Flight Data Monitoring and its Application on Algorithms for Precursor Detection

Pedro Filipe Martins Soares
pedro.martins.soares@ist.utl.pt

Instituto Superior Técnico, Lisboa, Portugal

November 2014

Abstract

With this work, R programming language algorithms were developed to support the main daily flight data analysis performed with AGS© software. In a first stage algorithms were developed regarding aircraft trajectory filtering from the original data mostly applied on the final approach and landing flight phases, touchdown point detection and threshold crossing point detection for the Airbus A320 family fleet, where the obtained results were exported to Google Earth©. A runway excursion risk diagram was implemented with the touchdown point distribution and respective ground speed at touchdown. It was also created an R algorithm that will automatically generate landing reports whose touchdown points are considered atypical based on an RLR model. The FMS data has been verified as the most accurate regarding the aircraft’s position and the new accurate position threshold detection method has been proved trustworthy. Also, the risk of having runway excursions at Lisbon international airport is very low.

Keywords: Flight Data Monitoring, Algorithms, Avionic Systems, Landing

1. Introduction

The aviation industry being of such importance for the world activity, it is mandatory to avoid as much as possible every type of incidents and accidents, first of all due to the very low rate of survivability in aircraft accidents given the linear momentum of an aircraft (high speed and high mass) which result in the loss of human lives. Accidents with human fatalities are by far the worst type of accidents and contribute enormously to a lower confidence on airlines and the aviation industry by passengers worldwide. However, not only fatal accidents contribute to this factor, every type of incident such as human error, mechanical failures, weather-related or incidents caused by other sources affect the passengers confidence and the sector itself.

Figure 1 shows the percentage of accidents related to the aircraft flight phase, fatal accidents and onboard fatalities occur primarily during the take-off or initial climb phases and during the final approach and landing phases, contributing with 20 per cent and 36 per cent respectively to the total number of fatal accidents.

The main objective of Flight Data Monitoring (FDM) is to actively prevent accidents and other sources of problems that may affect passengers and airlines, every commercial aircraft is equipped with data recording systems that record a large number of flight parameters (mandatory and non-mandatory) such as temperatures, pressures, control surfaces attitude, and many more. The recorded data is decoded and analyzed on the ground workstations on a daily basis procedure generating reports according to the safety limits and procedures imposed.

With the recorded data it is investigated the flight crew behavior and the aircraft operation during every commercial flight, the aim is to notice irregularities from the standard safety procedures defined by either the airline or manufacturer. These irregularities may go from isolated actions performed by the crew that diverge from the standard safety procedures to mechanical or electrical failures in the aircraft systems. When
this happens, it is essential to have a proper FDM database and safety procedures to detect faults and repair the aircraft systems as soon as possible, this is the preventive work that must be done in order to avoid the component failure, scheduling maintenance procedures according to the number of flight hours of the aircraft systems and components and whenever there is any prediction of a system malfunctioning. Often, post-flight statistical analysis and reports are also a great asset in understanding which procedures can be improved.

2. Aircraft Systems

2.1. Flight Management System (FMS)

The FMS is a system that performs navigation functions and flight planning functions by constantly analyzing data from other aircraft systems. The FMS involves two major components, a computer unit and a master computer display unit. The first one is responsible for the data processing of the flight data recorders as well as navigation systems to prepare the aircraft routes and flight planning while the second one is primarily a human/machine interface for data Input/Output (I/O) for the FMS [2]. Some of the FMS main functions that should be mentioned are [3]:

- The navigation function: responsible for determining the best estimate of the current state of the aircraft.

- The flight planning function: allows the crew to establish a specific routing for the aircraft and to get the fuel predictions along the flight plan.

- The trajectory prediction function: responsible for computing the predicted aircraft profile along the entire specified routing.

2.2. Global Positioning System (GPS)

The GPS is a space-based radio-positioning and time-transfer system. GPS provides accurate position, velocity, and time information to an unlimited number of suitably equipped ground, sea, air and space users in an available world-wide common grid system. The GPS consists of three major segments: Space, user and control. The User Segment consists of receivers specifically designed to receive, decode, and process the GPS satellite signals. Receivers can be stand-alone, integrated with or embedded into other systems. GPS receivers can vary significantly in design and function, depending on their application for navigation, accurate positioning, time transfer, surveying and attitude reference [4].

2.3. Inertial Reference System (IRS)

An Inertial Reference System (IRS) also known as Inertial Navigation System (INS) is a navigation system that relies on the usage of accelerometers and gyroscopes. It can determine the position of a vehicle without any other external reference, it needs however the initial position of the vehicle. This system is usually built with 3 accelerometers, measuring the acceleration along each space axis, and 3 gyroscopes also to measure the rotation around each axis. The accelerometers and gyroscopes are arranged so that their axes are aligned north-south, east-west and the direction normal to this plane (vertical axis indicating the altitude). Knowing the acceleration along an axis, if the output is integrated once the velocity is obtained, integrating once again and the position is obtained. The same principle is applied to gyroscopes, they give an output proportional to the angle trough which they have been rotated (about their input axes). By integrating gyroscopes’ output it will be obtained a means of precessing the input axis at a rate proportional to input current. [5].

2.4. Instrument Landing System (ILS)

The ILS is an internationally normalized system designed for the navigation of aircraft at the approach and landing flight phases, it is a standard system approved by the International Civil Aviation Organization (ICAO) since 1947. ILS provides vertical and horizontal guidance necessary for an accurate landing approach in Instrument Flight Rules conditions, thus in conditions of limited or reduced visibility [6]. The ILS is composed by the following subsystems. The VHF Localizer (LOC) is responsible for the horizontal guidance, the antenna is located in the centerline axis of the runway at the opposite end of the landing approach direction. This localizer emits two directional radiation patterns, the first one an amplitude-modulated wave with a harmonic signal frequency of 150 Hz while the other is a wave of the same nature but with an harmonic signal frequency of 90 Hz. The intersection of the two regions created by the transmitted signals determines the on-track course plane, the 150 Hz signal predominates on the right side of the course plane while the 90 Hz signal predominates on the left side, the localizer receiver of the aircraft measures the difference in depth of the two signals and based on the course deviation indicator the pilot is informed if the aircraft needs to fly to the left or right to adjust its position for the landing [7].
A UHF Glide Slope Transmitter provides the vertical guidance during the approach phase, the antenna system operates between 329.30 and 335 MHz and the transmitter is located from 750 ft to 1250 ft from the beginning of the runway. The concept of the GS transmitter is similar to the LOC, it also consists of two harmonic signals with a frequency of 150 Hz and 90 Hz. These two signals are arranged in such a way that the centerline of the glide slope signal makes an angle of approximately 3 deg above horizontal, however this signal can be set to a range of 2 deg to 4.5 deg over the horizontal plane of approach [6]. Again, based on the difference in depth of the two signals one can adjust the vertical position of the aircraft. The glide slope receiver antenna is located on the nose of the aircraft.

3. Aircraft Data Filtering Methods

3.1. Smoothing Splines

A spline is a polynomial function which can be used in various fields of engineering and science such as numerical analysis, computer aided design and image processing, trajectory planning problems and other types of data analysis in general [8]. There are several types of splines for numerous applications, however, for the purpose of trajectory smoothing the cubic Basis spline, or B-spline, is of most interest.

A B-spline is a generalization of the Bernstein-Bézier curve, or Bézier curve. Defining a knot vector as \( T = \{t_0, t_1, \ldots, t_i, \ldots, t_m\} \) where \( t_i > t_{i-1} \) and defining control points \( P = \{P_0, \ldots, P_n\} \), then a B-spline is associated with a basis function \( N_{i,j} \) at each control point [9]. The \( N_i,k \) basis functions are of order \( k \) and depend only on the value of \( k \) and the knot vector \( T \).

\[
N_{0,0}(t) = \begin{cases} 1, & \text{if } t_i \leq t < t_{i+1} \text{ and } t_i < t_{i+1} \\ 0, & \text{otherwise} \end{cases} \tag{1}
\]

\[
N_{i,k}(t) = \frac{t-t_{i+k-1}}{t_{i+k}-t_{i+k-1}} N_{i,k-1}(t) + \frac{t_{i+k+1}-t}{t_{i+k+1}-t_{i+1}} N_{i+1,k-1}(t) \tag{2}
\]

Where \( k = 1, 2, \ldots, p \). The curve \( C(t) \) defined by equation 3 is called a B-spline.

\[
C(t) = \sum_{i=1}^{n} P_i N_{i,p}(t) \tag{3}
\]

For a smoothing trajectory curve, \( x(t) \), are employed normalized and uniform B-spline, \( B_k \), functions as the basis functions, in such way that [10]:

\[
B_k(t) = \begin{cases} N_{0,k}(t) & 0 \leq t < 1 \\ N_{k,k-1}(t-1) & 1 \leq t < 2 \\ \ldots \ldots \end{cases} \tag{4}
\]

For a cubic smoothing spline it can be written that:

\[
x(t) = \sum_{i=-3}^{m-1} P_i B_3(\alpha(t-t_i))(t) \tag{5}
\]

Where \( m \) is an integer, \( P_i \) is a weight coefficient or control point and \( \alpha \) is a constant scaling the intervals between data points.

The cubic smoothing spline can be obtained by minimizing a cost function [10]:

\[
J(P) = \lambda \int_I (x''(t))^2 + \sum_{i=1}^{n} w_i(x(u_i - d_i))^2 \tag{6}
\]

Where \( u_i \) and \( d_i \) are a given set of data, \( \lambda \) is a smoothing parameter, \( w_i \) (0 \leq w_i \leq 1) are weights for approximation errors and \( I \) is the integration interval \( (t_{min}, t_{max}) \).

3.2. Gaussian Smoothing

The Gaussian smoothing method is based on the bell curve by Gauss as it is used to weigh calculated values. The probability density function of a normal distribution is given by equation 7 [11].

\[
g(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2 \sigma^2}} \tag{7}
\]

Where \( \mu \) is the mean value of the distribution and \( \sigma \) is the standard deviation.

For a trajectory smoothing method using the Gauss curve, it must be defined the convolution on \( t_0 \) of a function \( x(t) \).

\[
\xi(t_0) = \int x(t)g(t-t_0) \tag{8}
\]

However, equation 8 stands for the convolution of continuous parameters, since the data samples obtained from AGS® are discrete parameters, the convolution integral turns into a sum of each point \( t_0 \) calculated in the vicinity of \( \Delta T \).

\[
\xi(t_0) = \sum x(t)g(t-t_0) \tag{9}
\]

Using the definition of the Gauss bell curve (equation 7) and reminding that in a trajectory problem the mean value of a distribution is not a
significant parameter, $\mu$ can be set to zero and the distribution becomes:

$$g(t - t_0) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2} \frac{(t - t_0)^2}{\sigma^2}}$$ (10)

The function $g(t - t_0)$ is the weight assigned to each new calculation and it is chosen in a way that when $t \to t_0$, the highest is the weight calculated. The choosing of the $\sigma$ parameter is of great importance since it measures the filter size, the larger this value the more points are used in this method and therefore the final result with the smoothing trajectory will be less sensitive to signal fluctuations.

4. Landing Procedures
4.1. Threshold Detection Methods
Regarding the threshold crossing point detection, two different calculation forms were considered, one using the ILS and the other using the FMS aircraft position and the Haversine Formula.

4.1.1 ILS Approach
The ILS provides a glide-slope signal (radio beam) to guide the aircraft in his approach to the runway, generally the glide-slope signal is at an angle of 3 deg with horizontal (which is also the case of Lisbon airport RWY 21 and RWY 03), the glide-slope signal receiver antenna is located on the nose of the aircraft. The threshold crossing point can be detected when the signal emitted has a height of 50ft by definition. Therefore, for a 3 deg glide-slope magnitude the distance between the threshold and the glideslope emitter is $50/\tan(3) = 954$ ft.

Observing Figure 2, it shows an aircraft guided by an ILS approach to the runway, where $D_{TH}$ is the horizontal distance between the threshold and the glideslope emitter (constant distance of 954ft), $D_{GS}$ is the horizontal distance between the glideslope emitter and the glideslope signal receiver, $h_{GS}$ is the height of the glideslope antenna, $h_r$ is the radio altitude provided by the radio altimeter, $\gamma$ is the flight path angle, $\theta$ is the pitch angle and $\Delta GS$ is the aircraft glide-slope antenna's deviation in relation to the virtual slope since it is nearly impossible for a pilot to maintain a constant glide path of 3 deg due to turbulence and the aircraft’s vibrations.

$$D_{GS} = D_{TH}$$

$$h_{GS} = h_r + V_{GS}\cos(\theta) + L_{GS}\sin(\theta)$$ (12)

Where $V_{GS}$ and $L_{GS}$ are characteristic dimensions from the aircraft as shown in Figure 3.

Figure 2: Example of an ILS approach [12]

Figure 3: $H_{GS}$ calculation diagram [12]

4.1.2 Accurate Position Approach
This approach is more generic and there is no need for the airport to have an ILS available. The threshold point detection using this methodology is based only on the runway threshold coordinates defined in the airport database and the aircraft position provided by the Airborne Navigation System which can be inertial (IRS), satellite (GPS) or the composition of different systems computed on-board by the FMS.

The objective behind this method is to calculate the distance between the aircraft’s position and the runway threshold coordinates in a time interval fixed around the touchdown point, a safe distance for the aircraft to land safely.

Table 1: TAP’s fleet $V_{GS}$ and $L_{GS}$ dimensions [13]
time interval can be for example of 1 minute before the touchdown is detected until the touchdown occurs since there is only a few seconds difference between the threshold crossing and the aircraft touchdown, this way it is guaranteed that both the threshold crossing and the touchdown on the runway are inside the interval chosen.

To calculate the distance between two points defined by their latitude and longitude one can use the Haversine Formula [14], from a computational perspective the distance between these two points can be obtained as follows:

\[ a = \sin^2 \left( \frac{\Delta \phi}{2} \right) + \cos(\phi_1)\cos(\phi_2)\sin^2 \left( \frac{\Delta \lambda}{2} \right) \] (13)

\[ c = 2 \times \arctan \left( \sqrt{a}, \sqrt{1 - a} \right) \] (14)

\[ d = R \times c \] (15)

Where \( \Delta \phi = \phi_2 - \phi_1 \) and \( \Delta \lambda = \lambda_2 - \lambda_1 \), and \( \phi \) denotes latitude, \( \lambda \) denotes longitude, \( \arctan2 \) denotes the arctangent function with 2 arguments, \( R \) is the Earth’s mean radius (6371km) and \( d \) is the distance wanted. The \( \arctan2 \) function can be defined as [15]:

\[ \arctan2(x, y) = 2 \times \arctan \left( \frac{\sqrt{x^2 + y^2} - x}{y} \right) \] (16)

Using the previous relations a final formula for the distance \( d \) can be obtained:

\[ d = 2 \times R \times \arcsin \left( \sqrt{\sin^2 \left( \frac{\Delta \phi}{2} \right) + \cos(\phi_1)\cos(\phi_2)\sin^2 \left( \frac{\Delta \lambda}{2} \right)} \right) \] (17)

One of the points for this formula remains constant (runway threshold point) while the other one indicates the aircraft position during its approach. It is expected that this distance decreases as the aircraft approaches the runway, passes through a minimum (threshold crossing point) and then increases as the aircraft approaches the ground, lands on the runway and moves further away from the threshold point.

4.2. Touchdown Point Detection

The TOUCH_DOWNC parameter on AGS© indicates the touchdown instant in a flight data file, and it is a parameter that is 0 for the entire flight except for this instant where it changes to 1. The touchdown point detection is based on three conditions that are related to the radio altitude given by the two radio altimeters (RALTD1 and RALTD2) on the aircraft and the longitudinal acceleration (LONG). The radio altimeter returns the altitude of the main landing gear relative to the ground while the longitudinal acceleration is measured by the three-axes linear accelerometer along the longitudinal axis. If the radio altitude is less than or equal to zero (RALTD1 ≤ 0 or RALTD2 ≤ 0) and the longitudinal acceleration value switches from positive to negative (touchdown instant) then touchdown has occurred and the TOUCH_DOWNC parameter is stored for the instant that the first of these conditions is satisfied.

4.3. Flare

Flare is a landing maneuver performed by the pilot in order to reduce the vertical speed component, with this maneuver it is intended to avoid hard landings as there is a positive vertical acceleration. The nose of the aircraft is elevated during flare so that both lift and drag forces increase. This way it is possible to achieve weaker touchdown impacts which could damage the aircraft structure (specially the landing gear) [16].

The flare ending instant is relatively simple to define, it ends when the aircraft nose starts rotating towards the ground after touchdown, parameters LDGL and LDGR become 1 when the left and right main gear touch the ground respectively, thus marking the flare ending condition.

The flare starting instant is more complex to define, according to Simões (2011) [12] the flare starting conditions are:

- Radio altitude below 90 ft, the flare maneuver
is performed during the landing phase and near the runway threshold thus an altitude of 90 ft is a safe margin to work with.

- Maximum peak for the derivative over time of the PITCH RATE parameter. This means that during this peak there will be a higher aircraft nose elevation which is a flare characteristic.

- A decrease of the FPAC parameter. The flight path acceleration decreases because during flare the aircraft’s speed also decreases due to the increase of drag.

- An increase of the FPA and PITCH parameters. As the aircraft nose elevates for the flare start both pitch and flight path angle will have the tendency to increase.

- Flight phase after the approach, since this maneuver is only performed during landing.

4.4. Regularized Logistic Regression Model

A Regularized Logistic Regression (RLR) is a mathematical tool to, given a set of data \((u,v)\), classify that data into different labels (also known as classification problems). This is useful for example to create boundary lines or regions to separate data associated with a different label, this way it is also possible to predict which label should be assigned to new sets of data of the same nature as soon as the model is implemented.

The basic concept of a Regularized Logistic Regression is to extend the Logistic Regression model into a more resourceful tool adding a regularization term to the equations that describe the model. This can be useful to classify typical and atypical touchdown points or any other data samples to generate LaTeX reports from R Studio. The Regularized Logistic Regression will provide a boundary area to the sample data, for the touchdown point analysis, if the touchdown point lies inside the boundary area it is considered typical \((y = 1)\), on the opposite direction if the touchdown point lies outside the boundary area it is considered atypical \((y = 0)\) and a report is generated.

In order to adjust the data set from the touchdown points to the Regularized Logistic Regression to build a model, the data \((u,v)\) that represents longitude and latitude points suffered a coordinate transformation to place the data in the interval \([-1,1]\) and to change its disposition for a better fitting into the algorithm. The coordinate transformation was based on an elliptical coordinate transform [17].

\[
\begin{align*}
\zeta &= \cosh(u) \times \cos(u) \\
\eta &= \sinh(v) \times \sin(v)
\end{align*}
\]  

In addition to the coordinate transformation the new data set \((\zeta, \eta)\) was also scaled.

\[
\begin{align*}
\zeta_2^{(i)} &= \frac{\zeta^{(i)} - \mu_1}{2 \times \sigma_1} \quad \text{and} \quad \eta_2^{(i)} &= \frac{\eta^{(i)} - \mu_2}{2 \times \sigma_2}
\end{align*}
\]  

Where \(\mu_1, \mu_2, \sigma_1, \sigma_2\) represent the means and the standard deviations of the respective columns that compose the matrix with the data samples. For simplification purposes both \(\zeta_2^{(i)}\) and \(\eta_2^{(i)}\) representing the new transformed and scaled data sets will be referred as just \(\zeta\) and \(\eta\).

After the transformations made from \((u,v)\) to \((\zeta, \eta)\) in order to fit the data to the algorithm, the variable \(x\) present in the cost function and the Hessian matrix suffers another transformation where all the monomials (meaning polynomial terms) of \(\zeta\) and \(\eta\) to the sixth power are applied, creating a 28 entry column vector where \(x_1 = 1, x_2 = \zeta, x_3 = \eta, \ldots, x_{28} = \eta^6\).

\[
x = [1 \quad \zeta \quad \eta \quad \zeta^2 \quad \zeta \eta \quad \eta^2 \quad \zeta^3 \quad \ldots \quad \zeta^6 \quad \eta^6]^T
\]

The variable \(x\) represents an arrangement of the original data \((u,v)\) that was transformed to \((\zeta, \eta)\) to input into the Regularized Logistic Regression algorithm, the new cost function will be [18]:

\[
J(\theta) = \frac{1}{m} \sum_{i=1}^{m} [-y(i) log(h_\theta(x(i))) - (1 - y(i)) log(1 - h_\theta(x(i)))] + \frac{\lambda}{2m} \sum_{j=1}^{n} \theta_j^2
\]

The Newton’s Method update rule used is:

\[
\theta^{(t+1)} = \theta^{(t)} - H^{-1}\nabla_\theta J
\]

The Hessian \((H)\) and the gradient \(\nabla_\theta J\) are presented in equations 24 and 25 respectively.

\[
\nabla_\theta J = \begin{bmatrix}
\frac{1}{m} \sum_{i=1}^{m} (h_\theta(x(i)) - y(i)) x_0^{(i)} \\
\frac{1}{m} \sum_{i=1}^{m} (h_\theta(x(i)) - y(i)) x_1^{(i)} + \frac{\lambda}{m} \theta_1 \\
\frac{1}{m} \sum_{i=1}^{m} (h_\theta(x(i)) - y(i)) x_2^{(i)} + \frac{\lambda}{m} \theta_2 \\
\vdots \\
\frac{1}{m} \sum_{i=1}^{m} (h_\theta(x(i)) - y(i)) x_n^{(i)} + \frac{\lambda}{m} \theta_n
\end{bmatrix}
\]
\[ H = \frac{1}{m} \sum_{i=1}^{m} (h_\theta(x^{(i)}))(1 - h_\theta(x^{(i)}))x^{(i)}(x^{(i)})^T + \lambda \frac{m}{m} \begin{bmatrix} 0 & 1 & \cdots & 1 \end{bmatrix} \]  

(25)

The data set used to create the model corresponded to the touchdown points of 1223 flights landing at Lisbon on runway 21, out of these 1223 flights 145 touchdown points were selected and labeled as typical and 135 touchdown points were labeled as atypical.

Since the new touchdown points introduced are examined by the RLR Model in the transformed referential and the coordinate transformation is elliptical, an ellipse was adjusted to the several boundary lines obtained with the different \( \lambda \) selected, this ellipse (in dark blue in Figure 6) will be the final boundary adopted to classify the new data introduced.

5. Results

5.1. Landing Approach Trajectory

For a sample of 100 flights landing at Lisbon international airport on runway 21, the results obtained for the smoothed landing trajectory (with the smoothing splines method) using data from the IRS, GPS and FMS follow.

5.2. Threshold Detection Methods

5.2.1 ILS Approach

Using the ILS method to determine the threshold, for a sample of 1223 aircraft landing at Lisbon international airport on runway 21 the results for both GPS and FMS data are shown on Figures 11 and 10.
5.2.2 Accurate Position Approach

The following results were obtained with a sample of 751 aircraft landing at Lisbon international airport on runway 21.

Regarding the FMS, which was the system that presented the minimum average error related to the real threshold point, it is shown on the histogram of Figure 14 the error distribution for the flights considered, the outlier point (Figure 13) that corresponded to the maximum distance obtained was removed.

5.3. Runway Excursion Diagram

The touchdown point distribution and respective ground speed is of great importance to draw a runway excursion risk diagram. The construction of this diagram was proposed by Fábregas (2011) [19]. It is a simple graphical tool that is very useful to know if there are any risks regarding runway excursions for a set of touchdown points and each of the ground speeds at touchdown associated.

In order to build the diagram, it is required to determine the remaining available runway distance after touchdown, the ground speed at touchdown and the maximum deceleration rates for each risk condition that needs to be evaluated with the diagram such as runway conditions (contamination), type of braking, flap/slat configuration, thrust reverser and more.

The maximum deceleration rates for each condition are different for each type of aircraft as they also depend on the landing weight. For the Airbus A320 family these values are slightly different, however, if one takes an average value with respect to the landing weight of each aircraft type it still provides a valid and good approximation. In this case, the maximum deceleration rates were obtained for landing simulations with different landing weights from Performance Engineer’s Programme (PEP) which is a software regarding aircraft performance developed by Airbus.

The investigated risk conditions regarding runway...
contamination and auto braking with the respective maximum deceleration rates are given in Table 2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Max Deceleration Rate $a_{\text{max}}$ (m/s$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRY</td>
<td>3.97</td>
</tr>
<tr>
<td>WET</td>
<td>2.55</td>
</tr>
<tr>
<td>WATER 1/4′</td>
<td>1.85</td>
</tr>
<tr>
<td>WATER 1/2′</td>
<td>1.96</td>
</tr>
<tr>
<td>SLUSH 1/4′</td>
<td>1.93</td>
</tr>
<tr>
<td>SLUSH 1/2′</td>
<td>2.04</td>
</tr>
<tr>
<td>COMPACTED SNOW</td>
<td>2.30</td>
</tr>
<tr>
<td>ICE</td>
<td>0.94</td>
</tr>
<tr>
<td>AutoBrake LOW</td>
<td>1.70</td>
</tr>
<tr>
<td>AutoBrake MED</td>
<td>3.00</td>
</tr>
<tr>
<td>AutoBrake MAX</td>
<td>6.00</td>
</tr>
</tbody>
</table>

Table 2: Maximum deceleration rates

For each condition there is a corresponding curve, which is obtained with equation 26:

$$GSC = \sqrt{2 \times a_{\text{max}} \times D_{\text{available}}}$$  (26)

Where GSC is the ground speed, $a_{\text{max}}$ the maximum deceleration for each condition and $D_{\text{available}}$ the remaining available landing distance.

For the sample of 751 flights landing at runway 21, the runway excursion risk diagram is shown in Figure 15.

5.4. Automatic Report Generation

As every R analysis, the flight data files are placed in a certain computer directory that is specified in the R algorithms, all the data files in the working directory are read and afterwards the data can be saved and analyzed also with R, this was the main procedure until now. The next step is to generate automatic landing reports for atypical touchdown points, first using the RLR method to classify every touchdown point and then use the FMS data which has been proven more accurate to provide various information about the landing.

The R package used to establish the connection between R Studio and LaTeX is called brew, it is a templating framework for report generation according to its author Jeffrey Horner. For the full details about this package see [20].

Figure 15: Runway excursion risk diagram applied on a sample of 751 flights

The point in red shows the cloud centroid which is below every curve, this is a good indicator regarding runway excursion risks. However, there are some points which are above the RWY ICE curve, which is actually the most limitative and dangerous condition as shown by the maximum deceleration rates in both Table 2 and Figure 15.

As it is illustrated in the flowchart of Figure 16 the algorithm structure is simple, the CSV data files are analyzed by the R algorithm in a main loop where every loop increment corresponds to the analysis of one CSV file, the touchdown point is classified by the model created with the method described in section 4.4 (RLR method). The touchdown point is calculated with the FMS data after the trajectory being smoothed with the smoothing splines method, although the Gaussian smoothing method was also a possible option. The usage of the FMS as the chosen positional system to build the report is justified by the results obtained for the landing trajectories.

The algorithm (landing_report.R) loads the RLR model that was previously saved as an .RData file when built and calculates the smoothed landing trajectory, the touchdown point is evaluated with the smoothed trajectory correction. For a case of interest, where the touchdown point is considered atypical, an example is shown in Figure 17 where the tested touchdown point is highlighted in red.

Figure 16: R algorithm flowchart

Figure 17: Example of typical and atypical touchdown points
Figure 17: Touchdown point tested in the transformed referential

6. Conclusions

With this work, the need for trajectory smoothing techniques was clearly noted as these trajectory corrections will subsequently correct both threshold crossing points and touchdown points, the link between R algorithms and Google Earth was also an asset since it allows the observation of this flight data in a real environment. Regarding the Airborne Navigation System for the Airbus A320 family fleet, the FMS stands as the most trustworthy system to retrieve positional data from.

The importance of the air distance and the ground speed at touchdown are stated in a runway excursion assessment diagram, making these two parameters essential to monitor as long as landing safety is concerned.

As final notes, the ground station is of great importance on the airline company structure as it provides critical information for the operation of many other departments such as maintenance, safety or performance departments, increasing the overall efficiency of the company. The flight data obtained from the aircraft’s operation often needs treatments and corrections since several parameters are affected by inaccuracies from the respective sensors or systems which may be due to noise or other causes.

References


