,325	3,462	3,142	2,700	-3,031	-2,893
Flight 2	-0,181	-0,960	3,262	3,267	2,730	-2,220	-2,361
Flight 3	-0,335	-1,469	3,548	3,146	2,974	-1,986	-2,556

Table 15 – Results comparison

In table 15, the rows assigned as "DSR by algorithm" and "DFFBM by algorithm" correspond to the rows with values of DSR and DFFBM, respectively, obtained with the stability points with better quality identified by the developed algorithm for each one of the flights. For Flights 2 and 3 the DSR value obtained with the best stability point generated by the algorithm is superior to the one obtained by the stability point generated by the Cruise Performance Report, although in Flight 1 the trend is inverted. What is to be expected from the algorithm is not to conclude that the degradation level of the aircraft is inferior or superior than the one reached by the method that is used now by analyzing the Cruise Performance Report, but to conclude that the degradation level is as realistic as possible. In order to achieve that it is necessary to have a significant sample of stability points sufficiently consistent.
Then it was performed an analysis using a different approach. It is known that these flights were all performed in the same month so taking this in consideration they were performed in a short time span. Having this into account the aircraft degradation should not vary that much because all flights belong to the same airplane. If this does not happen it is due to an incorrect weight evaluation.
Analyzing the rows related to the degradation level, there is a greater fluctuation in the DSR and DFFBM obtained by the Cruise Performance Report than in the DSR and DFFBM obtained by the algorithm. It is also observed that if there is a slight difference in the instant of the stability point, it causes differences in these two parameters. This tendency makes believe that the stability points obtained by the studied algorithm are made with more consistent data (just as it has been analyzed before) and beyond that, analyzing table 15 again, it is possible that they better indicate the real condition of the aircraft than the points from the Cruise Performance Report. Figure 6 shows the whole cruise phase for Flight 3 which occurred between 11:15 and 12:30.

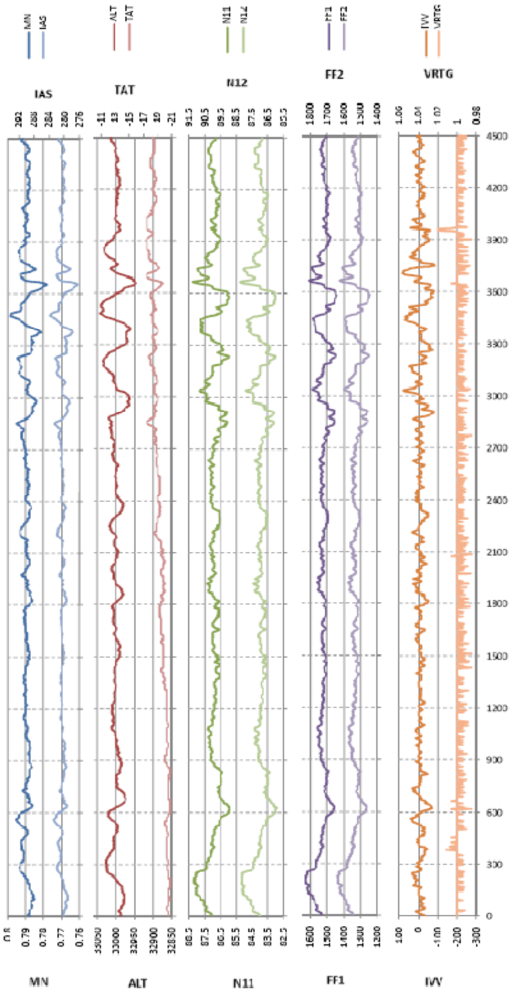

Figure 6 – Cruise phase for Flight 3

Analyzing the figure above it is possible to identify a period with such characteristics that allows it to be identified as a stability period located in the time span between seconds 900 and 1800. In the graph, the second 900 relates to 11:30 and the second 1800 to 11:45.
The aircraft system generated a Cruise Performance Report at 11:35 while the algorithm identified the best stability period at 11:36 with a lower (best) quality number than the one associated with the period generated by the Cruise Performance Report showing better quality in the data given by the algorithm. This point given by the algorithm is shown in tables 12 and 13 as being point 1 of Flight 3 (also highlighted in blue). Table 16 shows the quality numbers.

Quality number at 11h35m	Quality number at 11h36m
0,541078	0,369561

Table 16 – Quality numbers

The stability point indicated above generated by the algorithm was obtained with the most restrictive criterion, Criterion 2.
From the studied aircraft, the Airbus A321, 17 flights were analyzed which had Cruise

Performance Report available. The APM results for the stability points generated by Cruise Performance Report are shown in table 17.

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	-0,234	-1,084	3,956	3,315	-2,751
2	-0,335	-1,469	3,548	2,974	-1,986
3	-0,128	-0,536	3,525	2,693	-2,884
4	0,102	0,428	3,537	2,903	-3,828
5	-0,288	-1,503	2,722	2,295	-1,165
6	-0,220	-0,954	3,235	2,325	-2,201
7	-0,075	-0,325	3,462	2,700	-3,031
8	-0,181	-0,960	3,262	2,730	-2,220
9	-0,128	-0,536	3,525	2,693	-2,884
10	0,102	0,428	3,537	2,903	-3,828
11	-0,288	-1,503	2,722	2,295	-1,165
12	-0,087	-0,382	3,027	2,581	-2,566
13	-0,090	-0,391	3,225	2,255	-2,744
14	0,345	1,549	3,158	2,113	-4,540
15	-0,282	-1,303	3,288	2,427	-1,906
16	0,209	1,185	2,939	2,450	-3,993
17	0,134	0,625	2,768	2,652	-3,297
MV	-0,085	-0,396	3,261	2,606	-2,764
SD	0,198	0,944	0,344	0,311	0,949

Table 17 – APM results with 17 Cruise Performance Reports

The same analysis method used for Cruise Performance Report will be used for the greater quality stability points generated by the algorithm with filtered data.

First of all it is verified that 7 of the 17 flights do not satisfy the stability criterion leaving only 10 that generate stable cruise points. Table 18 shows the results for an APM analysis having as input the stability points with the best quality number obtained for the 10 flights mentioned above.

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	0,135	0,568	3,463	3,363	-3,893
2	-0,060	-0,265	3,076	2,834	-2,727
3	0,151	0,656	3,231	2,626	-3,761
4	0,019	0,102	2,641	2,534	-2,672
5	0,117	0,625	2,341	2,208	-2,894
6	0,163	0,720	2,903	2,864	-3,515
7	-0,068	-0,385	3,029	2,723	-2,565
8	0,332	1,501	2,751	2,435	-4,117
9	0,357	1,919	2,048	2,546	-3,852
10	0,250	1,370	2,697	2,883	-3,942
MV	0,140	0,681	2,818	2,702	-3,394
SD	0,147	0,750	0,418	0,314	0,609

Table 18 – APM results with 10 stability points generated by algorithm

Although these samples have a different dimension, it is verified that the standard deviations have close values even though there are 70% more flights in the first than in the second. For a better comparison the analysis will be performed specifically in the 10 flights that are common to these two samples. It should be noted that this comparison has its issues, since it is done a flight selection using the algorithm criterion that could never be actually verified. Table 19 presents the results obtained having points given by the Cruise performance Report of these 10 flights as input data for APM.

	DN1M %	DFFAM %	DFFBM %	DEGTM %	DSR %
1	-0,087	-0,382	3,027	2,581	-2,566
2	0,037	0,210	3,133	2,593	-3,241
3	0,101	0,452	2,898	2,408	-3,253
4	0,134	0,625	2,768	2,652	-3,297
5	-0,288	-1,503	2,722	2,295	-1,165
6	-0,075	-0,325	3,462	2,700	-3,031
7	-0,181	-0,960	3,262	2,730	-2,220
8	-0,234	-1,084	3,956	3,315	-2,751
9	-0,335	-1,469	3,548	2,974	-1,986
10	0,347	1,920	3,053	3,049	-4,791
MV	-0,058	-0,252	3,183	2,73	-2,830
SD	0,214	1,078	0,384	0,306	0,965

Table 19 - APM results for 10 Cruise Performance Report

Comparing the above tables it can be seen that the standard deviation associated with the DSR value is lower for the set of stability points obtained by the algorithm (0.609 <0.965) which does not necessarily mean a better quality of input data for APM. To assess whether there is a greater consistency of data we need to look at the values associated with DFFBM. The standard deviation of this parameter is higher with the data obtained by the algorithm than with the data points generated by the Cruise Performance Report. This situation was not expected since the points obtained by the algorithm presented always better quality number than those obtained by the Cruise Performance Report. One explanation for this is that the selection of flights to be eliminated has been done carefully. By increasing the number of samples of an APM analysis, the value of standard deviation decreases and making a random decrease in the sample the values of those deviations increase. At first sight 17 flights of the same aircraft were observed and this sample was reduced to 10 flights only. These two tests were performed with the Cruise Performance Report. As stated above, a random reduction in stability points should lead to a significant increase in standard deviations of DFFBM and DSR. For these two tests the standard deviations obtained are listed in Table 20.

	DFFBM	DSR
17 flights	0,344	0,949
10 flights	0,384	0,965

Table 20 – Standard deviations for DFFBM and DSR

As shown by the values of table 20 with analysis for 10 flights it is obtained a standard deviation only slightly better than that for 17 flights. This small difference is justified by the fact that the reduction of the sample was made based on the results obtained by the algorithm in a study that includes a stability criterion more restrictive and therefore identified stability points only in 10 of 17 flights. That is to say that the reduction of the sample was not made in a random way but was based directly in a stability criterion more stringent. If this choice had not been carefully done the values of standard deviations in the 10 flights analysis would exceed the values of standard deviations obtained with the 10 stability points obtained with the algorithm now developed.

For this it can also help the fact that the data processed by the algorithm is different from that used to generate the Cruise Performance Report. One example is the fact that there are two readings of some parameters, and what will be considered will be the average of these two readings for the

APM calculation. In the case of the data file read by the program it states only one reading of these parameters which probably comes from a different source, since differences were identified between the data file and the values of the Cruise Performance Report, as shown below. Inspecting some data files, differences were observed in some parameters, such as the vertical velocity (IVV), flight path acceleration (FPAC) - value in disagreement with the one presented by the Cruise Performance Report as shown in Table 21 - and vertical acceleration (VRTG) , this last one for the Airbus A320 studied earlier, yielded values always below unity suggesting a curvilinear cruise phase. The Mach number (MN) was also a parameter that has drawn attention because for the same flight was reported a Cruise Performance Report with a Mach number higher than all readings that have been done during the same period of time and recorded in the corresponding data file, suggesting an error of parameter extraction. Despite the less accurate VRTG reading having been detected only for some Airbus A320, together with other parameters, it is possible to conclude that there is a need to detect the sources of errors and eliminate them so that it can be processed data as reliable as possible. This is further work to be done as soon as possible to make this tool even more useful. It is expected that after these measures implemented the data obtained by the algorithm now developed will be even more consistent and have even of a better quality than those obtained by the Cruise Performance Report.

	Cruise Performance Report	**Stability point by algorithm**
Hora	20h41m	20h41m
ALT	35996	35996
MN	0,7805	0,7810
TAT	-27,25	-26,8
GW	60125	60121
CG	32,6	32,7
FPAC	0,0055	-0,0003
IVV	3,0	0,3
N11	83,4	83,5
N12	83,4	83,49
FF1	1177,0	1179,4
FF2	1203,0	1205,2
EGT1	601,1	601,6
EGT2	593,1	593,2
Pack Flow 1	0,42	0,422
Pack Flow 2	0,39	0,391

Table 21 – Differences between values from Cruise Performance Report and stability point obtained by AGS

7. Conclusions

To help increase the operational efficiency of airlines, this paper seeks the development of a tool that is based on flight data from the reading station be able to identify stability points which are essential for determining the aircraft performance degradation. This tool is presented as an alternative to the current process that uses the Cruise Performance Report which has the known limitations. This algorithm identifies periods of time where parameters variations are within the tolerances allowed by the stability criterion considered and allows the selection of the best stability point (lower quality number) from among all stability points achieved.

This algorithm was developed in C programming language and contains a set of optimal tolerances for the purpose of identifying periods with a fluctuation as low as possible. To evaluate the consistency of data several analysis were performed using the APM which were useful to conclude that the more tight tolerances are the more consistent are the parameters' values from the corresponding stability points obtained.

The results of the performance factor achieved despite the low standard deviations are higher than the degradation level currently under consideration and obtained from the Cruise Performance Report. These different values can be justified by the difference found in the parameters used to calculate the DSR, as the case of IVV, FPAC and the parameters related to the engines, including FF, EGT and N1. These distinct values are due to a number of factors that affect the preceding process of the use of the algorithm developed in this work and should be investigated in detail in a near future. Among these factors is the likely additional validation and filtering performed at the aircraft system which currently is unmatched in the suggested system, errors that can be consequence of a potential difference in accuracy of data as well as differences in the data recording method.

8. References

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