# Instant flight data analysis

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**Abstract**

Flight Data Recorders are continuously being improved. Examples are the recording media, the number of parameters recorded (and their precision and frequency) and the ways for retrieving data. Starting from magnetic wire, metal-foil, magnetic tape, up to present solid-state memories, the ways for reading have also changed from heavy equipment to light portable computers, which can also connect to the Internet to exchange data worldwide. This trend is allowing investigators to analyze flight data right in the field, instead of taking data or even the recorders themselves to complex and time-demanding centers. Although a detailed analysis is still a crucial task, a "fast lane" may be useful when gathering field information before it vanishes. An animation done while the elements of an accident scene are still fresh may shed light to the items to be checked in a more detailed way.

One solution that has already been implemented uses an application that converts flight data into a language that can be interpreted by geographic navigation systems, like "Google Earth®".

This allows not only an animation to be generated faster and to be sent as a very small file using an open language standard, but also implementing features like representing critical parameters over aircraft trajectory (instead of using time-plots), ambient elements (sun, wind, visibility, waypoints, navigation charts, buildings, obstacles etc), the point of view of the crew or observers (to check depositions, for instance), and create projections from original parameters (like deceleration, friction, distance to stop, etc).

Besides this, a three-dimensional viewing where real ambient elements like sounds and other effects may be added are a kind of universal language for exchanging information within people in all involved levels, thus improving the quality of the final job.

Application developed and some real cases are going to be presented.

## Introduction

As per an international convention, accidents are investigated by the states with jurisdiction over the area where the event occurs. When invited by the investigative agencies, other representatives may help providing technical expertise, and the data from the recorders may be shared to a group, in order to speed up the analysis process.

In a team-investigated accident or incident, a group that includes representatives from certain parties is formed. As per NTSB Manuals, at a minimum, the group should consist of the group chairman, an FAA participant, and a representative from the airframe and powerplant manufacturers. In addition, it will normally be helpful to include a cockpit flight crewmember who is employed by the involved operator and who is rated in the accident aircraft type. The investigator in charge (IIC) and the accredited representatives should have timely access to information derived from the Cockpit Voice Recorder/Flight Data Recorder (CVR/FDR), which is appropriate to guide the on-scene investigative efforts. A person serving as a Safety Board headquarters coordinator of critical information from the laboratory to the on-scene command post should ensure timely communication of critical information to this team.

Flight Data Recorder (FDR) technologies also have changed and downloading data has becoming easier. Instead of depending on specific equipment, like ground stations or hand held units, a laptop may be able to acquire and decode it. Data recorded in other equipment, like Quick Access Recorders (QAR), can give additional information. In the majority of cases of accidents and incidents, due to their particular construction and installation, Flight Data Recorders and even QARs may remain promptly readable.

Graphs, usually with several parameters plotted against time, have always been widely used, especially for representing specific trends or the correlation among curves. Animating flight data has also proven to be a valid way to analyze data and to present it to a mixed audience, in order to reach the consensus stated in the previous paragraph. Environment information, like terrain, visibility, and positioning of references like waypoints, antennas, buildings, sun, wind, clouds, fog, other aircraft, etc, surely will help painting a more complete picture of the event. The scene can be enhanced with aerial pictures and charts, and information about the landing gears tracks onto the ground. Several non-visible elements like landing cover (coverage region for glide path and localizer deviation signals), marker beacon antenna beams, waypoints, approaching profiles, terrain awareness system limits, etc. would also be desirable. Additionally, instead of having parameters plotted against time, what about representing them in a three-dimensional and realistic space, along the flight (or ground) path? And what if all this information, shown in an animation from the point of view of the pilot or from somewhere outside the aircraft, including sound effects or even the audio from the CVR itself, is available in less than one hour after having access to the data from the recorders?

Maybe relevant evidences are still fresh enough, and maybe the decision on which part should be sent for a more detailed analysis is clearer... One may better choose the people for the interviews, and what to specifically ask to them. To deliver all these features, yet keeping hardware and software requirements to a minimum in order to allow the use of an ordinary portable computer, an application was developed by EMBRAER. This application generates an output file to be interpreted by a 3D geographic browser (like Google Earth, for instance), which is a widespread resource for 3-D processing over a realistic terrain representation.

## Rebuilding events

Information comes in several ways. Usually, having access to the flight data is necessary, but not always enough. Landing gear marks, pictures, surveillance cameras recordings, interviews and other resources shall be used, as in any investigative process. What an investigator needs for sure is a way to quickly integrate all this information. This is the main reason why this application was developed.

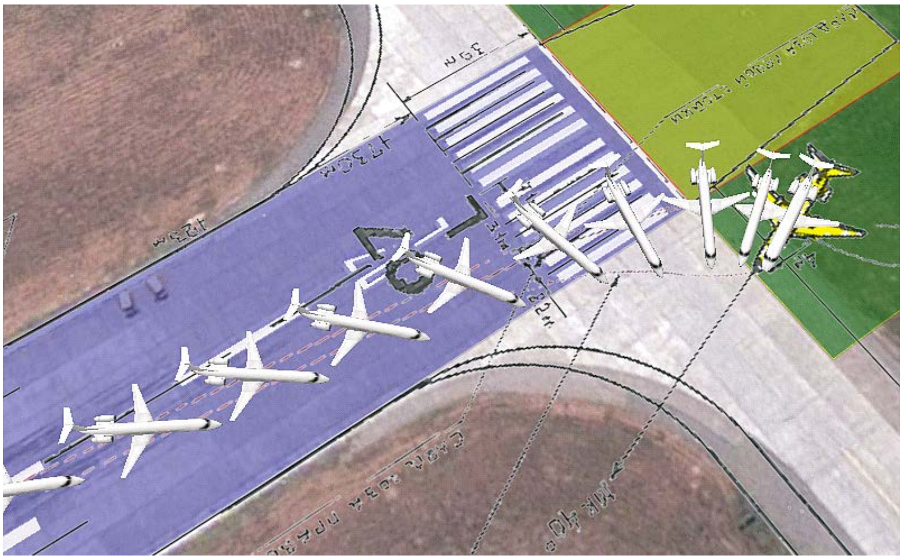

***Figure 1.*** *Runway overrun, shown "frame-by-frame". A sketch made by the operator with tire tracks was placed over the terrain to rebuild the aircraft path and specially its heading during the final portion.*

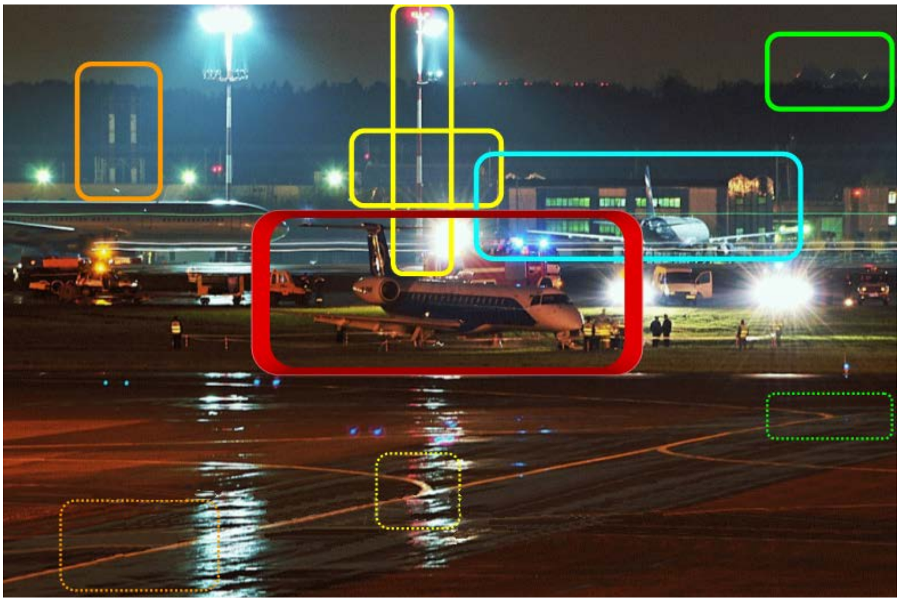

***Figure 2.*** *Runway overrun (veering to the right).The final position was projected from this single picture, using specific points for referencing, like ground markings, buildings and light poles.*

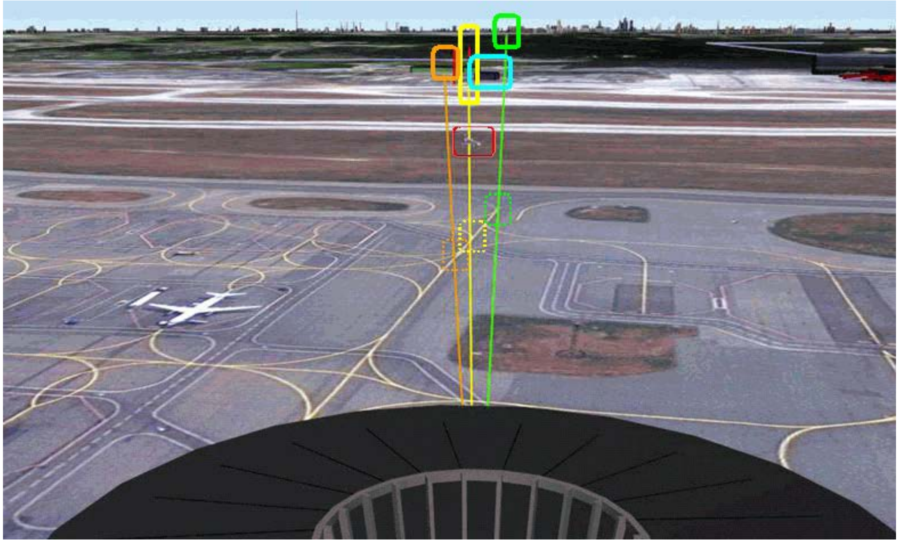

***Figure 3.*** *Visual alignment of the references seen in the previous picture, using a geographic browser, in order to find the relative positioning of the aircraft (found to be inside the "red box").*


***Figure 4.*** *Reconstruction of the above event. Final position was derived from that picture above, found to be taken from the point where the three lines converge to. A sketch made by the operator (even with parts not in scale) was superimposed to the terrain.*

Sometimes, environmental conditions may play a significant role. Sun incidence, wind speed and direction, horizontal visibility and other information need to be shown in a natural way.

For many items, it is possible to calculate or even to directly gather the information from the Internet, as in the case of METAR (METeorological Aerodrome Report), and generate a representation (see Figures 6 and 9). Other environmental conditions can be set using the facilities already provided in the geographic browser.

As updating is continuous, maybe an older event took place in conditions that are different today (mainly runway characteristics or some natural change on the environment). In this case, it is also possible to make use of historical images stored on the geographic browser server in order to match the event conditions.

Finally, after all data, animations and scene elements were loaded to the geographic browser, it may offer the possibility to save the entire set to a convenient compressed file, small enough to be quickly sent to anyone through electronic mail, and then viewed with all the functionalities of the original files kept. Some browser versions also offer the possibility of recording movies from the data, using standard video coding.

Several aircraft models and detailed help on browser language are already available on Internet.


***Figure 5.*** *Bounced landing. Dashboard at left shows the main parameters (live). Curves represent brake pressure (only plotted if "Weight On Wheels" reading is true). The sun position is emphasized.*

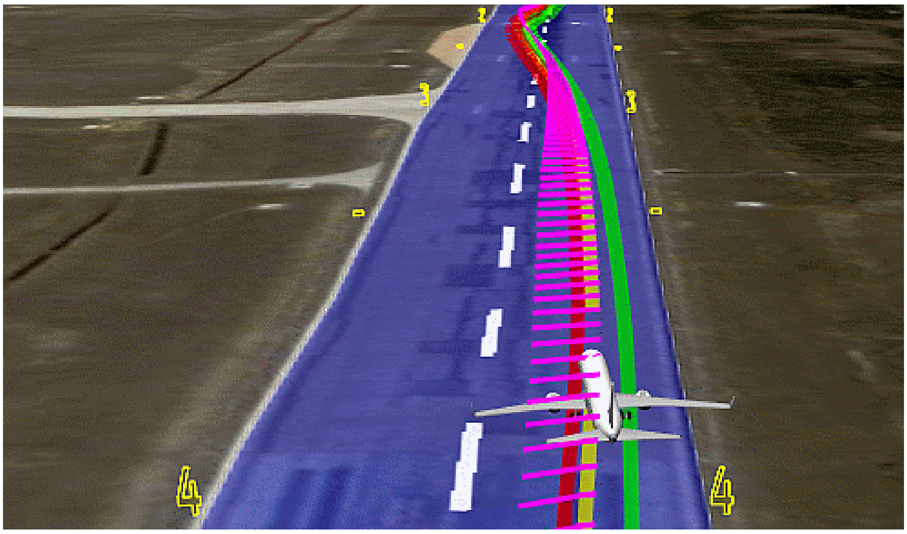

***Figure 6.*** *Crosswind landing, showing deviation from runway centerline. Wind is represented by magenta arrows coming from the left. Numbers in yellow stand for the remaining runway length (in 1000 ft).*

## Enhanced vision

Many of the information about the scenario which is crucial to an event analysis may not be visible, but can be represented in a proper way using a 3D geographic browser. This consists in a very convenient way, as lines, radiation patterns, surfaces and volumes are generally well defined in terms of geometry. Drawing them as the scene of an event is a matter of changing coordinates and scaling.

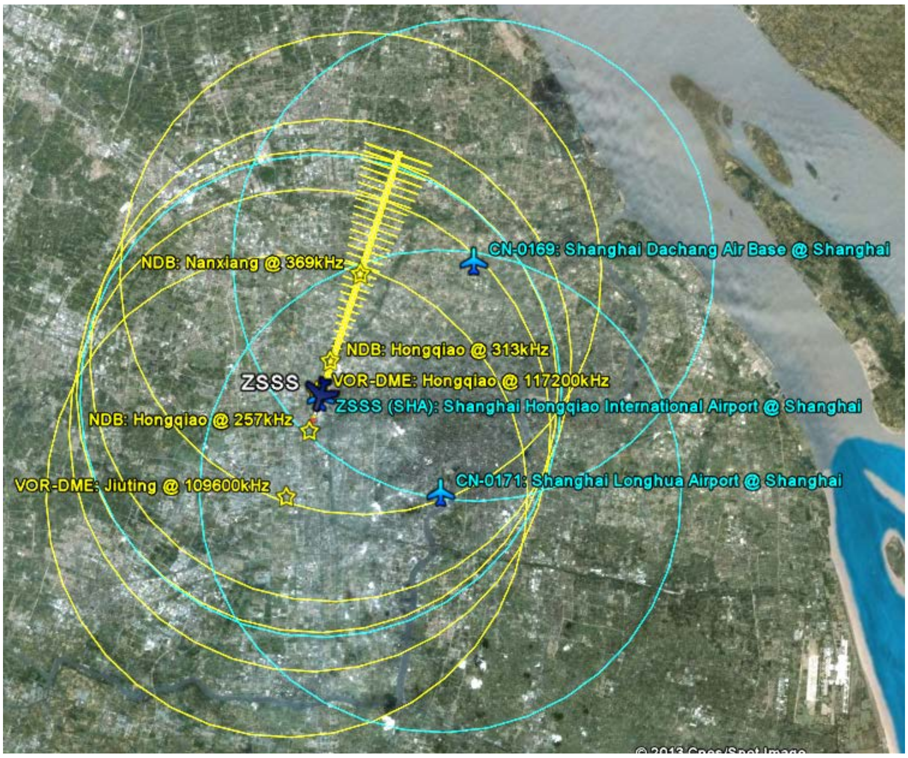


***Figure 7.*** *Airports found in the neighborhood of the event (in cyan), together with the navaids (in yellow). A database is used for searching over tenths of thousands entries for those which are in the vicinity of the path.*


***Figure 8.*** *Simultaneous animation allows studying events involving more than one aircraft, as well as comparing two distinct landings of the same aircraft at the same airport, for instance. A runway may be drawn to improve visualization (especially interesting when a poor image is available from the geographic browser).*

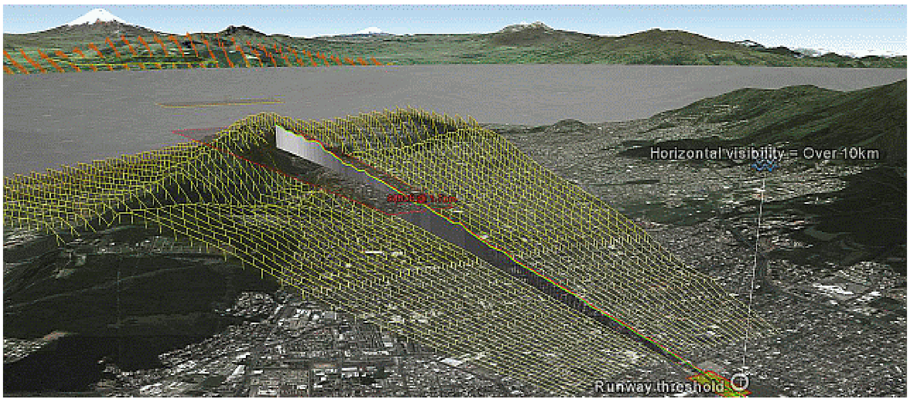


***Figure 9.*** *Landing in a runway with surrounding mountains. The yellowish mesh denotes a sector of the EGPWS (Enhanced Ground Proximity Warning System) limits, and the transparent red surfaces denote instrument approach chart references. The gray wall between near and far mountains is placed at the horizontal visibility limit got from METAR.*

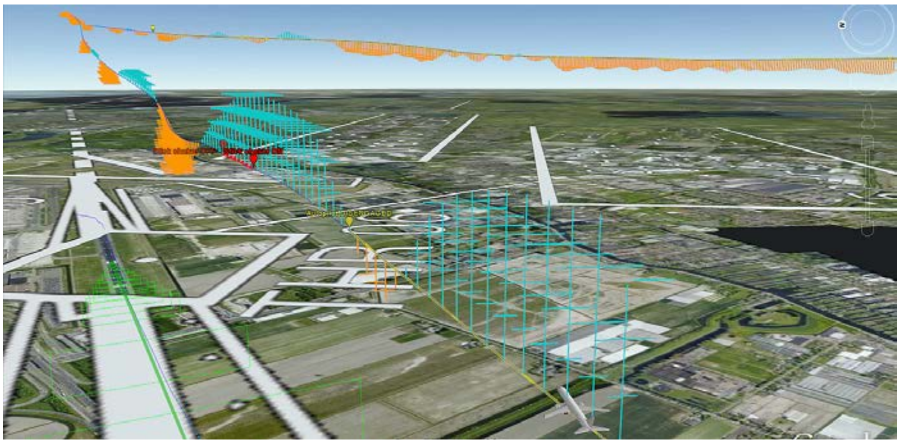

***Figure 10.*** *Approach (missed) done very over the landing cover (in green, it the lower left corner). The vertical plots over the yellow path line represent the glide deviation (up, in cyan; down, in orange), with false readings (multipath) due to this irregular flight profile. The small path region in red stands for a stick shaker actuation. The approaching chart (in white) was placed over the terrain.*

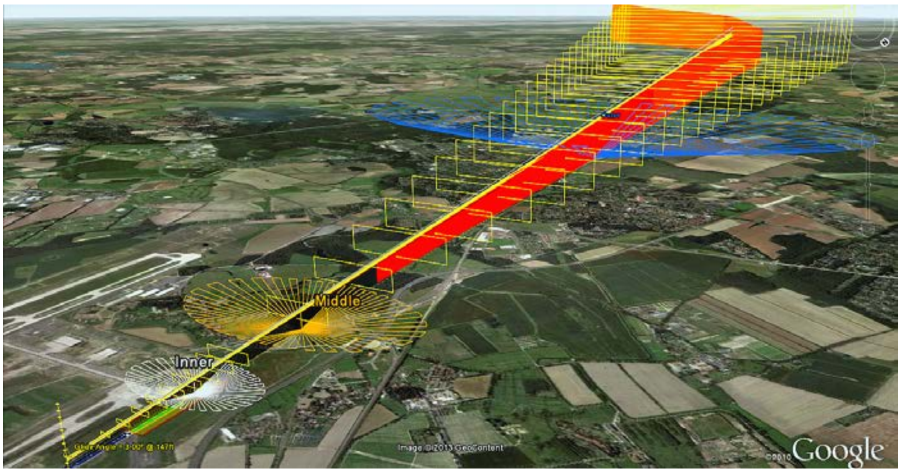


***Figure 11.*** *Landing, showing marker antennas beam (white for Inner, amber for Middle and blue for Outer). Landing cover is in yellow, with a central thick line for Glide Path (@3.0º). In this case, the flight path is reddish, when Pressure Altitude is used as reference and black, when Radar Altimeter is the source.*

**Witness’ eyes**

Recalling information from witnesses may be hard, if the confirmation about the facts is restricted to words. By giving them a replay, information can be confirmed or even searched deeper. Crew or other observers can then check their depositions and add valuable information, while facts in their memory are still fresh.

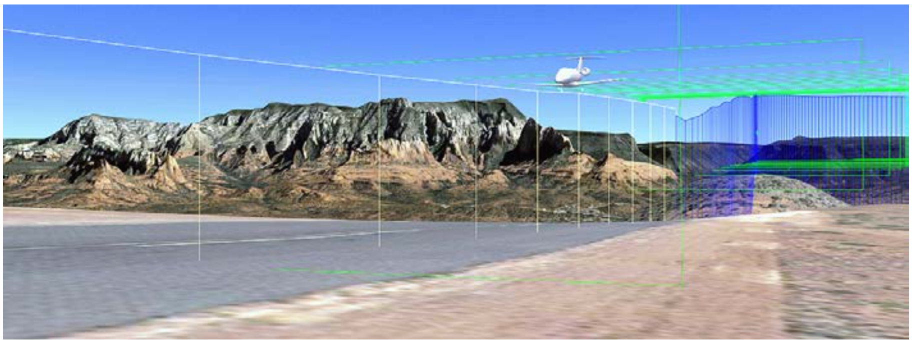

***Figure 12.*** *Landing, as seen from someone on the ground.*

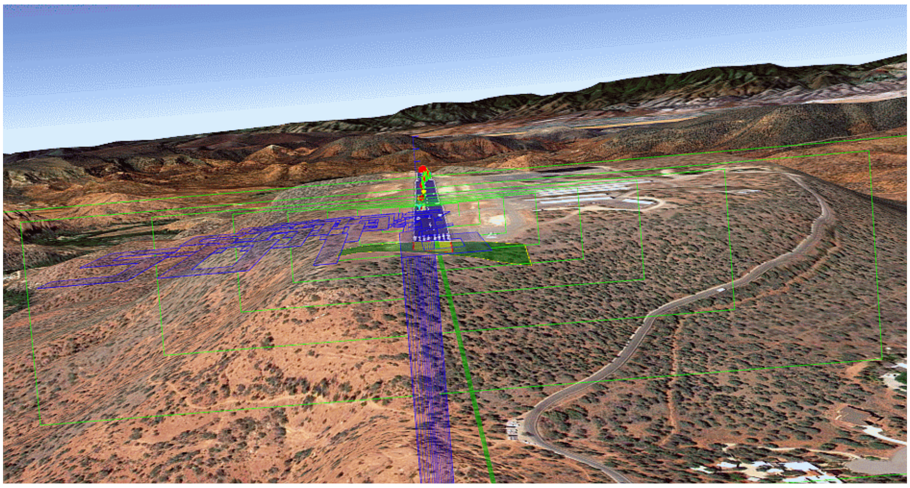

***Figure 13.*** *Same event, as from the pilot’s perspective.*


***Figure 14.*** *Event can be reviewed by the crew in a way they are familiar with. In this case, an animation of the HUD (Head-Up Display) running together with the "dashboard".*

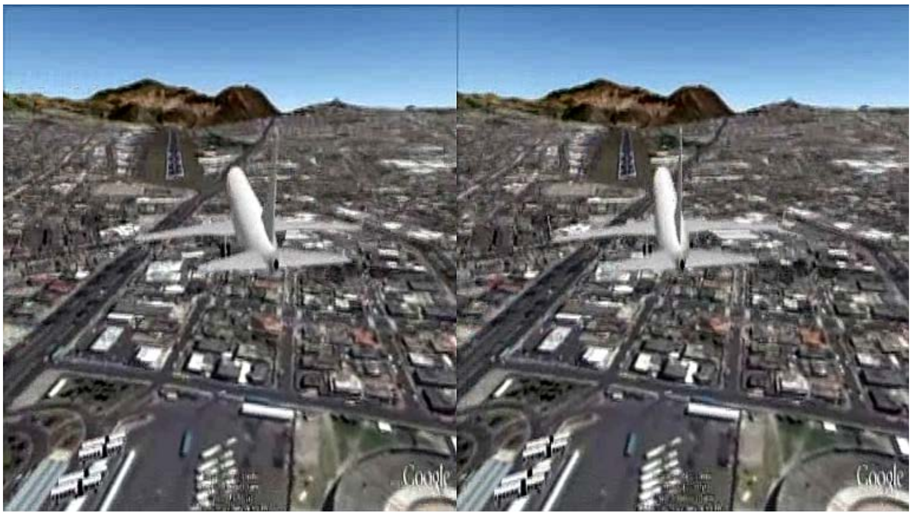

***Figure 15.*** *One special function in the application allows generating three-dimensional movies at one click, by producing two animations with symmetric camera displacing. They can be combined using any suitable video editor (in the above case, coded in the "side-by-side" format). Even ordinary movies can be viewed in television sets with built-in 3-D effect, thus enhancing the visual experience.*

## Beyond the readings

Several analyses depend on very specific calculations, which demand time and are usually done some days after the data is collected. Nevertheless, after the method is established, performing the calculations is a matter of processing data, which is a fast task for a computer. By using some special algorithms already embedded, the result can be viewed together with the original data.

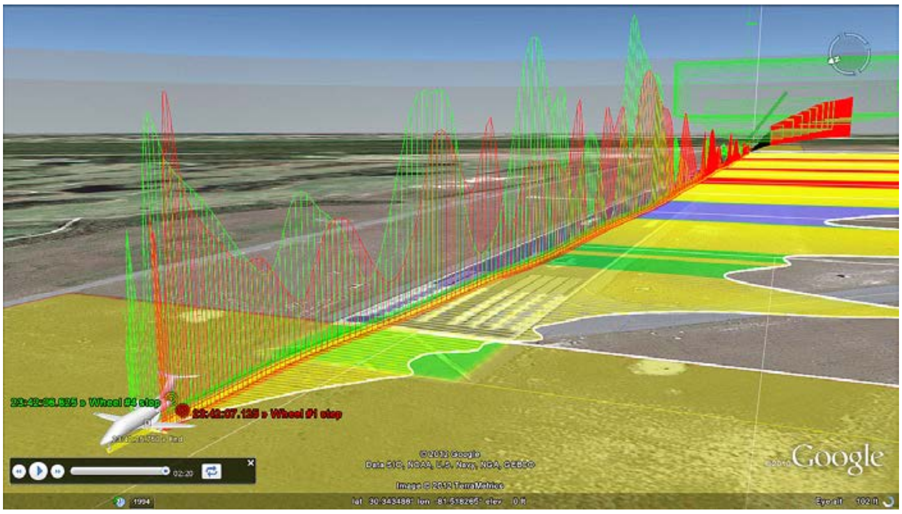

***Figure 16.*** *Runway overrun, showing vertical graphs for brake pressure, and a graph clamped to ground with a prediction of the total distance to stop at each aircraft position (where blue region means that prediction is "inside runway", green is "within stopway", yellow is "within clearway" and red is "beyond clearway").*

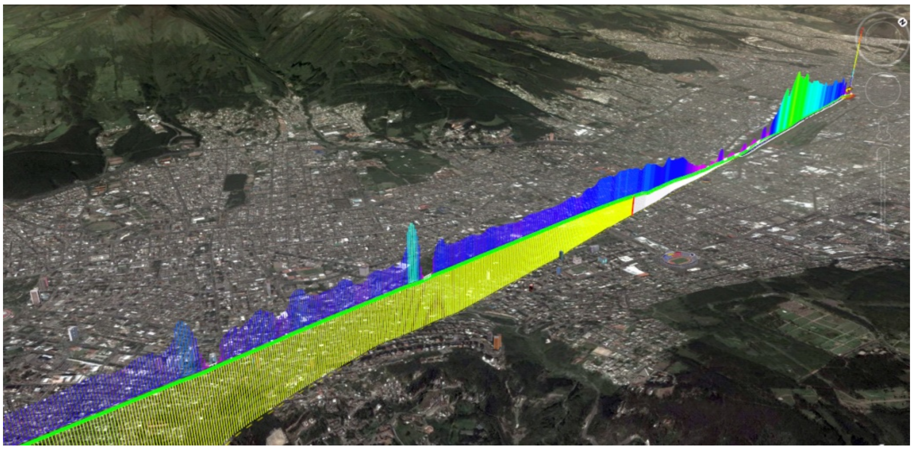

***Figure 17.*** *In this accident during landing, the flight path is represented by the yellow (Pressure Altitude) and white (Radar Altimeter) portions of the curve. Above it, a bluish (in fact, a "rainbow" curve) denotes aircraft total energy variation, even in air or on ground. This very irregular energy variation profile denotes an unstable approach and braking.*

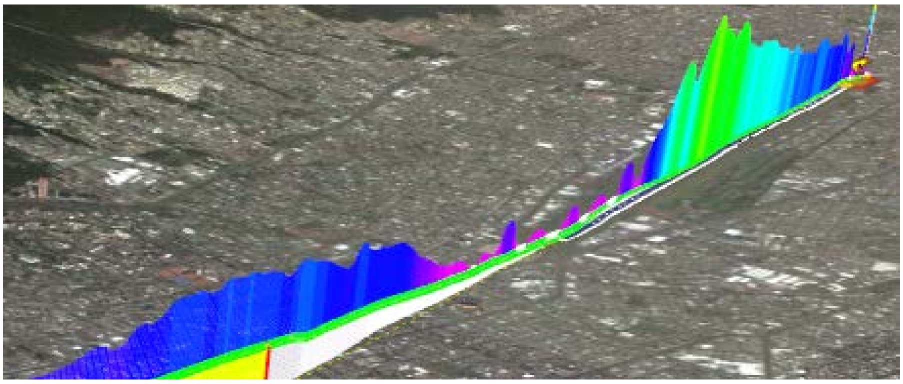

***Figure 18.*** *Detail of the last figure (landing), evidencing a very irregular energy variation profile, especially just before touching down.*

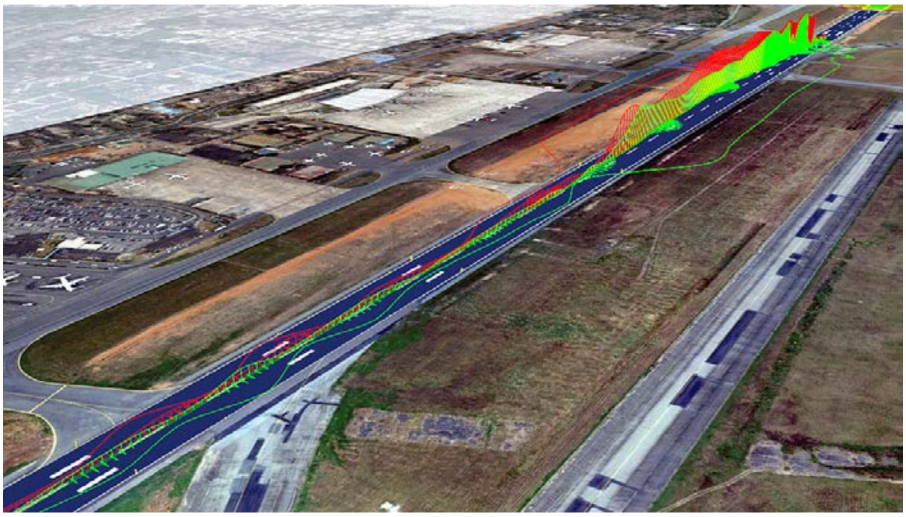

***Figure 19.*** *Aborted takeoff. Rudder corrections (intended) and brake action (unintended – brake pressure shown as vertical red/green plots) were applied simultaneously. After a large heading variation (shown as horizontal red/green plots), both brake pedals were fully pressed (red/green lines clamped to ground correspond to left/right brake pedal position).*

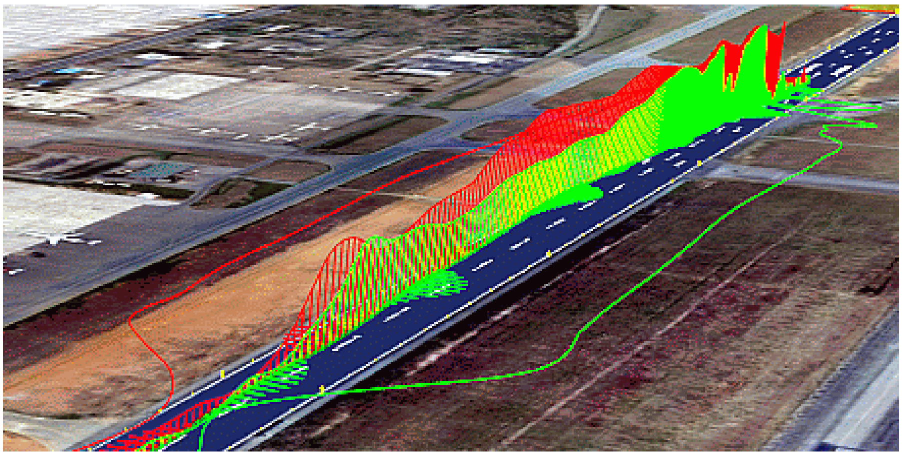

***Figure 20.*** *Zooming on the final section of the last picture.*

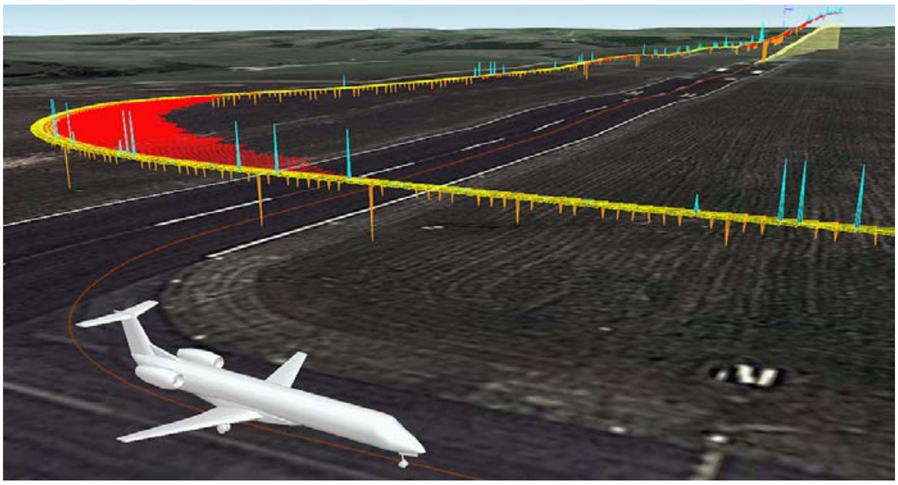

***Figure 21.*** *Acceleration profile during landing. Vertical readings are shown in cyan (up) / orange (down), left (red), right (green), backward (yellow).*

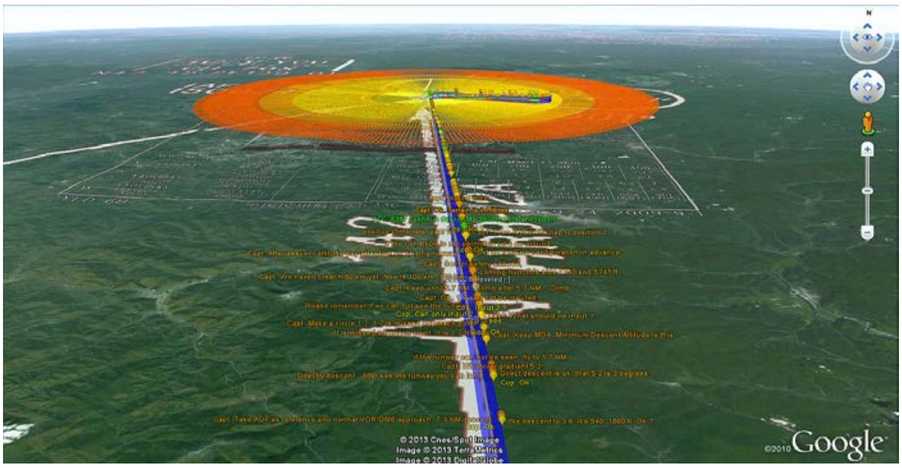

***Figure 22.*** *Sometimes, a spatial representation is the only way to gather all relevant information to explain one event. In the above screenshot, it is possible to see the charts superimposed to the terrain, the EGPWS profile (yellow/orange circular region) and the CVR transcript in several balloons along the flight path. A document with this high information density can be sent in a compressed file and then viewed in proper angles and zoom magnification to allow full comprehension of every detail.*

Some parameters are recorded, others are not. Some of them may even have been corrupted or degraded. Rebuilding events needs a main set of specific parameters in a good shape. The algorithms already implemented in the application include:

- Latitude & Longitude, from Ground Speed and Heading, forward or backward;
- Magnetic declination along flight path (as per NOAA website);
- Vertical speed, Radar altimeter, Gross weight, Outside temperature, Mach number;
- Total Energy (and Energy variation), predicted touching and stopping position etc.

In order to fill the spaces between successive readings, an interpolation is available according to each parameter nature. Some examples are given below:

- COPY: navigation frequencies (well-defined positions, with no intermediary values);
- LINEAR: gross weight (and other time-dependent readings);
- SMOOTH: pilot commands, surfaces positions (continuous, with well-defined steps)
- SPLINE: Latitude, longitude, accelerations, air data (general continuous data).

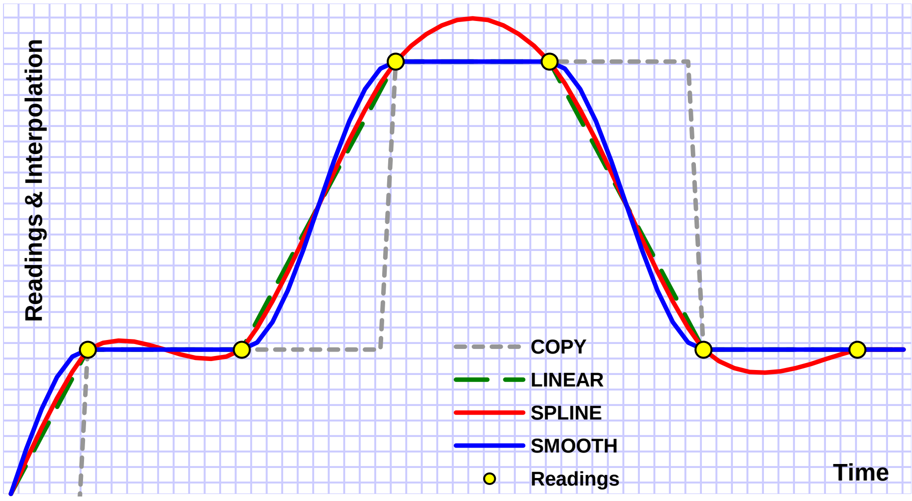


***Figure 23.*** *Different interpolation methods, chosen as per parameter nature. Variable digital filtering is also available, together with scale adjustment and spike detection for each parameter.*

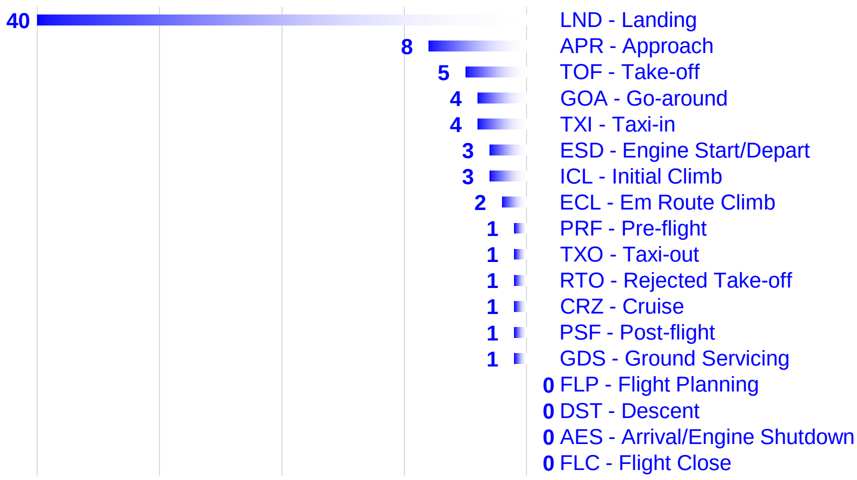


***Figure 24.*** *Accidents per phase of flight in 2012 (as per IATA). The vast majority of accidents happened inside or in the vicinity of airports. That is why many of the features developed for the application focus on the elements surrounding the aerodrome area.*

## Conclusion

This paper presented an application developed by EMBRAER to provide a fast yet very comprehensive visualization of the flight data retrieved from on-board recorders. The uses include, besides the analysis related to an investigation, the video production for training, debriefing or other educational purposes, the development and simulation of warning algorithms using real event data, etc.

Although incidents and accidents are always undesirable, if they happen there must be a commitment to unveil all contributing factors in order to avoid recurrence. Time is critical when dealing with any safety event. Not only because usually there is a need to clear the area and/or the equipment, but mainly because evidences may vanish or remain undiscovered if a quick yet comprehensive analysis is not performed. This includes not only the witnesses' memory and ability to tell the story, but also the clues degradation under the environmental conditions of the event site and the care taken during parts removal.

Most of the features in the application were developed to fulfill the requirements established for real cases, following well known investigation techniques and also making use of new ones. EMBRAER is committed to assist the investigation authorities on investigating every relevant occurrence, using this or any other suitable tool, together with its technicians' expertise, as a permanent effort to work in all layers of the air safety.

## Acknowledgments

The author wishes to thank ISASI for the opportunity to share this information to the investigators community, hoping that it will be helpful for increasing aviation safety levels. Thanks also to all colleagues who have collaborated, using it to analyze data and sending valuable opinions for continuous improvement, and especially to Mr. Umberto Irgang, Embraer Air Safety Manager, for the encouragement and for providing the necessary resources for developing this tool.

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