# Calculation of in-flight cruise performance for integration in an EFB System

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**Abstract**

Information technology is slowly but surely revolutionizing commercial aviation operations, in and out of the cockpit. Manual processes and paper documentation are gradually being replaced by computerized systems, thanks to the increasing computational power and portability of electronic devices. Flight Crew members use portable electronic devices, known as Electronic Flight Bags (EFB), which unlock a higher operational safety and efficiency. The use of EFB systems by airline companies has been growing significantly in recent years. It unleashes the potential of aircraft performance tools and critical documentation by making it portable and accessible to flight crew members, without the need to carry large or heavy bags. The present work focuses on the development of a computational tool that allows flight crew members to compute emergency descent profiles in real time, taking the most recent meteorological information into consideration. Atmospheric information released before a flight is prone to change. This implies that safer emergency routes are likely to arise as atmospheric data gets updated. This work helps the airline take advantage of those atmospheric updates, and make flight operations safer. The application allows the user to compute emergency descent profiles for depressurization and engine failure scenarios. By comparing the computed profile against minimum flyable altitudes, the application can rapidly verify if the calculated flight path satisfies regulatory requirements for the targeted emergency procedure. Integrated in TAP's EFB solution, this tool could prove to be a game changer in how escape routes are managed.
**Keywords:** Electronic Flight Bag, Emergency Descent, Aircraft Performance, Engine Failure, Depressurization

## 1. Introduction

There's a need for a more dynamic processing of atmospheric data. As weather updates get released during the course of the flight, it would be beneficial to verify if the initially planned escape routes remain the best option. Flight crew would greatly benefit from a tool with which they can automatically scan the remaining route for the best emergency descent procedures. The development of such a tool and the computational methodology that supports it is the main motivation for this work.

### 1.1. Electronic Flight Bag

According to European Aviation Safety Agency's (EASA) AMC 20-25, EFB is defined 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]. It seeks to replace the original flight bag, a heavy device that carries printed documentation that pilots need while they operate an aircraft. Flight bags at TAP used to weigh around 20kg before being gradually replaced by its digital counterpart.

The first significant advantage of the EFB is the significant reduction of paper-based documentation, allowing it to be accessed digitally instead. The second one is the potential for increased operational efficiency and safety, through the deployment of custom computational applications.

EFBs have evolved from installed Global Positioning System (GPS) aircraft devices with additional features built into them, to powerful and allround portable devices like tablets, available today. The current versatility and potential of EFB systems is very significant, and translates into a positive impact on the airline's balance sheets at the end of the year, as on its environmental footprint and operational safety [2].

## 2. Emergency Descent Operations

Two types of cruise failure scenarios will be considered in the present work. The first is the failure of aircraft pressurization systems, also called depressurization. The second is engine failure, leading to a drift down procedure.

2.1. Leveled Flight Mechanics
The lift and drag equations for level flight are as follows [3]:

$$L = W = m \cdot g = \frac{1}{2}\rho\,(TAS)^2 S\,C_L \tag{1}$$

$$D = T = \frac{1}{2}\rho\,(TAS)^2 S\,C_D \tag{2}$$

Where $L$ is the lift force, $W$ is the weight, $m$ is the mass, $g$ is the gravitational constant, $\rho$ is the air density, $TAS$ is the True Air Speed, $S$ is the area of the lifting surface, $C_L$ is the lift coefficient, $D$ is the drag force, $T$ is the engine thrust, and $C_D$ is the drag coefficient.

2.2. Descent and Drift Down Performance
When an aircraft is cruising and at least one of its engines becomes inoperative (OEI), it must descend to a new altitude. This is called a drift down maneuver. A drift down is an un-accelerated descent which occurs while an airplane descends from its all-engines operational altitude to a lower altitude where the available thrust from its remaining engine(s) is enough for level-flight [3]. Figure 1 shows the acting forces in a drift down flight condition.

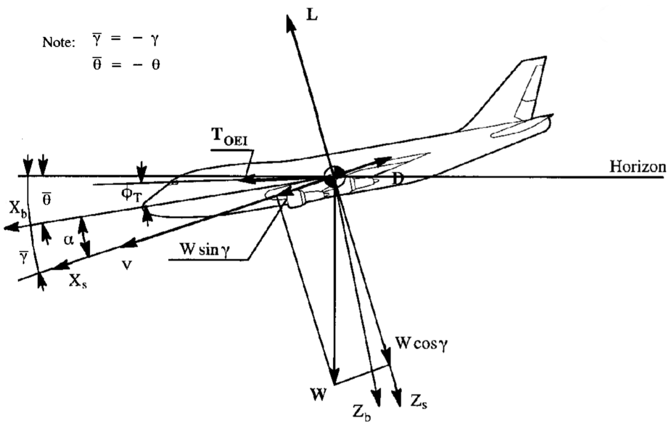


Figure 1: Forces and angles - Drift Down Descent [3]

Where $X_s$ is the stability X-axis which points through the center of gravity (CG) and along a steady-state velocity vector; $X_b$ is the body fixed X-axis which points through the CG and along an arbitrary line; $\alpha$ is the angle of attack defined as the angle between $X_b$ and $X_s$; $\theta$ is the airplane pitch attitude angle, defined as the angle between $X_b$ and the horizon; $\gamma$ is the airplane flight path angle, also called climb angle, defined as the angle between $X_s$ and the horizon; $\phi_T$ is the thrust inclination angle, defined as the angle between the resulting thrust direction and $X_b$.

The equations of motion along the flight path and perpendicular to the flight path can be taken from Figure 1 and are as follows [3]:

$$T\cos(\alpha + \phi_T) - D + W\sin(\bar{\gamma}) = 0 \tag{3}$$

$$T\sin(\alpha + \phi_T) + L + W\cos(\bar{\gamma}) = 0 \tag{4}$$

Most descents are performed with small descent gradients. Let the thrust inclination, $\phi_T$, the angle of attack, $\alpha$, and the flight path angle, $\gamma$, be sufficiently small so that following simplifications are possible [3]:

$$\begin{aligned} \sin(\alpha + \phi_T) \approx 0 \qquad \cos(\alpha + \phi_T) \approx 1 \\ \sin(\gamma) \approx \gamma \qquad\qquad \cos(\gamma) \approx 1 \end{aligned} \tag{5}$$

With these assumptions, Eqs. (3) and (4) become:

$$T - D + W \cdot \bar{\gamma} = 0 \tag{6}$$

$$L = W \tag{7}$$

The expression for the descent angle is, from Eq. (6):

$$\bar{\gamma} = \frac{D - T}{W} \tag{8}$$

In a drift down maneuver, the remaining engine(s) are kept at Maximum Continuous Thrust (MCT). This is the maximum thrust that can be used unlimitedly in flight. For this case, Eq. (8) becomes:

$$\bar{\gamma} = \frac{D_{OEI} - T_{OEI}}{W} = \frac{T_{req_{OEI}} - T_{av_{OEI}}}{W} \tag{9}$$

Where $T_{req_{OEI}}$ corresponds to the thrust required to overcome the Drag force acting on the aircraft, and $T_{av_{OEI}}$ is the available thrust of the remaining engine(s) at MCT setting.

The rate of descent, RD, is defined as:

$$RD = -\frac{dh}{dt} = V \cdot \sin\bar{\gamma} \approx V \cdot \bar{\gamma} \tag{10}$$

Inserting this relation in Eq. (8) yields:

$$RD = \frac{(D - T) \cdot V}{W} \tag{11}$$

For drift down condition, Eq. (11) becomes:

$$RD = \frac{(T_{req_{OEI}} - T_{av_{OEI}}) \cdot V}{W} \tag{12}$$

A drift down descent is carried on until the aircraft has reached the so called drift down ceiling. Initially, when the drift down begins, the available thrust is not enough to balance the Drag force of the aircraft ($T_{req_{OEI}} > T_{av_{OEI}}$). Inserting this result in Eqs. (9) and (12), one can see that the aircraft starts descending:

$$\bar{\gamma} > 0 \quad \text{and} \quad RD > 0$$

Recalling Eqs. (2) and (9) one can write:

$$T_{req_{OEI}} = \frac{1}{2}\rho\,(TAS)^2 S\,C_D \tag{13}$$

Due to the lack of thrust, the Drag force causes the aircraft decelerate, and to reduce its TAS. From Eq. (13), $T_{req_{OEI}}$ also diminishes. Eventually the required thrust balances the available thrust ($T_{req_{OEI}} = T_{av_{OEI}}$). From Eqs. (9) and (12):

$$\bar{\gamma} = 0 \quad \text{and} \quad RD = 0$$

When this happens, the aircraft has reached the drift down ceiling, and stops descending further. The drift down ceiling is the maximum altitude that can be flown in level flight, at green dot speed . The Green Dot Speed is the speed for which the lift-to-drag ratio (L/D) is maximum, and corresponds to the minimum descent angle [4].

## 2.3. Depressurization Procedure

Pressurization systems ensure that the pressure inside the cabin is high enough for the air to be breathable. When a depressurization occurs, it is assumed that the pressure inside the aircraft is the same as the atmospheric pressure outside. Usually the altitude at which airplanes cruise doesn't contain sufficient oxygen concentration to allow a human to breathe. Therefore, supplemental oxygen systems have to be installed, which are activated in these situations. An important aspect to keep in mind is that the oxygen supply of these systems is limited. This means that the aircraft has a limited time to reach 10000ft, where atmospheric pressure is considered to be high enough to allow safe breathing [4].

While descending, the aircraft has to follow a profile that satisfies the constraints published by the manufacturer in the Flight Crew Operating Manual (FCOM). An example is illustrated in Figure 2, where the red line corresponds to the FCOM's depressurization profile. The aircraft has to be at or below this profile when descending along the depressurization flight path.

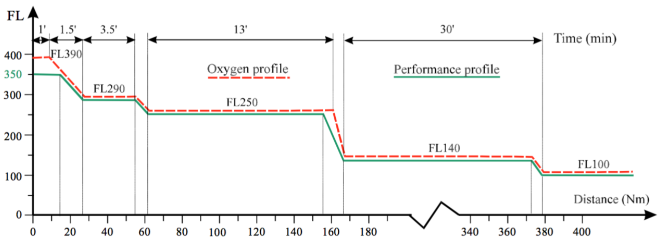


Figure 2: Oxygen vs. Performance Profile of A319 - 21min oxygen system [4]

Albeit serving as a guide, the above profile depicted in Figure 2 doesn't take the performance limitations of the aircraft into account. It plots the altitude in relation to the elapsed time. This is only dependent on the oxygen system's capability. Only by first converting it into a distance-based profile can one depict the aircraft's descent capability.

This means that the real profile will look more like the one in green, depicted in Figure 2. The aircraft may have to start descending earlier then predicted in the FCOM profile, to achieve the various time constraints.

To ensure that the aircraft remains as high as possible for the longest possible distance, two measures are usually applied: Descent branches are performed at $M_{MO}/V_{MO}$, with extended airbrakes, for an increased rate of descent; Cruise branches are performed at $M_{MO}/V_{MO}$. This also ensures that the number of possible escape route is maximized.

$M_{MO}/V_{MO}$ is the maximum operating Mach number/Speed, which may not be exceeded in any regime of flight.

## 2.4. Drift Down Procedure

When at least one engine fails during normal operation, an emergency procedure is conducted with the goal of safely landing the aircraft at a near aerodrome. The thrust of the remaining engine(s), when one (or more) of them become inoperative, is set to Maximum Continuous Thrust (MCT) setting. The available thrust at MCT is not enough to match the opposing drag force and to maintain the design cruise scenario. The aircraft must reduce its speed and descend to a new altitude (drift down ceiling) where level flight is possible.

For conservative purposes, the flight path considered in aviation regulation for engine failure situations doesn't correspond to the path actually flown by the aircraft. The path flown by the aircraft, or gross flight path, has to be penalized by a given gradient penalty. This yields the so called net flight path, which is the one used for obstacle clearance verification purposes. An example can be seen in Figure 3.

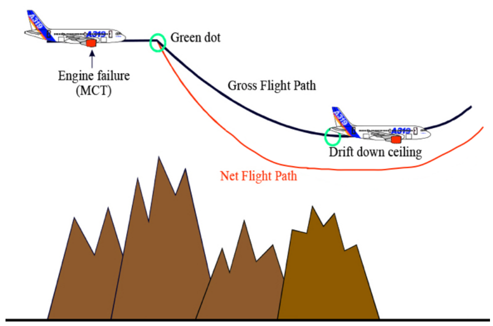


Figure 3: Gross and Net Drift Down Descent Flight Path [4]

The net descent gradient is obtained as follows:

$$\bar{\gamma}_{net} = \bar{\gamma}_{gross} - \bar{\gamma}_{penalty} \tag{14}$$

Where the gradient penalty depends on the number of operational engines and the number of installed engines. This information is presented in Table 1 and can be found in [5].

Table 1: Gradient Penalties applied to Drift Down Gross Flight Paths

| | $\bar{\gamma}_{penalty}$ | |
|---|---|---|
| | Two engines | Four Engines |
| One engine out | 1.1% | 1.6% |
| Two engines out | - | 0.5% |

## 2.5. Route Study

Generally speaking, both engine failure and depressurization must always be expected to occur at the most critical points of the planned route. Moreover, since their descent profiles differ, the critical points may differ between the two failure cases. These are points that separate two segments with differing escape strategies. An example is shown in Figure 4, where two critical points A and B are depicted.

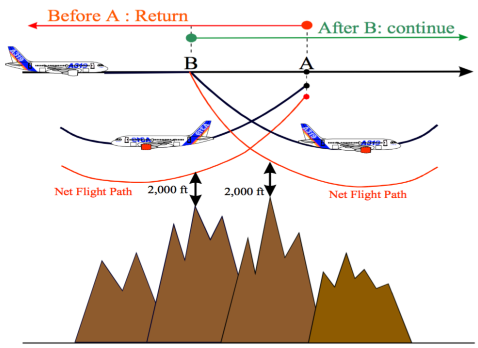


Figure 4: Critical Points [4]

It is important to notice that regulations dont require to consider performance to cope with both failures simultaneously. The disadvantage of dealing with both failure cases separately, is that the number of critical points and specific escape routes increases. This increases the workload of flight crews and thereby the risk of errors.

For this reason, whenever possible, it is preferred to define identical critical points and escape routes for all failure cases. This reduces the reaction time and the risk of committing mistakes. In such a case, the route study should be based on the most penalizing descent profile. Figure 5 illustrates both failure descent profiles for a A319 over a mountainous area.

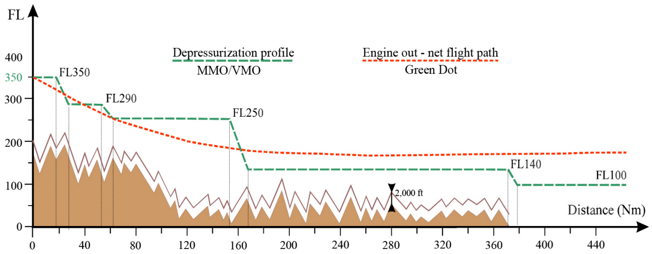


Figure 5: Obstacle Clearance Profiles Engine Failure and Depressurization[4]

## 3. Implementation

An Emergency Profile Application (EPA) was developed in order to develop the computational tools and methodologies which seek to achieve the objectives of the present work. The main purpose of EPA is to verify if, at any point along a given route, an aircraft can execute an emergency descent safely along that same route.

EPA allows the computation and verification of emergency flight profiles for depressurization and engine failure scenarios. After computing the flight profile, it verifies if the profile can be flown, given current aircraft location and navigational constraints. For its computations, EPA considers the most updated weather information, stored in the EFB's database (DB). Flight performance calculations are executed by Airbus' Performance Engineer's Program (PEP) software.

### 3.1. PEP integration

PEP is the computational motor of EPA. It is an Airbus software capable of performing every aircraft performance calculations needed for EPA purposes. PEP computations should be as seamlessly integrated into EPA as possible. Ideally, EPA would only be required to execute a batch file which would read the input .DAT file and return a .PRN file with the computation results. This would allow PEP's computations to translate into a few lines of code in EPA, and to run in a very time efficient manner, requiring no interaction from the user. This solution exists and can be distributed by Airbus.

The main PEP component used by EPA is the In Flight Performance (IFP) module. IFP allows to execute various computations regarding cruise, climb and descent scenarios. It is used by EPA in order to compute depressurization profiles, branch by branch, and to get drift down gross profiles. Unfortunately, as of the time at which this work was written, no solution was made available by Airbus that allows PEP IFP computations to be executed without having to use the PEP standalone desktop application. This means that PEP's input files, produced by EPA, have to be manually imported into PEP by EPA's user, and manually run. This applies to the computation of depressurization profiles and gross drift down profiles.

On the other hand, the net drift down profiles can already be computed automatically. PEP's APCMTP module, which includes flight planning software and can simulate drift down emergencies, runs independently from PEP. APCMTP gets called from EPA and doesn't require any interaction from the user. It allows EPA to compute the net drift down profile path which is to be verified against Minimum Altitude (MA) constraints.

### 3.2. Flowchart Symbology

The flowcharts used in the following Subsections respect the symbology presented in Figure 6. They are based on Unified Modeling Language (UML) guidelines, and will be used to explain different algorithms and processes executed by EPA.

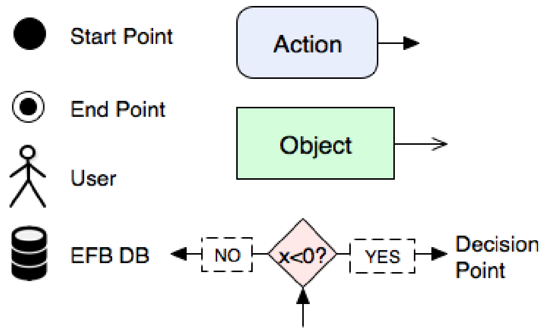


Figure 6: Flowchart Symbols Legend

### 3.3. EPA Structure

EPA's computational structure can be divided into four main steps:

1. Configuration of Input Data
2. Computation of Flight Profile
3. Verification of MA constraints
4. Report Result to User

The order of these steps is as presented above, and they can be organized as shown in Figure 7.

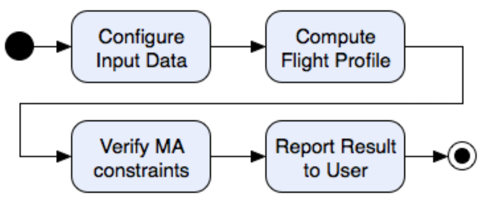


Figure 7: EPA Basic Structure

### 3.4. Input Data

In order to compute an adequate flight profile, EPA requires data regarding the route, the aircraft and atmospheric conditions. This data is required in order to write the input files that are to be read by PEP, or to compute values for these input files. The way the data is gathered by EPA is illustrated in the flowchart of Figure 8.

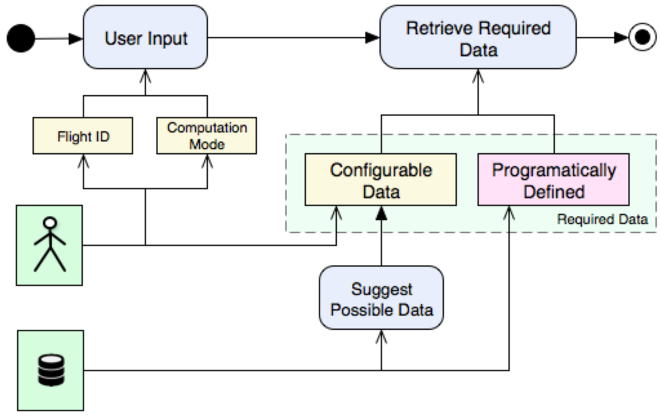


Figure 8: EPA Data Retrieval Algorithm

EPA first requires the user to enter a valid Flight ID, which is a unique flight identification code. Without entering the Flight ID, EPA doesn't allow the user to advance any further in the application. The Flight ID associates different types of data on the DB to the corresponding flight. This includes the aircraft model and registration, route and weather information, among other data. It is therefore an essential value.

As illustrated in Figure 8, the required data is divided into two categories:

1. Configurable Data
2. Programmatically Defined Data

Configurable Data is suggested to the user based on the flight context and the computation mode selected. The user can then customize this data. For example, if the user selects Depressurization Mode (DM), EPA will suggest that all engines are operating. However, this can also not be the case, so this option can be customized.

Programmatically Defined Data includes all the values and information that are stored in the DB, or are established by regulation authorities, and that are not to be changed by the user. This also includes values computed by EPA and not open to user interaction. An example is the atmospheric conditions along the route, which are retrieved by EPA based on the current aircraft location, and are not to be changed by the user.

### 3.5. Flight Profile Computation

The computation of a descent flight profile is the core component of the EPA. It calculates depressurization profiles branch by branch, following FCOM and regulatory requirements. Atmospheric conditions are computed based on information available in the DB, and appended to PEP's input files. Coordinate tools have been developed to calculate distances, heading angles, and other quantities related to global coordinates.

There are two computation modes configured into EPA. The first one is Depressurization Mode (DM). As the name points out, this mode calculates a depressurization descent profile, tailored according to the oxygen system installed in the aircraft. The second mode is Engine Failure Mode (EFM), which is used in case of drift down calculations following engine failure.

### 3.6. Depressurization Mode (DM)

DM allows the user to compute a depressurization profile along the default flight route, using the most updated meteorological conditions. Using the oxygen profile information (see Figure 2), EPA builds a depressurization profile tailored to the FCOM's constraints. It follows the algorithm depicted in Figure 9.

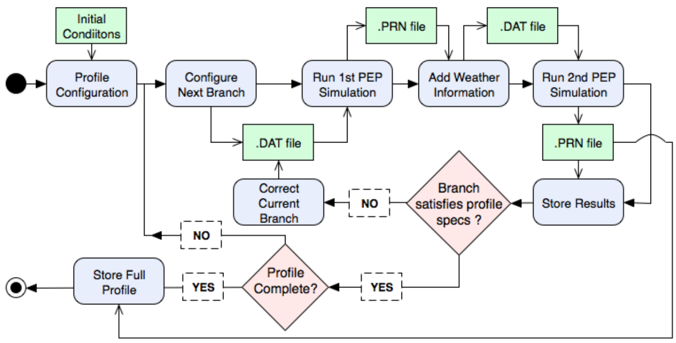


Figure 9: EPA Computation Algorithm for DM

EPA starts by gathering all the required information provided by the DB and the user, which together form the input data cluster.

To compute the full profile, EPA calculates and handles each profile branch individually. This means that each cruise and descent branch is computed individually, and verified against the FCOM oxygen profile requirements. This process is therefore iterative. Once a given branch compu and verification is complete, EPA advances next one. This proceeds until every branch ha successfully computed and satisfies the FC constraints.

One important problem to keep in mind i only cruise branches are adjustable. This that if a given descent branch turns out to en than imposed by the FCOM profile, the precedent cruise branch has to be shortened. The opposite is also true. If a given branch ends sooner than required, the necessary adjustments are made to ensure that the aircraft spends the highest amount of time, and thus covers the longest distance at the highest altitude possible. Figure 10 illustrates the adjustable branches for a depressurization profile corresponding to an aircraft cruising at an initial altitude of 27300ft, with an installed oxygen system of 12 minutes. The profile is composed of 6 branches, half of which are adjustable cruise branches. These are the branches that EPA can extend or shorten in order to achieve the FCOM time constraints depicted in the time axis (x-Axis) of Figure 10.

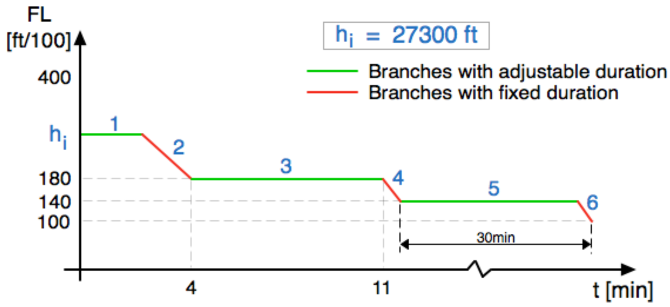


Figure 10: Fixed and Adjustable Branches for 12 minutes Oxygen Profile

The difference between the 1st and the 2nd PEP simulation/computation for each branch is that the latter includes the required weather information. Since weather information varies between every two Waypoints (WPT) of the route, it has to be averaged per altitude, and per branch. It can only be included after the branch length is known, since the length is a required value to average the weather information of each branch.

As soon as the full profile has been successfully computed and satisfies all FCOM requirements, it is stored so it can be later verified against MA constraints.

### 3.7. Engine Failure Mode (EFM)

EFM allows the user to compute a drift down profile along the default flight route, using the most updated meteorological conditions. EFM is executed according to the algorithm illustrated in Figure 11.

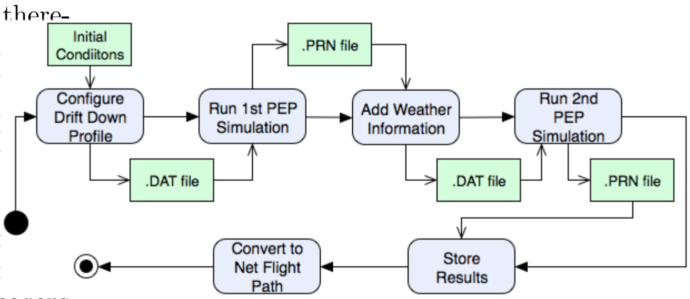


Figure 11: EPA Profile Computation Algorithm for Engine Failure Mode

Similarly to what happens in DM, EPA starts by gathering all the required information provided by the DB and the user, which together form the input data cluster.

A drift down profile corresponds to a single branch or segment, contrasting with the multi branch depressurization profile. This means that a drift down profile can be calculated by PEP in a single computation, and it simplifies the computation process for EFM mode immensely.

The fact that EFM requires two computations is because, similarly to what happened with other branches in DM, the latter computation includes weather information and yields the final results. Since weather information varies between every two Waypoints (WPT) of the route, is has to be averaged per altitude, for the entire drift down profile. It also can only be included after the branch length is known, since the length is a required value to average the weather information of the profile.

EFM requires an additional step, not necessary in DM. After the gross flight profile has been computed by PEP and the results have been stored, EPA penalizes the descent gradient in order to obtain the net flight path. It follows the guidelines presented in [5], and uses a dedicated PEP module for it. This module obtains the net profile directly, given the initial descent conditions. This way, EPA now has a gross and a net drift down profile available as well.

### 3.8. Verification of Minimum Altitude Constraints

After having computed the descent flight profile, EPA needs to verify if the computed profile can be flown safely, satisfying the obstacle clearance rules imposed by regulations found in [5] and [6]. For more detail on obstacle clearance rules please consult the main Thesis document.

Wether coming from DM or EFM, EPA now holds the full descent profile in a list of the type *List(Of ProfileCOORD)*, where *ProfileCOORD.vb* is an object class created for storing each individual profile point. A profile point corresponds to a step- or sub-computation executed by PEP. For example, each time PEP computes a drift down profile, it performs several sub-computations between the initial and the final profile point. For each one of these sub-computations, PEP presents the elapsed time, distance covered, fuel burned, and other information. These values are each stored in a corresponding *ProfileCOORD.vb* object, to build the entire flight profile.

For each profile point, EPA calculates two Minimum Altitude (MA) constraints:

- MSA - Minimum Safe Altitude
- MORA - Minimum Off-route Altitude

The MSA is retrievable from the DB, and is released together with the flight's OFP. It clears all terrain and man-made structures by 2000ft [7]. It is usually available for every cruise segment of the route, and therefore establishes the minimum flight altitude between two route WPTs. EPA extracts the MSA of a given profile point by crossing the information of the profile's coordinates with the corresponding route segment.

The MORA, on the other hand, defines a MA for a certain rectangular area. Therefore, MA constraints imposed by MORA are less restrictive than the ones that derive from MSA. It clears all terrain and man-made structures by 1000ft in areas at or below an elevation of 5000ft, and by 2000ft in areas above an elevation of 5000ft [7]. MORA information is listed in Aeronautical Information Publications (AIP), released according to the Aeronautical Information Regulation And Control (AIRAC) cycle. EPA uses Honeywell's AIP, which is subscribed by TAP, and loads the MORA information onto the DB. It then uses specifically developed methods to determine the MORA at a given geographic coordinate.

After EPA has gathered available information about the MSA and the MORA at the coordinates of each profile point, it just compares the altitude of each point against those MA conditions. The MSA is less restrictive than the MORA, and therefore the altitude of each profile point is first compared against the MSA. Moreover, the availability of an MSA value depends on wether it was filled in the OFP. If by any reason the MSA value is not available or retrievable from the DB, EPA compares the altitude of that point against the MORA.

The procedure is simple: If EPA finds that any of the profile points has an altitude at or below the MSA/MORA condition at that location, the profile cannot be flown, as it doesn't meet regulatory approval. If, on the other hand, all point altitudes are above their MSA/MORA requirement, the profile is safe.

### 3.9. Report Result to User

After establishing if the profile satisfies all MA constraints and meets regulatory approval (see Subsection 3.8), the result is communicated to the user with a simple message. This message indicates whether the profile satisfies all MA constraints, or if it violates MA requirements at one or more of its points.

## 4. Results

Some sample flight routes were provided by TAP in order to test EPA's functionalities. All flights provided are long haul flights over the ocean. This means that the corresponding MA requirements at the chosen locations are at their minimum. Sample computations were executed with EPA, and the results obtained are thereby presented.

Some data tables of the DB are mentioned in the next paragraphs, as well as auxiliary tools developed for specific coordinate calculations. For more information on the DB and these tools, please consult the main Thesis document.

Also note that some International Civil Aviation Organization (ICAO) codes will be used in order to refer to specific global locations like airports and aerial WPTs. These include LPPT, KMIA, EMAKO and TASNI.

### 4.1. Flight Scenario

A specific flight scenario was chosen in order to demonstrate EPA's functionality. The same flight scenario will be used for both DM and EFM testing.

Flight Nr. 3051 is going to be utilized in order to test EPA's DM and EFM. Flight 3051 departs from Lisbon Airport (LPPT) and its destination is Miami's International Airport (KMIA). The aircraft flying this route is the Airbus A330-223, with a 12 minute oxygen system on board.

The flight information table (OFP_RouteInfo) was filled until the WPT EMAKO, simulating thus a depressurization or and engine failure that happened after the aircraft passed EMAKO and before it reached the next WPT (TASNI). EMAKO is therefore the last WPT considered by EPA. According to flight data records provided by TAP of the very same flight, after WPT EMAKO the aircraft had an initial weight of close to 170000kg, and was cruising at 38000ft, as predicted in the OFP. These were therefore the initial conditions chosen for this computation.

The WPT EMAKO has the following coordinates: (+31,397°/-68,238°) (Latitude/Longitude). TASNI has the coordinates (+30,9°/-69,225°). The two WPTs are 58,84NM away from each other, and the bearing when the aircraft flies over EMAKO is 58,84°.

A simple coordinate utility was developed to perform calculations with coordinates. Using this utility, an arbitrary point after EMAKO was chosen. The initial coordinates considered for this calculation are (+31,399°/-68,575°). These coordinates correspond to a point situated 20 NM after the aircraft passes EMAKO. It is situated above the Atlantic Ocean. This is assumed to be the point where the aircraft must start descending along its depressurization or drift down profile.

### 4.2. Depressurization Mode Computation

EPA took a total of 22 PEP calculations to compute the full depressurization profile. The results of the final computation were extracted to a .CSV file and are illustrated in Figure 12.

The aircraft takes a total of around 42 minutes and covers 286 NM before it reaches FL100.

During its computations, EPA verified each branch in order to adjust the cruise branches and maximize the time and distance at each altitude. If EPA didn't have to verify and adjust the branches, it would only require 12 computations. This would correspond to two computations per branch (the first to compute the branch without atmospheric conditions, and the second already with this information).

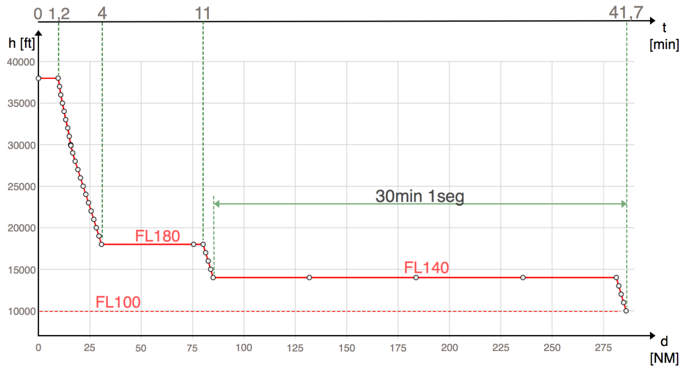


Figure 12: Depressurization Profile computed by EPA

Please compare the results profile of Figure 12 to the FCOM profile depicted in Figure 10.

One can easily see that the time limits at 4 minutes and 11 minutes have been successfully respected. As soon as the aircraft reaches the corresponding profile points, it starts descending along the next branch. EPA successfully guarantees that the aircraft stays on each required altitude for the maximum amount of time and the for the longest distance possible.

The only observed FCOM requisite that EPA couldn't keep was the last 30min time limit above 10000ft, starting from the point where the aircraft reaches 14000ft. The duration of the last two branches combined is $30,02\,min = 30\,min\,1\,seg$. This error is however negligible:

$$\triangle = \frac{0,02}{30} \approx 0,067\%$$

After finishing its computations, EPA displayed a message informing that the profile satisfies all regulatory requirements and doesn't violate any MA constraints. The MORA and the MSA values are kept at a minimum throughout the flight path, since the aircraft is supposedly flying over the sea. This result was therefore expected.

### 4.3. Engine Failure Mode

The same flight scenario was used by EPA in order to compute the drift down profile. The computation of gross profile only required two PEP computations, and only a small fraction of time when compared to DM.

EPA then obtained the net profile path using the APCMTP module. Both the gross and the net profiles can be analyzed in Figure 14. Please note that the time axis corresponds to the gross profile path.

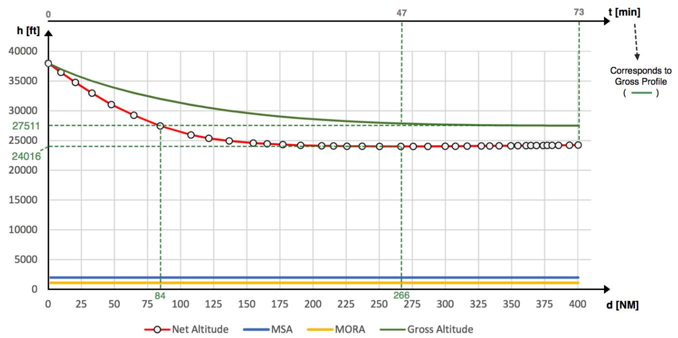


Figure 13: Drift Down Profile computed by EPA

The gross profile is computed until it reaches the level-off altitude, at 27511ft. The aircraft takes 1h13min to reach this point, and covers a total distance of 400,3NM. If the flight were to continue at this point, the aircraft would start cruising again, and increase its altitude as it became lighter.

In contrast to this, the net profile is computed to and beyond its level-off point. Since the net level-off point is reached in a shorter distance than the gross one, the aircraft already started climbing when it reaches the gross level-off coordinates. The net level-off altitude is situated 266 NM ahead of the TOD. The net profile reaches the gross level-off altitude, 27511ft, only 84 NM beyond passing the TOD. This corresponds to approximately a fifth of the distance required by the gross profile to achieve the gross level-off altitude.

The difference between gross and net level-off altitudes is 3495 $ft$, which corresponds to $\frac{3495 \cdot 100}{27511}\% = 12,7\%$ of the gross level-off altitude.

For the EFM, despite not having temporal constraints to compare the results against, like in DM, the results are satisfactory. EPA successfully computes both the gross and the net profiles, and compares the latter against the corresponding MA constraints. In an operational context, the gross profile is not required, since the net profile is the one to be compared against MAs. However, it was easily obtainable using the tools already developed for DM, and allows the user to easily compare both results.

### 4.4. Combined results

Figure **??** shows the three resulting profiles overlapped, in order to visually be able to compare them. One can see that the depressurization profile is by far the most penalizing in terms of altitude. It maintains the initial 38000ft for just 1 minute and 14 seconds, and afterwards starts descending at a RD of over 11000 $\frac{ft}{min}$. After a ground distance of 31 NM the aircraft is already cruising at 18000ft, well below the 33254ft at which the aircraft finds itself along the (net) drift down profile after an equivalent ground distance from the TOD.

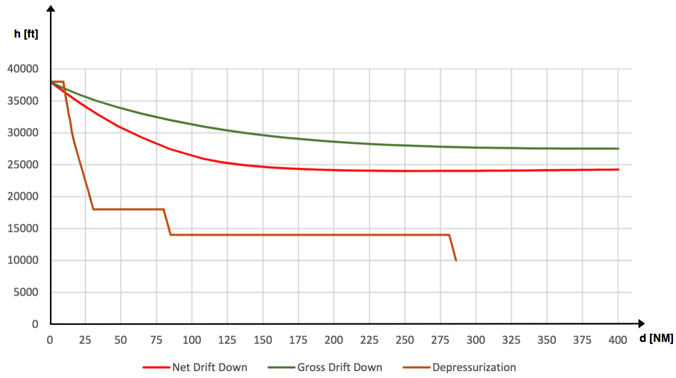


Figure 14: Combined Results - Depressurization and Engine Failure

## 5. Conclusions

This section presents an overall balance of the work, and future work.

### 5.1. Balance

The overall balance of this work is positive. The main objectives were successfully accomplished. An application was developed, which contains the computational methodology to compute flight profiles for emergency descent scenarios, for both depressurization and engine failure scenarios. The application considers the most updated weather data, and also verifies the computed flight profiles against the appropriate altitude constraints, determining wether the profile is valid or not.

However, to further expand and integrate the developed methodology in TAP's EFB solution, some developments are required. The fact that PEP's computations cannot currently be dissociated from it's desktop application, means that, for now, computations have to be executed manually. This is a very time consuming process, as EPA requires a high number of computations to complete a depressurization profile. The user has to import each file manually and execute the corresponding simulation. This issue should be solved if EPA is to be integrated in more complex route analysis applications. It can only be solved if Airbus releases a batch application to TAP, which can be called to run PEP simulations independently from PEP's desktop application, similarly to the APCMTP module used for net drift down profile calculation.

All-in-all, one can say that the work presented achieved its proposed goals within the given constraints. EPA shouldn't be viewed as a software with low operational application, but rather as a computational foundation with high-value tools, which TAP's EFB team can build upon.

### 5.2. Future Work

As mentioned at the end of Subsection 5.1, EPA is a computational foundation upon which TAP's EFB team can build upon. Its tools can be applied to more robust and complex verification of escape routes, making this process run in a seamless way, throughout the flight.

Currently, EPA only considers the main route in its calculations, meaning that it is along that route that it calculates the emergency descent profiles. It is also along this route that EPA verifies if the profile is valid and safe.

In the future, parameters like the aircraft altitude and weight could be automatically sent from the aircraft to the EFB through a direct data link. Together with an independent execution of PEP's computation module (see 3.1), this would unlock the full potential of EPA. The software can then be expanded to analyze alternative emergency routes. The application could then evolve into scanning entire flight routes, identify critical points automatically and suggest appropriate escape routes, each time a new weather update becomes available.

Flight crews can then be sure that the procedures they follow in case of failure rely on the most recent meteorological conditions. This would translate into an improved operational safety in regard to cruise emergency procedures.

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