Calculation and replication of several In Flight Performance scenarios from the Quick Reference Handbook

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January 2021

Abstract

In recent times, information technology has assumed a key role in the transformation of airlines' operations. Constant technological advances and the consequent increase of the devices' computing power allow for the digital transformation of paper-based processes and publications. Pilots have at their disposal a computer tool called Electronic Flight Bag (EFB). This device allows them to perform complex performance calculations in real-time and consult various aircraft operations-related publications. The introduction of EFBs into the cockpits has increased the operational safety and efficiency of airlines. This work's foundation is the Quick Reference Handbook (QRH), a printed manual that contains aircraft performance data regarding various flight scenarios. This project was motivated by Airbus' planned removal of some of these scenarios from the printed version of the QRH. The objective of this work is the replication of said scenarios in digital format, for TAP's current fleet. This thesis covers the entire replication process for a specific type of aircraft, the Airbus A320neo. Special focus is placed on the data retrieval methods for the various scenarios to be replicated, and their subsequent inclusion into a database structure. The obtained results are then applied to two specific cases and compared with the corresponding values in the QRH. Eventual discrepancies between the two data sets are then discussed. Finally, the prospective developments for the presented solution are evaluated, namely its inclusion into TAP's EFB.

Keywords: Aircraft Performance, Quick Reference Handbook, Electronic Flight Bag, Airbus Performance Engineer's Programs

1. Introduction

The present work aims to replicate several flight scenarios from the High Speed Performance (HSP) section of the Quick Reference Handbook (QRH), that is published in paper format by Airbus.

To achieve that, the present project focuses on developing a computational solution to calculate the performance data that is presented in said scenarios of the QRH. To do so, the project resorts to Performance Engineer's Programs (PEP), a calculation software developed by Airbus.

Following Airbus' announcement regarding the removal of several flight scenarios from the paper-based QRH, TAP has decided to develop its own, alternative tool. Said tool is intended to cover the functionalities that were previously contained in the paper version of the QRH.

When completed, TAP plans to integrate the aforementioned tool into its in-house developed EFB solution. This project aims to be a relevant contribution to achieve TAP's goal.

2. Electronic Flight Bag

The European Union Aviation Safety Agency (EASA) defines the EFB as "An information system for flight deck crew members which allows storing, updating, delivering, displaying, and/or computing digital data to support flight operations or duties" [1]. This device is gradually replacing the traditional flight bag, which contains several aircraft manuals and navigation charts in paper format.

Over time, an ever-increasing number of tools have been incorporated into the EFB. The first EFBs comprised built-in Global Positioning System (GPS) units and Very High Frequency (VHF) radio transmitter/receivers. Nowadays, EFBs include powerful aircraft performance calculation modules and relevant flight manuals and documents, that were previously made available in paper format.

EFB solutions introduce a series of advantages to airline's operations. The transition into a paperless format translates into an increased level of safety and efficiency for the flight crew's duties. The update process of these devices is also simplified, which provides additional mechanisms to mitigate human error and improves efficiency from an environmental point of view.

Notwithstanding, these solutions involve a significant initial investment. As with every digital infrastructure, EFBs also raise concerns about security breaches.

In the end, the transition into an EFB-based infrastructure is a bet that pays off in the long run. An airline with the required financial capability to support the initial investment can then benefit from the improved operational safety, efficiency and flexibility provided by these solutions.

3. Relevant operating speeds

3.1. Green Dot speed

Green Dot (GD) is a flight speed estimation that maximizes the lift-to-drag ratio for a given aircraft's altitude and weight. In One Engine Inoperative (OEI) scenarios, it provides the maximum climb gradient that the aircraft can achieve [2]. Likewise, during descent in OEI conditions, the GD speed grants the minimum descent gradient.

3.2. Long Range Cruise speed

Before introducing the Long Range Cruise (LRC) speed, it is important to clarify the concept of Specific Range (SR). This parameter provides the covered distance per unit of fuel [nm/kg of fuel].

The LRC speed is the speed at which, for a given aircraft's weight and flight altitude, the SR corresponds to 99% of the maximum SR [2].

4. QRH's flight scenarios

The present work aims to replicate the following flight scenarios from the QRH:

- OEI:
  - Ceilings;
  - Gross Flight Path Descent at GD Speed;
  - Cruise at LRC Speed;
  - In Cruise Quick Check Long Range;
- Flight Without Cabin Pressurization:
  - In Cruise Quick Check Flight Level (FL) 100 Long Range;
- Climb Gradient:
  - Maximum Climb Gradient:
    - Maximum Climb Gradient - ISA[1]+10 & below;
    - Maximum Climb Gradient - ISA+20;
  - Approach Climb Gradient:
    - Approach Climb Gradient - ISA+10 & below;
    - Approach Climb Gradient - ISA+20;

The most complex scenarios are going to be described hereafter.

4.1. OEI

The scenarios that are included in this category assume a Maximum Continuous Thrust (MCT) setting. This is the maximum thrust that can be used indefinitely during a situation of engine failure without causing damage to the remaining engine(s).

4.1.1 Gross Flight Path Descent at GD Speed

This scenario provides estimates on the time, distance, fuel consumption and level-off altitude during a descent motivated by engine failure.

This procedure is also known as Drift Down descent. After an engine failure, when the aircraft can no longer maintain level flight, the flight crew must select MCT setting on the remaining engine, decelerate to GD speed and descend until reaching the Drift Down ceiling.

Two types of flight paths are associated with this procedure. The gross flight path is the path that is actually flown by the aircraft. On the other hand, the net flight gradient results from imposing a penalty of 1.1% to a twin-engined aircraft's climb performance, which will in turn affect its descent gradient [5]. The aforementioned flight paths regarding the Drift Down procedure are illustrated in Figure 1:

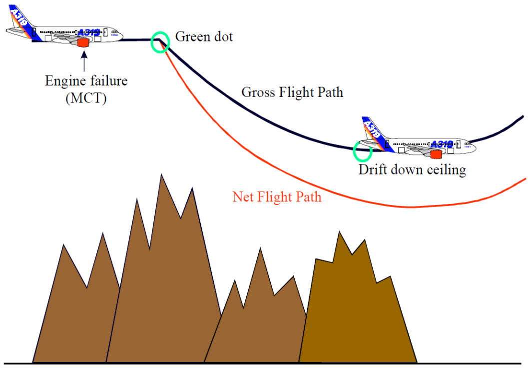

Figure 1: Drift Down descent procedure (adapted from [2]).

4.1.2 In Cruise Quick Check Long Range

The flight scenario covered in this QRH's table comprises two stages: cruise flight at constant altitude and LRC speed, followed by a descent and landing.

The descent stage is executed at a constant IAS/-Mach law of M0.78/300kt/250kt. The descent profile that results from imposing this law is summarized in Figure 2.

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[1] ISA: International Standard Atmosphere

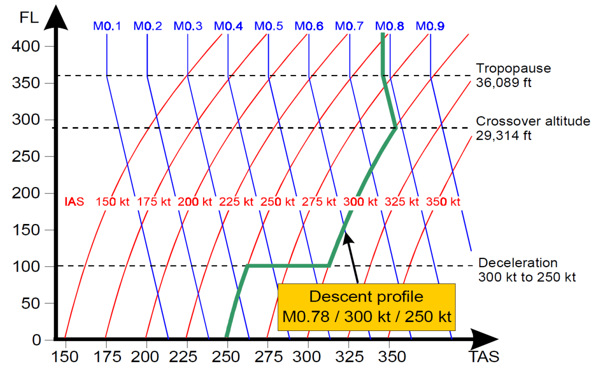

Figure 2: Descent procedure at constant IAS/Mach law: M0.78/300kt/250kt [2].

4.2. Climb Gradient

All the scenarios that are covered in this QRH's section make reference to the aircraft's climb gradient. This is defined as the ratio between the increase of altitude and the covered, horizontal air distance [2].

The climb gradient is related to the climb angle, γ, which is the angle between the aircraft's aerodynamic axis and the horizon. This relationship can be extracted from a balance of the forces acting on the aircraft during climb, as is illustrated in Figure 3:

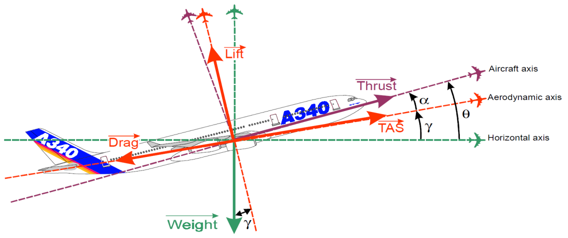

Figure 3: Balance of forces during climb (adapted from [2]).

The balances of forces along the aerodynamic and the vertical axes are given by:

$$\text{Thrust} \times \cos\alpha = \text{Drag} + \text{Weight} \times \sin\gamma \tag{1}$$

$$\text{Lift} = \text{Weight} \times \cos\gamma \tag{2}$$

where α represents the angle of attack.

Let γ and α be small enough so that the following expressions are valid:

$$\begin{gathered} \sin\gamma \approx \tan\gamma \approx \gamma\,[rad] \\ \cos\gamma \approx 1 \approx \cos\alpha \end{gathered} \tag{3}$$

Replacing these approximations in Equations (1) and (2) results in:

$$\begin{gathered} \text{Thrust} = \text{Drag} + \text{Weight} \times \gamma \Rightarrow \\ \Rightarrow \gamma[rad] = \frac{\text{Thrust} - \text{Drag}}{\text{Weight}} \end{gathered} \tag{4}$$

$$\text{Lift} = \text{Weight} \tag{5}$$

Establishing the equality of Eq.(5) into Eq.(4) yields:

$$\gamma[rad] = \frac{\text{Thrust}}{\text{Weight}} - \frac{\text{Drag}}{\text{Lift}} \tag{6}$$

By introducing the Lift-to-Drag ratio (L/D), the expression for the climb angle becomes:

$$\gamma[rad] = \frac{\text{Thrust}}{\text{Weight}} - \frac{1}{L/D} \tag{7}$$

Therefore, and following the approximations defined in Eq.(3), the climb gradient can be defined according to the following expression:

$$\begin{gathered} \text{Climb Gradient}[\%] = 100 \times \tan\gamma \approx \\ \approx 100 \times \left(\frac{\text{Thrust}}{\text{Weight}} - \frac{1}{L/D} \right) \end{gathered} \tag{8}$$

5. Computational methodology

As previously mentioned, the performance data to feed the proposed solution is calculated using Airbus' PEP software. In particular, two PEP's modules are used: In Flight Performance (IFP) and Flight Manual (FM).

Each PEP session requires two input files. The first is a .PEP file that defines the session, and is common to both modules. The second file details the assumed flight conditions for the session, and its type varies with the program's module that is being used: .DAT file for the IFP module, and .ACG for the FM.

This project made use of the .CSV[2] file outputs that are generated by PEP. This file type's specific structure expedited the data manipulation process, as well as its incorporation into an appropriate database (DB) infrastructure. This topic will be covered during the current Section.

5.1. Input file generation

This project involved a significant amount of PEP sessions. To automatize the process of creating the required input files, the author developed a C# routine. The workflow of this routine, as well as the interactions between its several methods, is presented in Fig. 4.

The several colours used in Figure 4 indicate the following types of methods:

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[2] CSV: Comma-Separated Values

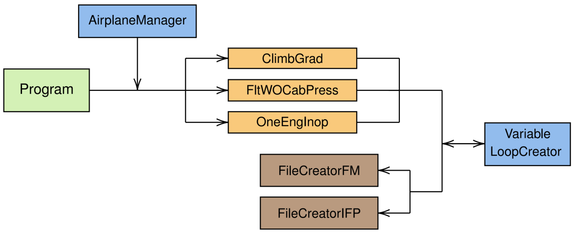


Figure 4: Workflow of the input file generation program.

- **Green:** initialization method;
- **Blue:** auxiliary method;
- **Yellow:** method that defines a set of conditions for each flight scenario;
- **Brown:** file-writing method.

The developed program generates the required PEP sessions to replicate the several QRH's scenarios, based on the aircraft's configurations that are stipulated in these scenarios. Additionally, the program also defines PEP sessions for alternative configurations of Anti Ice (AI) and Air Conditioning (A/C) that are not directly covered in the QRH.

5.2. Database planning and construction

To store the performance data contained in PEP's output files, the author developed a relational DB infrastructure. This type of DB allows the user to identify and access data in relation to another piece of data that is also stored in the DB [4].

The developed DB was named 'EFB-HSP_Data' and comprises four tables:

- **'Dataset':** main table that contains the performance data parameters that are obtained from PEP's CSV output files;
- **'Airplane':** incorporates information regarding the aircraft that are part of TAP's fleet;
- **'PEPdatabase':** indicates the PEP-specific aircraft performance DBs that were used during the calculation of a given data set;
- **'Case':** establishes an unequivocal connection between any piece of data and the specific flight scenario to which it belongs.

Every table contains an 'Author' and 'UpdateDate' fields to ensure the correct tracking and management of the information included in the DB.

5.3. Import of performance data

As was previously mentioned, PEP sessions generated a sizeable amount of output data. The author decided to automatize the import process of such data into the DB structure that was discussed in the previous Subsection.

This stage of the development process relied on 'CsvHelper', an open-source .NET library specifically designed to read and write CSV files [3]. When combined with Entity Framework, this library was used to import PEP's CSV output files into a data set and then use it to populate the aforementioned DB.

The output files' structure, namely the order of the columns and the data parameters that are displayed, varies depending on the type of PEP calculation that generated the file. Therefore, CsvHelper's seed method requires one class mapping per computation case. This procedure consists of matching the properties of each DB's table to its respective column position on the CSV output file.

5.4. Data fetching

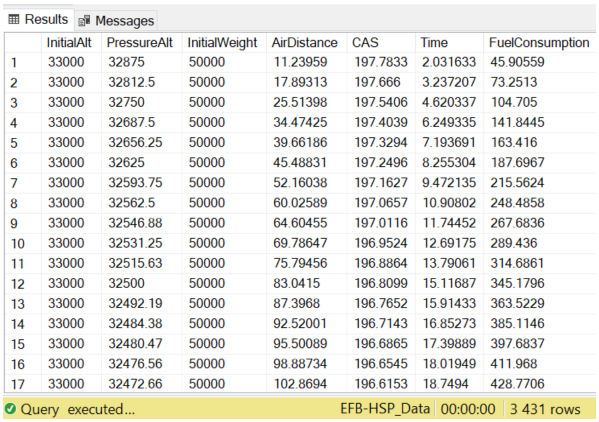
Having populated the DB with PEP's output performance parameters, it is now possible to retrieve information from it. To do so, one should use the appropriate SQL[3] syntax and a compatible software. During this project, the author used Microsoft SQL Server Management Studio.

As an example, the query that retrieves the relevant data parameters for replicating the 'Gross Flight Descent at GD Speed' QRH's scenario is presented in Listing 1:

Listing 1: SQL Query applied to `EFB-HSP_Data` database.

```
SELECT InitialAlt, PressureAlt, InitialWeight,
    AirDistance, CAS, Time, FuelConsumption
FROM [EFB−HSP_Data].[dbo].[Dataset]
WHERE (Airplane_Id = 5 AND Case_Id = 6
    AND SpeedRule = ‘GD’ AND CG = ‘0.33’
    AND ISA = 0 AND AntiIce = ‘0’
    AND AirConditioning =‘C’)
```

Executing this query produces the results that are displayed in Figure 5:



	InitialAlt	PressureAlt	InitialWeight	AirDistance	CAS	Time	FuelConsumption
1	33000	32875	50000	11.23959	197.7833	2.031633	45.90559
2	33000	32812.5	50000	17.89313	197.666	3.237207	73.2513
3	33000	32750	50000	25.51398	197.5406	4.620337	104.705
4	33000	32687.5	50000	34.47425	197.4039	6.249335	141.8445
5	33000	32656.25	50000	39.66186	197.3294	7.193691	163.416
6	33000	32625	50000	45.48831	197.2496	8.255304	187.6967
7	33000	32593.75	50000	52.16038	197.1627	9.472135	215.5624
8	33000	32562.5	50000	60.02589	197.0657	10.90802	248.4858
9	33000	32546.88	50000	64.60455	197.0116	11.74452	267.6836
10	33000	32531.25	50000	69.78647	196.9524	12.69175	289.436
11	33000	32515.63	50000	75.79456	196.8864	13.79061	314.6861
12	33000	32500	50000	83.0415	196.8099	15.11687	345.1796
13	33000	32492.19	50000	87.3968	196.7652	15.91433	363.5229
14	33000	32484.38	50000	92.52001	196.7143	16.85273	385.1146
15	33000	32480.47	50000	95.50089	196.6865	17.39889	397.6837
16	33000	32476.56	50000	98.88734	196.6545	18.01949	411.968
17	33000	32472.66	50000	102.8694	196.6153	18.7494	428.7706

✓ Query executed... EFB-HSP_Data 00:00:00 3 431 rows

Figure 5: Query execution result.

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[3] SQL: Structured Query Language

6. Results

6.1. QRH replication

The computational process that is described in the previous Section generates the required performance data to replicate the QRH's scenarios that are listed in Section 4. Based on the solution's DB, the author is able to reproduce the several QRH's tables and charts in similar formats to the ones that are used in that manual.

The differences between the QRH's parameters and the ones that are retrieved from the solution's DB (P_{QRH} and P_{DB}, respectively) are evaluated based on the following expressions for Absolute and Relative Error (AE and RE, respectively):

$$AE = P_{DB} - P_{QRH} \tag{9}$$

$$RE[\%] = \frac{P_{DB} - P_{QRH}}{P_{QRH}} \times 100 \tag{10}$$

Overall, the discrepancies that are verified between the QRH and the DB's values are mainly motivated by the degree of precision associated with each of these two data sources. While the QRH's values are conservatively rounded off, the values in the DB correspond to the exact values that are generated during PEP sessions, without any rounding or approximation.

As was indicated in Section 4, the QRH contemplates two 'In Cruise Quick Check' scenarios: 'In Cruise Quick Check Long Range' and 'In Cruise Quick Check FL100 Long Range'. These two scenarios involve a significant amount of PEP sessions: 2280 and 8190 sessions, respectively. As was detailed in the aforementioned Section, these cases comprise two flight stages: cruise and descent. For each individual combination of cruise+descent (that corresponds to a square in the QRH's tables), continuity between both these stages must be ensured. As a result, the process of recreating these tables involves a multi-stage iterative process. Given the extensive amount of data pertaining to these scenarios, the author was not able to develop an efficient method to automatically match the corresponding cruise and descent phases. Notwithstanding, the necessary performance data was obtained using PEP and then incorporated into the solution's DB.

Apart from the two aforementioned 'In Cruise Quick Check' scenarios, all of the remaining QRH's flight scenarios were successfully replicated.

During the replication of the 'Maximum Climb Gradient - ISA+20' table, the author detected a considerable average RE of 6.68% associated with the climb gradient parameter. The author concluded that the issue was motivated by the fact that the QRH's values were calculated for a different AI setting (Total AI On) than the one that is indicated in the table's heading (AI Off). TAP's engineers were alerted for this issue and validated the author's theory. When replicating the aforementioned scenario considering a Total AI On setting, the average RE was reduced to 0.04%, which confirms the accuracy of the obtained results.

6.2. Application to simulated flight conditions

The developed solution is now subjected to a test in order to assess its computational capabilities. This test comprises two cases regarding the 'Gross Flight Path Descent at GD Speed' QRH's flight scenario for the Airbus A320-251 aircraft type [6]. Both cases' conditions were arbitrarily defined and are presented below:

- **First case:**
  - ISA[4] deviation: None;
  - Position of CG[5]: 33% of MAC[6];
  - Initial Gross Weight: 56400 kg;
  - Initial Altitude: FL310;
  - A/C setting: High;
  - AI setting: Off;
- **Second case:**
  - ISA deviation: None;
  - Position of CG: 33% of MAC;
  - Initial Gross Weight: 67200 kg;
  - Initial Altitude: FL370;
  - A/C setting: High;
  - AI setting: Total AI On;

For each case, the required performance data is retrieved from the QRH and from the solution's DB. Both data sets are then compared to the exact values that are calculated with PEP. This comparison is based on the notion of Relative Error (RE) that is presented in Eq.(11):

$$RE_{QRH,DB}[\%] = \frac{P_{QRH,DB} - P_{PEP}}{P_{PEP}} \times 100, \tag{11}$$

where $P_{QRH,DB}$ is the value of a given parameter that is either obtained from the QRH or from the solution's DB, respectively, and P_{PEP} is the corresponding parameter's value that is obtained from PEP.

6.2.1 First case

Calculation based on the QRH

As can be observed in Figure 6, this case's target Initial Gross Weight (GW) of 56400kg is not covered by the QRH's table. Instead, this is an intermediate GW located between the 56 and 58 ton rows

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[4] ISA: International Standard Atmosphere

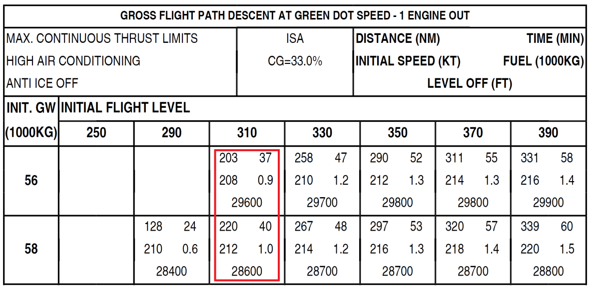
[5] CG: Center of Gravity

[6] MAC: Mean Aerodynamic Chord

of the table. Therefore, the performance values for this case must be retrieved from the QRH through a process of linear interpolation. The method to interpolate a given QRH's performance parameter P, for a specific initial altitude h and gross weight GW_i, is described in Eq.(12):

$$P(h, GW_i) = P(h, GW_1) + \\ +(GW_i - GW_1) \times \frac{P(h, GW_2) - P(h, GW_1)}{GW_2 - GW_1}, \tag{12}$$

where GW_1 and GW_2 are two consecutive values of initialGW that are covered by the table and that verify the following condition: $GW_1 < GW_i < GW_2$.



GROSS FLIGHT PATH DESCENT AT GREEN DOT SPEED - 1 ENGINE OUT							
MAX. CONTINUOUS THRUST LIMITS HIGH AIR CONDITIONING ANTI ICE OFF			ISA CG=33.0%		DISTANCE (NM) TIME (MIN) INITIAL SPEED (KT) FUEL (1000KG) LEVEL OFF (FT)		
INIT. GW (1000KG)	INITIAL FLIGHT LEVEL						
	250	290	310	330	350	370	390
56			203 37 208 0.9 29600	258 47 210 1.2 29700	290 52 212 1.3 29800	311 55 214 1.3 29800	331 58 216 1.4 29900
58		128 24 210 0.6 28400	220 40 212 1.0 28600	267 48 214 1.2 28700	297 53 216 1.3 28700	320 57 218 1.4 28700	339 60 220 1.5 28800

Figure 6: Snapshot of the 'Gross Flight Path Descent at GD Speed' QRH's table for the first case (adapted from [6]).

The QRH's performance values for all the aforementioned initial GWs and the case's initial altitude are presented in Table 1:

Table 1: QRH's performance data for $h = FL310$, including the case's Initial GW = $56400kg$.

Parameter	**Initial GW [ton]**		
	56	**56.4**	**58**
Distance [NM]	203	206.4	220
Initial speed [kt]	208	208.8	212
Time [min]	37	37.6	40
Fuel [kg]	900	920	1000
Level off [ft]	29600	29400	28600

Calculation from the solution's DB

The DB's performance data set has enough resolution to include the case's target initial GW and altitude. Therefore, the required parameters can be retrieved from the DB without any interpolation process. This can be executed through the SQL query that is displayed in Listing 2:

Listing 2: SQL query regarding the first case.

```
SELECT AirDistance, CAS, Time, FuelConsumption,
     PressureAlt
FROM [EFB−HSP_Data].[dbo].[Dataset]
WHERE (Airplane_Id = 5 AND Case_Id = 6
     AND SpeedRule = 'GD' AND CG = '0.33'
     AND ISA = 0 AND InitialWeight = 56400
     AND InitialAlt = 31000 AND AntiIce = '0'
     AND AirConditioning ='C')
```

The results that are returned by this query are displayed in Table 2:

Table 2: DB's performance data for $h = FL310$ and Initial GW = $56400kg$.

Parameter	**DB's value**
Distance [NM]	215.3156
Initial speed [kt]	208.8
Time [min]	39.38129
Fuel [kg]	1000.45
Level off [ft]	29403.75

Calculation from a PEP session

The exact values for this case can be directly obtained through a PEP session, using the IFP module. The corresponding .DAT input file is displayed in Listing 3:

Listing 3: .DAT input file for a PEP session regarding the first case.

```
A320−251                        1     0     1     3
AERO       03/03/16   AE251A02.BDC
ENGINE     12/05/16   ME251A03.BDC
GENERAL    03/03/16   GE251A02.BDC
Gross flight path with engine(s) out
 235  131  000    0  0  1  0C6   KG
00000  DC  PC                       0  0
3         100        .33        0         0
0         0          0          18590     0
   1    1    1    2    1    0
0
56400
0
1         1
31000
0         0          0          1         1
0         0          0          0
END
```

The case's relevant parameters that are obtained from this PEP session are presented in Table 3.

6.2.2 Second case

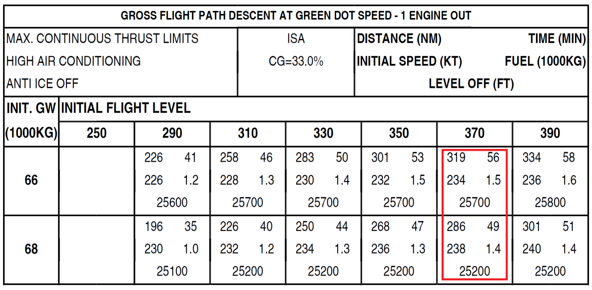
Calculation based on the QRH

Similarly to what was verified in the first case, the QRH's table that is presented in Figure 7 does not contemplate the current case's target initial GW of 67200kg. Therefore, the required performance data is obtained by interpolating the values in the QRH for the case's initial altitude, according to the

Table 3: PEP's performance data for $h = FL310$ and Initial GW = $56400kg$.

Parameter	PEP's value
Distance [NM]	215.3156
Initial speed [kt]	208.8
Time [min]	39.38129
Fuel [kg]	1000.45
Level off [ft]	29403.75

method that was detailed in Eq.(12). Said values, as well as the results from the interpolation, are presented in Table 4.



GROSS FLIGHT PATH DESCENT AT GREEN DOT SPEED - 1 ENGINE OUT

MAX. CONTINUOUS THRUST LIMITS | ISA | DISTANCE (NM) TIME (MIN)
HIGH AIR CONDITIONING | CG=33.0% | INITIAL SPEED (KT) FUEL (1000KG)
ANTI ICE OFF | | LEVEL OFF (FT)

INIT. GW (1000KG)	INITIAL FLIGHT LEVEL 250	290	310	330	350	370	390
66		226 41 226 1.2 25600	258 46 228 1.3 25700	283 50 230 1.4 25700	301 53 232 1.5 25700	319 56 234 1.5 25700	334 58 236 1.6 25800
68		196 35 230 1.0 25100	226 40 232 1.2 25200	250 44 234 1.3 25200	268 47 236 1.3 25200	286 49 238 1.4 25200	301 51 240 1.4 25200

Figure 7: Snapshot of the 'Gross Flight Path Descent at GD Speed' QRH's table for the second case (adapted from [6]).

Table 4: QRH's performance data for $h = FL370$, including the case's Initial GW = $67200kg$.

Parameter	Initial GW [ton]		
	66	67.2	68
Distance [NM]	319	299.2	286
Initial speed [kt]	234	236.4	238
Time [min]	56	51.8	49
Fuel [kg]	1500	1440	1400
Level off [ft]	25700	25400	25200

Nonetheless, one may verify that while the QRH's table provides values for AI Off, the present case assumes a Total AI On setting. Therefore, the obtained values in Table 4 must be converted to the case's conditions by applying the QRH's corrective factors that are listed in Table 5.

The corrected values are now displayed in Table 6.

Calculation from the solution's DB

Since the case's target GW and altitude are covered by the DB, the required data can be retrieved without any interpolation process. To do so, one should run the SQL that is displayed in Listing 4.

Table 5: List of QRH's corrective factors for Total AI On setting [6].

Parameter	Corrective factor
Distance [NM]	+15%
Time [min]	+16%
Fuel [kg]	+18%
Level Off [ft]	-700ft

Table 6: QRH's performance data for $h = FL370$, Initial GW = $67200kg$ and Total AI On.

Parameter	QRH's value
Distance [NM]	344.1
Initial speed [kt]	236.4
Time [min]	60.1
Fuel [kg]	1699
Level off [ft]	24700

Listing 4: SQL query regarding the second case.

```
SELECT AirDistance, CAS, Time, FuelConsumption,
    PressureAlt
FROM [EFB−HSP_Data].[dbo].[Dataset]
WHERE (Airplane_Id = 5 AND Case_Id = 6
    AND SpeedRule = ‘GD’ AND CG = ‘0.33’
    AND ISA = 0 AND InitialWeight = 67200
    AND InitialAlt = 37000 AND AntiIce = ‘0’
    AND AirConditioning =‘C’)
```

The relevant values that are returned by this query are listed in Table 7. One should note that the values that are returned by the query are valid for an AI Off configuration. Therefore, these values must be converted to Total AI On using the QRH's corrective factors that were previously introduced in Table 5. The corrected values for Total AI On are also presented in Table 7:

Table 7: DB's performance data for $h = FL370$ and Initial GW = $67200kg$.

Parameter	DB's value	
	AI Off	Total AI On
Distance [NM]	302.1717	347.4975
Initial speed [kt]	236.4	236.4
Time [min]	52.30453	60.67325
Fuel [kg]	1464.41	1728
Level off [ft]	25408.11	24708.11

As was previously mentioned in Section 5, the proposed solution also includes data for alternative aircraft configurations that are not directly covered by the QRH. Therefore, the required performance data for this case can also be directly retrieved from the DB, without the need for additional corrections.

To do so, one can adapt the SQL query that is presented in Listing 4 by modifying the ‘AntiIce’ parameter from ‘0’ to ‘G’ (i.e., from ‘AI Off’ to ‘Total AI On’). The results that are returned by the modified query are summarized in Table 8:

Table 8: DB’s performance data for $h = FL370$, Initial GW = $67200kg$ and Total AI On.

Parameter	**DB’s value**
Distance [NM]	285.2906
Initial speed [kt]	236.4
Time [min]	49.41196
Fuel [kg]	1411.876
Level off [ft]	25259.44

Calculation from a PEP session

The accurate performance values that are valid for this case can be obtained from a PEP session. Said session is defined by the .DAT input file that is presented below in Listing 5:

Listing 5: .DAT input file for a PEP session regarding the second case.

```
A320−251                  1    0    1    3
AERO       03/03/16  AE251A02.BDC
ENGINE     12/05/16  ME251A03.BDC
GENERAL    03/03/16  GE251A02.BDC
Gross flight path with engine(s) out
 235 131 000    0 0 1 GC6  KG
00000 DC DG                   0 0
3        100     .33      0        0
0        0       0        18590    0
   1   1   1   2   1   0
0
67200
0
1        1
37000
0        0       0        1        1
0        0       0        0
END
```

The parameters of interest for the present case that are provided by the PEP session are listed in Table 9:

Table 9: PEP’s performance data for $h = FL370$, Initial GW = $67200kg$ and Total AI On.

Parameter	**PEP’s value**
Distance [NM]	285.2906
Initial speed [kt]	236.4
Time [min]	49.41196
Fuel [kg]	1411.876
Level off [ft]	25259.44

6.3. Final remarks

The obtained results throughout the present section for the first and second cases are summarized in Tables 10 and 11, respectively:

Table 10: QRH’s, DB’s and PEP’s performance data for the first case.

Parameter	**First case**		
	QRH	DB	PEP
Distance [NM]	206.4	215.3156	215.3156
Initial speed [kt]	208.8	208.8	208.8
Time [min]	37.6	39.38129	39.38129
Fuel [kg]	920	1000.45	1000.45
Level off [ft]	29400	29403.75	29403.75

Table 11: QRH’s, DB’s and PEP’s performance data for the second case.

Parameter	**Second case**			
	QRH	$\mathrm{DB_I}$	$\mathrm{DB_{II}}$	PEP
Distance [NM]	344.1	347.4975	285.2906	285.2906
Initial speed [kt]	236.4	236.4	236.4	236.4
Time [min]	60.1	60.67325	49.41196	49.41196
Fuel [kg]	1699	1728	1411.876	1411.876
Level off [ft]	24700	24708.11	25259.44	25259.44

In Table 11, the ”$\mathrm{DB_I}$” column contains the values that were retrieved from the DB for AI Off setting, and then corrected for Total AI On using the QRH’s factors. On the other hand, the values in ”$\mathrm{DB_{II}}$” were directly retrieved from the DB considering the Total AI On setting.

The values that were calculated based on the QRH and on the solution’s DB can now be compared with the ones that were obtained from PEP sessions. To do so, one can use the expression for the Relative Error (RE) that was introduced in Eq.(11). This is accomplished in Tables 12 and 13 for each of the two cases, respectively:

Table 12: Error analysis regarding the calculated performance parameters for the first case.

Parameter	**First case**	
	RE_{QRH}	RE_{DB}
Distance [NM]	-4.14%	0.00%
Initial speed [kt]	0.00%	0.00%
Time [min]	-4.52%	0.00%
Fuel [kg]	-8.04%	0.00%
Level off [ft]	-0.01%	0.00%

Table 13: Error analysis regarding the calculated performance parameters for the first case.

Parameter	Second case		
	RE_{QRH}	RE_{DB_I}	$RE_{DB_{II}}$
Distance [NM]	20.61%	21.80%	0.00%
Initial speed [kt]	0.00%	0.00%	0.00%
Time [min]	21.63%	22.79%	0.00%
Fuel [kg]	20.34%	22.39%	0.00%
Level off [ft]	-2.21%	-2.18%	0.00%

By analysing the error values expressed in Tables 12 and 13, it can be concluded that, for both cases, the performance values that were retrieved from the solution's DB match exactly with the ones that were obtained from PEP for the same aircraft configuration. This match is not unexpected, since the data sets that were used to populate the DB were also generated by PEP.

Regarding the initial speed parameter for both cases, the difference between the obtained values from both the QRH and the DB, and the actual PEP's values is null. This fact indicates that the precision of this result is not affected by interpolation process that was applied to the QRH's values.

One noticeable aspect in the table is the significant error that is verified for most of the second case's performance parameters: distance, time and fuel. Furthermore, the error associated with the level off altitude has also increased considerably, when compared with the error value for the same parameter in the first case. As was mentioned in topic 6.2.2, the calculation process of these four parameters included a QRH-imposed correction factor to account for the Total AI On setting. The obtained results indicate that the QRH's correction factors can be a potential source of error during the calculations.

Moreover, one can observe that, apart from the level off altitude and initial speed parameters, the RE associated with the first data retrieval method from the DB (i.e., RE_{DB_I}) is marginally higher than what is verified for the QRH-based retrieval method. The reader should be reminded that the former method resorted to the corrective factors that are presented in the QRH to convert the DB's values from AI Off to Total AI On setting. To minimize the differences that were verified at this stage, the author reccomends the calculation of DB-specific corrective factors. Nonetheless, these differences are not verified when using the DB's performance data set that was directly calculated for the Total AI On conditions, as is demonstrated in the $RE_{DB_{II}}$ column of Table 13.

The test that was carried out in this Section highlights the operational benefits of the solution, when compared with the traditional, QRH-based data retrieval process. When using the QRH, the method involved five intermediate interpolations for the first case. For the second case, this process was even more laborious, having required a total of five interpolations and four corrections. By comparison, the necessary data for each of the two cases was fetched from the solution's DB through a single SQL query.

All in all, this test has demonstrated that the proposed solution is a valid alternative to the QRH's tables and charts. For the two cases in analysis, the solution was able to provide more accurate performance parameters in a more direct and expeditious manner, when compared to the QRH.

7. Conclusions

7.1. Remarks

The initial challenge proposed by the e-Operations group of TAP Air Portugal was accepted with great enthusiasm by the author. The opportunity to provide a relevant contribution to the airline industry, and particularly to TAP's flight operations, has been the author's most preeminent motivation throughout the project.

Despite the fact that the thesis' primary objective was the development of a computational tool, a substantial initial effort was made to understand the inner workings of PEP. This stage examined the software's internal methods, capabilities and limitations, particularly those related with the FM and IFP modules. The architecture of PEP's different input and output files was also analysed in detail. This ended up being one of the most time-consuming phases of this project. However, considering that PEP is the primary data source of the proposed solution, this stage has paved the way for the project developments that took place from that point onwards.

It is worth noting that Airbus did not disclose the required PEP's input parameters to generate each of the QRH's flight scenarios that are covered in this thesis, despite TAP's several requests. Therefore, and based on the summarized information that is provided in the QRH, as well as the guidance provided by TAP's engineers, the author had to determine said parameters through a trial-and-error approach. In the end, the project employed the parameters that produced the closest results to the ones that are presented in the QRH.

The development process involved working for the first time with software tools such as Microsoft Visual Studio, Entity Framework and SQL. By using this set of tools, the author was able to create two main programs to automatically generate PEP's input files and to import the corresponding outputs into a custom-made database infrastructure, respectively.

7.2. Achievements

The core goals that the author has set out to achieve with the present work were previously defined in Section 1. At this point, one could now assert that these have been successfully attained. As intended, the computational solution that was developed during this project is capable of presenting the adequate performance parameters to recreate the selected HSP's flight scenarios of the QRH. Additionally, the solution is also capable of performing direct performance calculations, without the need for any intermediate interpolations or corrections.

Initially, one of the project's goals was the development of a software application for TAP's EFB solution. However, this goal was readjusted during the course of this project to prioritize TAP's short-term operational needs. From that point onwards, the project concentrated efforts on replicating the QRH's tables and charts that are discussed in this work.

When put up to test against the QRH, the proposed solution provided more accurate results than the latter with minimal user's involvement. To obtain the required performance parameters for each of the two cases that were considered in this thesis, the QRH-based method involved up to five interpolations and four corrections, to account for alternative aircraft's systems configurations. In contrast, the corresponding data retrieval from the solution's DB was executed through a single SQL query.

7.3. Future Work

TAP's e-Operations team is now empowered with a tool that covers a vast amount of information regarding the QRH's flight scenarios that are approached in this thesis. Moreover, the developed tool is valid for all the aircraft types that are part of TAP's fleet as of November 2020. Given its increased level of detail over the QRH's tables and charts, this information could be used in future operational planning activities. Using these resources, the team can now perform more comprehensive analyses of different flight scenarios, such as flight descent profiles and climb and cruise performance.

Since the initial development stages, this solution was designed to support future developments that the e-Operations team might conduct. Therefore, the solution is prepared to include additional aircraft types and flight scenarios, that can belong either to the QRH or to other performance manuals. This feature is intended to future-proof the solution and to increase its operational flexibility.

Ultimately, the proposed solution could be used as a solid computational basis, upon which the e-Operations group could build an application for the company's EFB. Combining the accurate performance calculation capabilities of the solution with an optimized GUI would ultimately translate into significant gains in operational efficiency and safety.

Acknowledgements

The author would like to express his appreciation and gratitude to Prof. António Aguiar and to Eng. Carlos Figueiredo for granting him the opportunity to be involved with such a relevant and interesting project. Moreover, their guidance throughout the several stages of the project played a decisive role in achieving success.

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