On the use of Flight Operating Procedures for the Analysis of FOQA data

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Abstract

The paper proposes an adaptation of the process used to analyze flight parameters recorded during routine operations. The main contribution is to introduce a model of the crew activity (flight profiles) that allows both the identification of how the standard operation procedures are used during flights, and the definition of new events closely related to the crew activity. It is an important step towards a better introduction of leading indicators in safety management systems.

1. Introduction

Worldwide, aviation is growing in a more and more complex environment and safety remains a significant challenge both for regulators and air operators. The management of safety is evolving while international organizations (such as the International Civil Aviation Organization) and national authorities urge the aviation community to adopt a more structured and proactive management of safety. These changes are captured by the growing influence of Safety Management Systems (SMS) that identify a standardized, data driven system of hazards identifiers, risk assessment, and risk mitigation that enable highly complex systems to run [1]. The implementation of a SMS becomes often mandatory and the core components of SMS –pro-active risk assessment, risk mitigation, data acquisition, and constant revisiting of safety goals and realizations [2, Section 3] are better defined.

SMS are based on the fact that there will always be hazards and risks, so proactive management is needed to identify and control these threats to safety before they lead to mishaps [3]. Proper risk assessment is the key to a successful SMS program and is understood to consist of two necessary components: severity and likelihood. But assessing the severity and likelihood of events is a tough task which often relies on qualitative analyses, highly dependent on the opinion and foresight of individuals within an organization [1].

One main way allowing the improvement of this risk assessment, relies on the ability to obtain a reliable view of the life-threatening situations and risks encountered in flight. The digital flight data available on all modern aircraft represents a major source of information to acquire such an understanding of what happens during routine operations. For that matter, ICAO includes in their definitions of SMS [2, Section 3.3.6] the need for flight data analysis and accumulation of that data. Nevertheless, there is no instruction defining how the analysis has to be performed.

Many of the major airlines set up highly sophisticated data collection programs (called FOQA or FDM program) dedicated to the systematic download and analysis of these data recorded during flights and feed huge databases. These databases should permit identification of situations in the course of routine or irregular operations that present an unacceptable risk of accident, injury or damage and the implementation of corrective actions that eliminate this risk or reduce it to acceptable levels. But the analysis tools used on these data are too modest and a breakthrough is required to challenge a real proactive safety management based on the identification of new threats. So, the development of new data analysis methodologies is a key element required to go one step beyond in the management of safety.

In this paper, we present principles of the flight data analysis processes implemented in major commercial flight data analysis software, and underline their strengths and weaknesses. Then, we describe how new safety performance indicators could be defined, based on an adaptation of this analysis process. The main idea promoted in this article is that the flight operating procedures can be better used to shape the analysis process. Finally, we apply the target methodology on a set of flights and demonstrate the feasibility of this new approach.

2. The flight data analysis process implemented in commercial software

Major commercial airlines routinely download the digital flight data recorded during flights and analyse them to manage safety. They have to cope with a large number of flights, often millions of flights per year, and the global process has to be highly automated. Worldwide, the most widely used FDM tools [4] (Teledyne AirFASE, Spirent GRAF and, Sagem AGS) primary rely on the identification of prescribed exceedances that characterize events that fall outside operator-determined standards. This section will produce an overview of the process used by all these software. The use of a FDM tool in an airline's safety department can be roughly described as a four steps process as depicted by the figure 1.

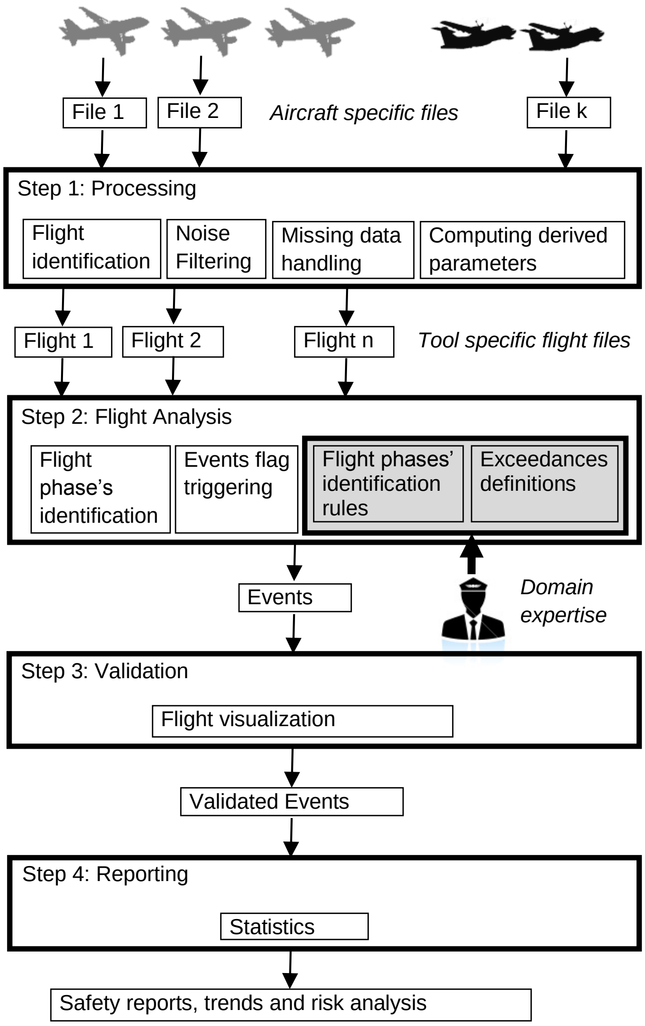

Figure 1: The four steps exceedance-based analysis process

Let us now look at these four steps and point out the key mechanism used to define the safety events.

2.1. Step 1: Processing

The data files downloaded from the aircraft are processed in order to identify the various flights they contain. The data are filtered, converted in engineering units and some derived parameters can also be calculated (by combination of recorded parameters). It allows the identification and the removal of bad data.

2.2. Step 2: Flight Analysis

Each flight is then analysed in order to trigger events that fall outside operator‑determined standards. The accurate definition of these deviations from normal operations is a key element for a comprehensive flight data analysis [5].

This step is realised in two stages. First, the flight is decomposed in flight phases, for example from taxi-out to taxi-in. The number of possible flight phases and their starting conditions varies with the software, but are usually based on combination of thresholds for some parameters.

As an example, in one tool, the Approach phase starts when:

1. The aircraft has been, at least for 10 seconds, below 4000Ft above ground level with a rate of descent over 420Ft/mn and one engine below 90% N2.
2. When this first condition has been fulfilled, the Approach phase is validated if the aircraft is between 3000Ft and 1000Ft AGL for at least 10s.

The set of rules defining all the possible flight phases are set by experts and is embedded in the tool. After this first stage, the flight is split up in successive flight phases (Figure 2).

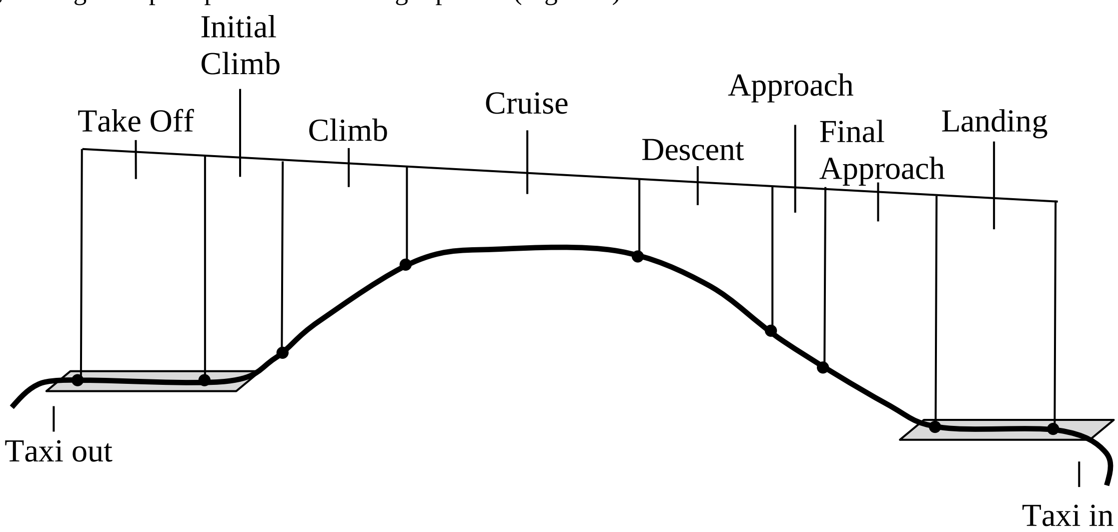

Figure 2: Example of flight phases

The second stage is the triggering of the events. It relies on the definition of prescribed exceedances which capture deviations from normal operations that the safety department wants to identify and to use as safety performance indicators. These unwanted situations are characterized by small sets of parameters that exceed some predefined thresholds. Both the choice of parameters and thresholds rely on human expertise.

For example the triggering of "Heading deviation at take-off" events could be defined as follow:

(1) the flight phase is Take-OFF
(2) the Ground Speed of the aircraft is over 100Kt and the Pitch is under 1°
(3) the reference heading (HeadingRef) is the heading of the aircraft when it just go over 100Kt during the Take-Off flight phase
(4) the current heading deviation (Dev) is calculated as the absolute value of the difference between the current heading of the aircraft and the heading Reference
Dev(t) = ABS(Heading(t) – HeadingRef)
(5) an event of high severity is triggered if the current heading deviation is over 4° during 3s
else an event of medium severity is triggered if the current heading deviation is over 3° during 3s
else an event of low severity is triggered if the current heading deviation is over 2.5° during 2s

Rules (1) and (2) define the temporal window in which the exceedance will be searched for. Rules (3) and (4) set how is calculated the parameter which has to be compared to prescribed thresholds. Finally rule (5) describes the conditions required to trigger the events with an associated severity level.

The definition of all these rules is a complex task that requires lot of expertise. These sets of rules are usually built in the airline and completed when new issues are discovered [6].

2.3. Step 3: Validation

For each flight, high severity events (if any) are validated by a safety officer. Commercial FDM software usually provides a visualization tool which allows the representation of the aircraft situation at the time of the event. Two main outputs are expected from this validation: (1) a short reaction time to severe events while the safety officer will be able to trigger warning signals in the airline and (2) a more reliable high severity event database as the safety officer can reject bad events (bad data for example). The safety officer can usually contact the aircrew to have more information if required.

2.4. Step 4: Reporting

Reports are then produced (monthly, weekly…) and report the occurrences of each event. Sophisticated statistics and graphs can usually be built by the FDM software.

2.5. Strengths and weaknesses of the approach

While outputs used to support safety management are the statistics on safety indicators (safety events), the crucial point of the methodology is the second step. Relevance of the safety indicators is highly dependent on the type of events produced and their accuracy. Also, such a methodology is well fitted to manage known safety issues that can be clearly specified thanks to operational deviations. Significant safety improvements have been done by airlines that routinely use these tools on all their flight data. The strength of this approach consists in the reliability of the search of these prescribed events on all the available flights. So an objective view of how flights complies with these specific deviations can be set up. Such tools are a major piece in a Safety Management System because it allows an objective valuation of the severity and the likelihood of safety events (such as un-stabilized approaches). These tools are used to implement indicators for low level system failure (by opposition to system failure in the organisation or the training which is considered to a higher level and less directly measurable) and safety events. These safety events are primarily used to monitor specific safety issues and measure the effectiveness of safety controls or barriers put in place to mitigate the risks associated with these hazards.

The obvious lack of this analysis methodology is that it is limited to the search of known safety events and will not help to discover new emerging risks. So there is a flagrant need of complementing methodologies, especially to develop new leading indicators that should measure both: things that have the potential to become or contribute to a negative outcome in the future and things that contribute to safety [7]. Such leading indicators should help anticipating emerging weaknesses and vulnerabilities. It is an important element to keep the safety management in a more dynamic process allowing a quick adaptation required by the evolution of the complex and growing aeronautical environment.

ONERA – NASA collaborative works explore how different flight data analysis methodologies and algorithms could fill the gap. One approach is based on the use of data mining tools that allows the definition of a new knowledge discovery process [8], while the other one described in this paper relies on a better use of the prescribed crew activity.

3. Towards an improved flight analysis process

3.1. On the use of the flight operating procedures

The challenge that faces organizations is in being able to anticipate vulnerabilities rather than to merely react to them when they occur [9]. The aim is to control the system in such a manner that it remains within the boundaries of its envelope of safe performances. So, safety management is now understood as something more than the absence of risk and the indicators should also be able to focus on the positive side of safety [10].They have to indicate how the system functions normally.

In the aeronautical world, practical information on how to operate an aircraft is described in many documents, including the airline training policy, the flight crew training manual and, the flight crew operating manual. Moreover dedicated procedures are published for airports and controlled airspaces, such as the Standard Terminal Arrival Routes, or approach and departure procedures for each runway. All these documents are used by the crew and shape their activity. Nevertheless, even in a so normalized professional world, operators have some freedom to adapt their activity to environmental constraints (traffic, weather, ATC clearances…) or to modify their way of doing depending on their abilities, training needs or personal preferences (level of automation…). While some of the choices are clearly dictated by the air traffic controller, other ones depend on the crew. The flight data analysis process described in section 2 relies on these data but only to underline some discrepancies, the negative side of safety. They are not used to explore the choices made by the crew, their links with specific operational conditions nor to highlight how operations comply with the expected behavior of the system. We claim that a more significant use of these data could help to manage safety.

Let us take the example of a landing at Milan airport on runway 35L. Figure 3 displays the procedure for a precision approach with the Instrument Landing System (ILS). The higher part of the chart states the lateral manoeuvers, with associated constraints, that the crew has to do to align the aircraft on the runway and follow the runway heading. The lower part specifies the vertical manoeuvers that allow intercepting and following the descent path.

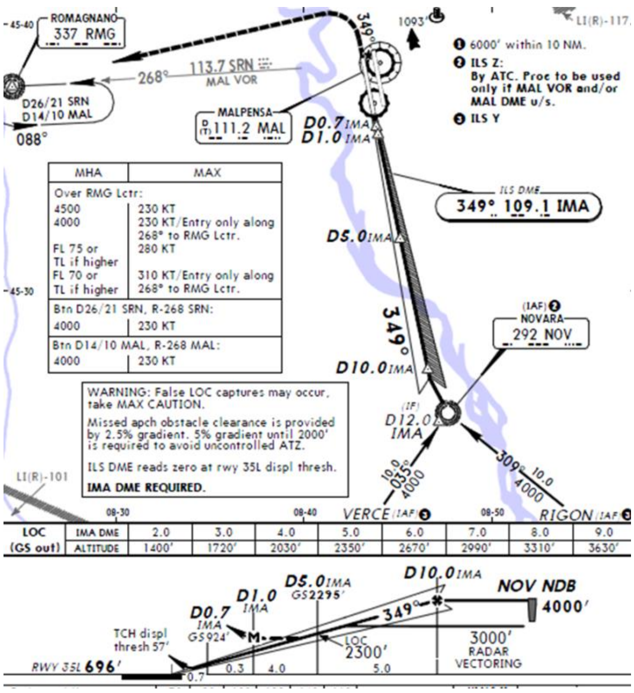

Figure 3: Example of an ILS procedure

This procedure is only one of all the possible landing procedures. The crew can also use other types of approaches, such as a VOR non-precision approach, or a visual approach. Each procedure, associated with the flight crew operating manual, defines sequences of subtasks that have to be made for a safe landing. Identifying which procedures are used and how they are implemented by the crew would be a step towards a better understanding of how the system functions normally.

The hypothesis underling this work is that the information contained in available procedures and operating manuals could be used to better:

1. Analyze and qualify the flight execution,
2. Understand relations between contextual factors and crew activity and,
3. Highlight meaningful links between crew activity and safety elements.

3.2. An adapted flight analysis process

We propose to modify the four steps exceedance-based analysis process described in section 2 (Figure 1) so as to introduce a step for the identification of the flight profile. This step takes the place of the "Flight Phases' identification" stage and significantly modifies its scope: from an identification of temporal windows within which the exceedance will be searched for, we now define a more complex process allowing the identification of hierarchized activity elements related to the practice of flight operating procedure in a specific context (Figure 4). This new step will be described in section 3.3.

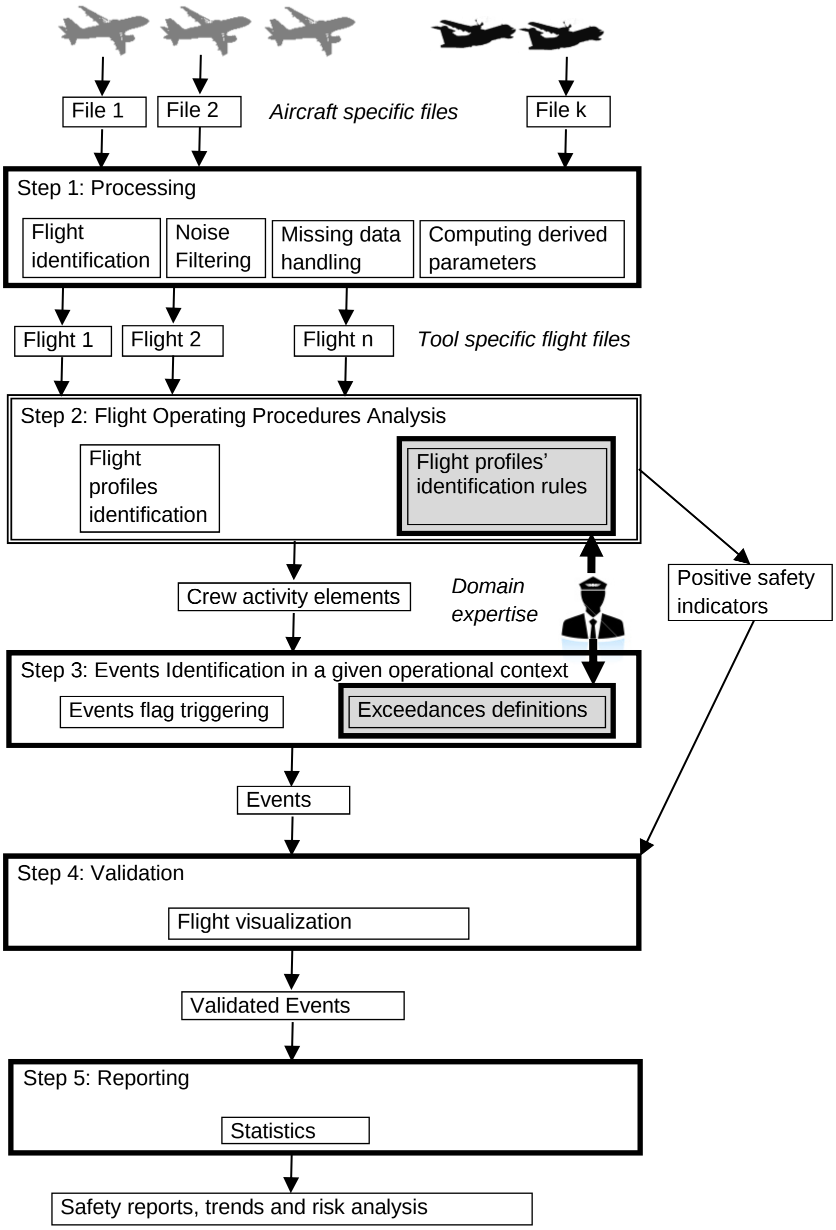

Figure 4: The "Flight Operating Procedures Analysis" step in the global process

This modification of the analysis process will allow the identification temporal windows coherent with the crew activity. As an example, on Figure 3, the procedure shows that the crew has to: (1) align the aircraft to the runway heading with an altitude of 4000Ft, (2) follow the runway heading at 4000Ft and intercept the descent path and, (3) follow both the runway heading and the descent path. The use of this new analysis process is dedicated to find such activity elements in the analysed flights and to characterize their operational context: an automated ILS procedure, a visual approach… It paves the way for the definition of more specific exceedances, related to an operational context (step 3), but also for the definition of positive safety indicators related for example to which flight operating procedures are really used.

3.3. Flight Operating Procedures analysis

The use of elements described in SOPs or in training manuals to identify coherent flight portions requires first to represent them in an adequate model. Also, our methodology relies on a language dedicated to model the crew activity. The approach adopted to represent these activities is inspired by the script definition given by Schank and Abelson [11]: “A script, as we use it, is a structure that describes an appropriate sequence of events in a particular context… For our purpose, a script is a predetermined, stereotyped sequence of actions that define a well-known situation”. The resulting language, called LDA (a French acronym standing for Activity Description Language), has been shortly presented in [12] and more completely specified in [13].

Roughly, the LDA is based on a hierarchical representation of the activity. The higher level is called a “Phase” and is used to model a significant part of the flight, as for example the descent or the final approach. It can normally be associated with a crew high level objective. Often, there are several possibilities allowing completing this task. In other words, there are several stereotyped sequences of events usable to fulfil the goal. Each of them will be captured by a “Profile”. So a profile is a specific sequence of actions that can be used to reach the phase’s objectives.
Each profile contains a sequence of events (or actions) representing this particular “way of doing” that can be used. These events that compose the profile are called ‘Schemas’. For example, one profile representing the Final Approach phase may contain the three following schemas: “Align the runway”, “Final descent”, and “Flare” that represent the three mains goals for the crew during this flight phase. Then, each “Schema” can contain more elementary actions, called “Modules” that represent how the “Schema” is implemented by the crew. Modules are the lowest level of actions taken into account by the LDA language and should represent elementary activities which make sense for the task captured by the Schema. For example, inside an ILS final approach, the schema “Align the runway” could contain at least three modules: “Follow a converging segment”, “Capture the Localizer” and, “Capture the Glide Slope”.

It can be noted that the first two activity elements used in the section 3.2 (align the aircraft to the runway heading with an altitude of 4000Ft and, follow the runway heading at 4000Ft and intercept the descent path) could be associated with Modules of the Schema “Align the Runway” while the third one (follow both the runway heading and the descent path) has been captured by the Schema “Final descent”. Building such a representation of the target activity is a complex task which requires a good understanding of the crew activity.

Temporal constraints can also be associated with modules and schemas, allowing the specification of events’ sequences. Figure 5 shows a hypothetical flight phase X for which two ways of doing have been described. Profil 1 displays the first one for which three sequential schemas are expected. While the first schema (1.1) contains two Modules that can be made in parallel, the second schema is directly considered as an elementary action and so has no decomposition in modules. In the second profile, which describes the other way of doing, the second schema (2.2) can start before the end of the first one.

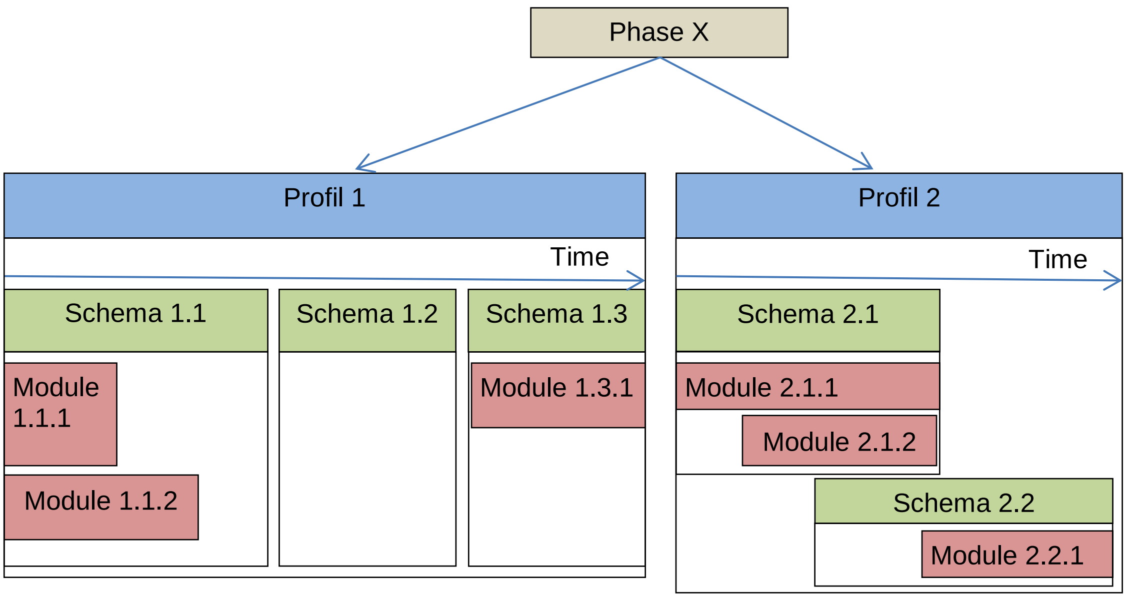

Figure 4: Example of crew activity representation with the LDA

The next step is to be able to identify which profile has been used in a given flight through the analysis of the time evolution of the flight parameters. As the flight profile is mainly characterized by its composing schemas and modules, the first stage is to be able to identify these sub-elements. The approach adopted relies firstly on rules defining specific points (key points) in the flights (such as the touch down) from the flight parameters evolution and then on rules defining modules, schemas and profiles from the identified points.

4. Application to the study of final approaches

This new flight data analysis methodology, based on the identification of flight profiles, has been applied to a set of 2241 flights, from a single type of aircraft, landing at a particular airport. This airport has two parallel runways, with three possible ILS approaches.

4.1. Definition of the flight profiles

Based on prescribed ILS landing procedures, the typical sequence of activities kept for this study is:

- Maneuvers to align the runway and put the aircraft on the descent path
  - Turn to have a converging segment to intercept the localizer
  - Maintain a flight level to intercept the glide slope
  - Capture the localizer
  - Capture the glide slope
- Follow the descent path
- Flare

Nevertheless, this sequence of action can be done with or without the use of automated modes of the auto pilot. Four level of automation have been identified:

1. Level 1: Manual (no automation). The aircraft system is not configured to catch the ILS signal (ILS OFF).
2. Level 2: Guidance. The aircraft system is configured to catch the ILS signal (ILS ON), but the auto pilot is not set up to capture and follow the ILS slope. So the crew has indication of the ILS slopes positions in the flight director but has to fly the aircraft to follow them (manually or with other auto pilot modes).
3. Level 3: Partial automation. The aircraft system is configured to catch the ILS signal (ILS ON), and the auto pilot is set up to capture and follow the ILS slope. The crew primarily monitors the system for the capture of the ILS and the final descent. But the end of the final descent and the flare are flown manually.
4. Level 4: Full automation (autoland). The crew only monitors the system, from the beginning of the final descent up to the touchdown.

A flight profile has been defined for each level of automation. At a high level of description, only small differences distinguish each profile, as shown on figure 5 (or even none, as for the first two profiles). But the accurate definition of each module and schema allows the distinction between the four profiles. Moreover, other modules or schemas are also searched for, even if they are not supposed to belong to the standard activity. In this study we define an "overshoot" module dedicated to capture maneuver to correct the localizer capture and an "In Close Approach Change (ICAC)" schema for the identification of late runway change as the airport has two parallel runways.

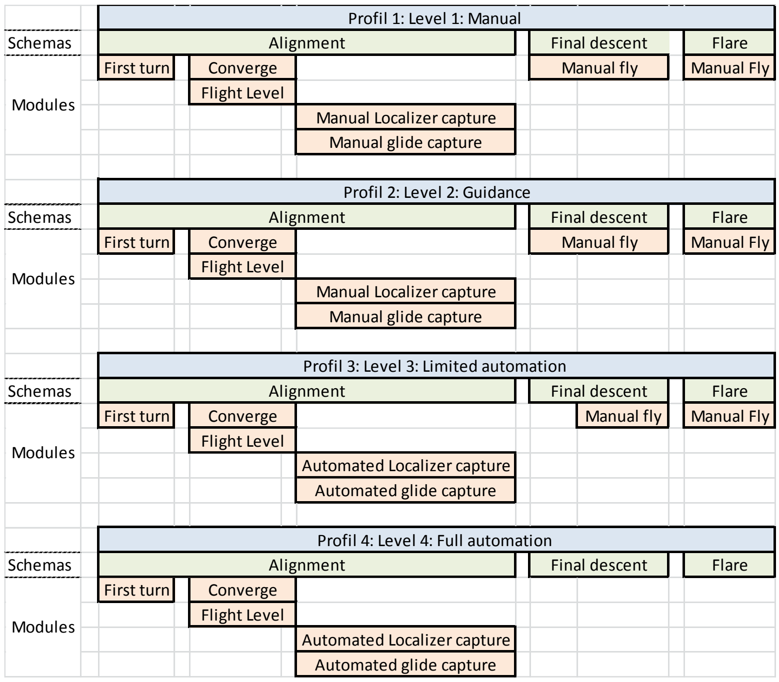

Figure 5: High level description of the 4 flight profiles

Then, the four profiles have been implemented in the ONERA’s flight analyses software and the 2241 flights processed. Some results are produced in the next section.

4.2. Main results

This new analysis methodology allows the identification of the level of automation used for each flight. In this study, a large majority of flights are done with a high level of automation (86% with level 3). This result is consistent with the airline policy that recommends the use of automated modes for landing (often until the decision height) on major airports. This result can support new positive safety indicators linked with the global application of the airline policy, or indicators that reveal practices ensuring the ongoing competences for each pilot.

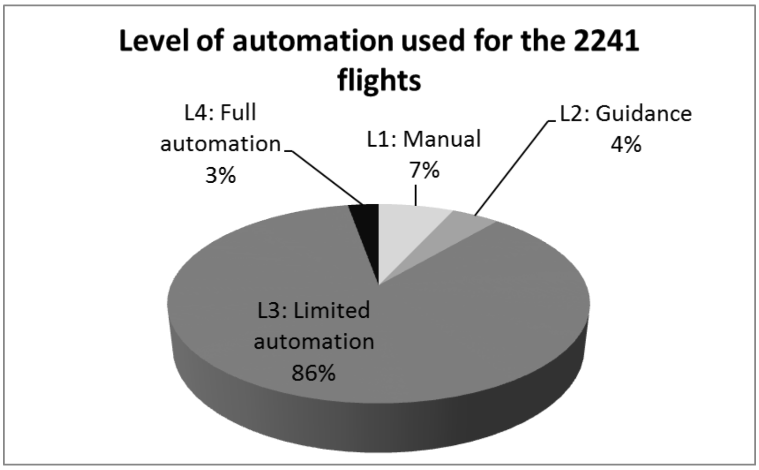

Figure 6: breakdown of the flights by level of automation

The schema “In Close Approach Change” has been identified in 34 flights, that is to say in 1.5% of flights. Figure 7 displays the ground track of one flight on which we can see that the aircraft first aligned on the left runway and in the middle of the final descent switched to the right Runway. These types of manoeuvres are known but often their frequency is not precisely measured. Some predefined exceedances (based on the roll of the aircraft during the final approach) can be used, but hardly differentiate ICAC from unstabilised approach or bad weather conditions.

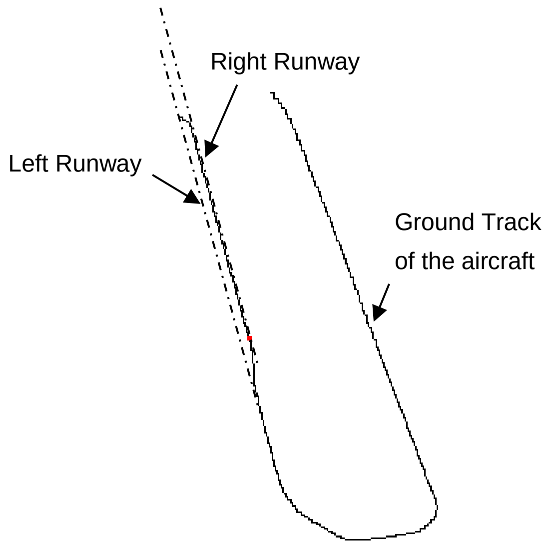

Figure 7: Example of ICAC

Also, the analysis of these flights reveals that the module “Converge” is missing in 18.4% of flights. We can deduce from this result that two “ways of doing” are used: with or without a converging segment (see figure 8). The more standard way of doing is made up of four steps: (1) a first turn that put the aircraft on (2) a converging segment leading the aircraft to cross the axis of the runway, (3) a turn when the aircraft is close to the runway axis and (4) the final descent on the runway heading. The alternative procedure consists in a first turn that directly brings the aircraft on the runway heading. Identifying these two “ways of doing” should invite the airline to investigate benefits, risks and training as for these two possible procedures and is part of a proactive management of safety.

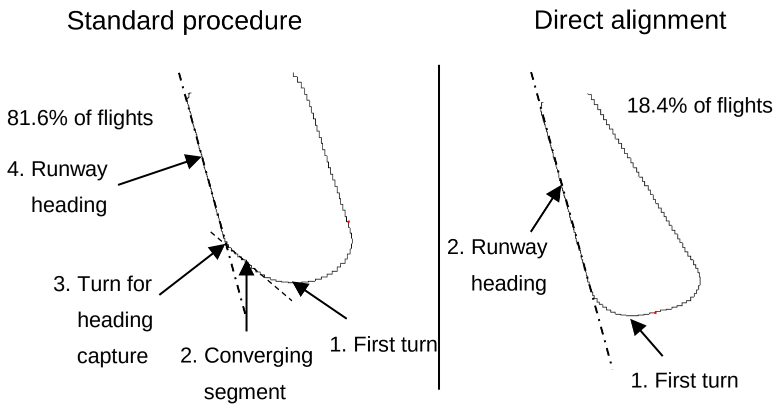

Figure 8: Two procedures for the capture of the ILS

Then, a study has also be done (restricted to flights with a converging segment) in order to see if the level of automation had an influence on the duration of the landing. Statistical results (see figure 9) indicate significant differences both for the duration of the approach and for the altitude of the beginning of the final descent: the level of automation L2 conducts to shorter durations and lower altitudes. Such results raise other types of questions such as: Is the manual landing used by the crew as a way to save time? If yes, in which conditions?

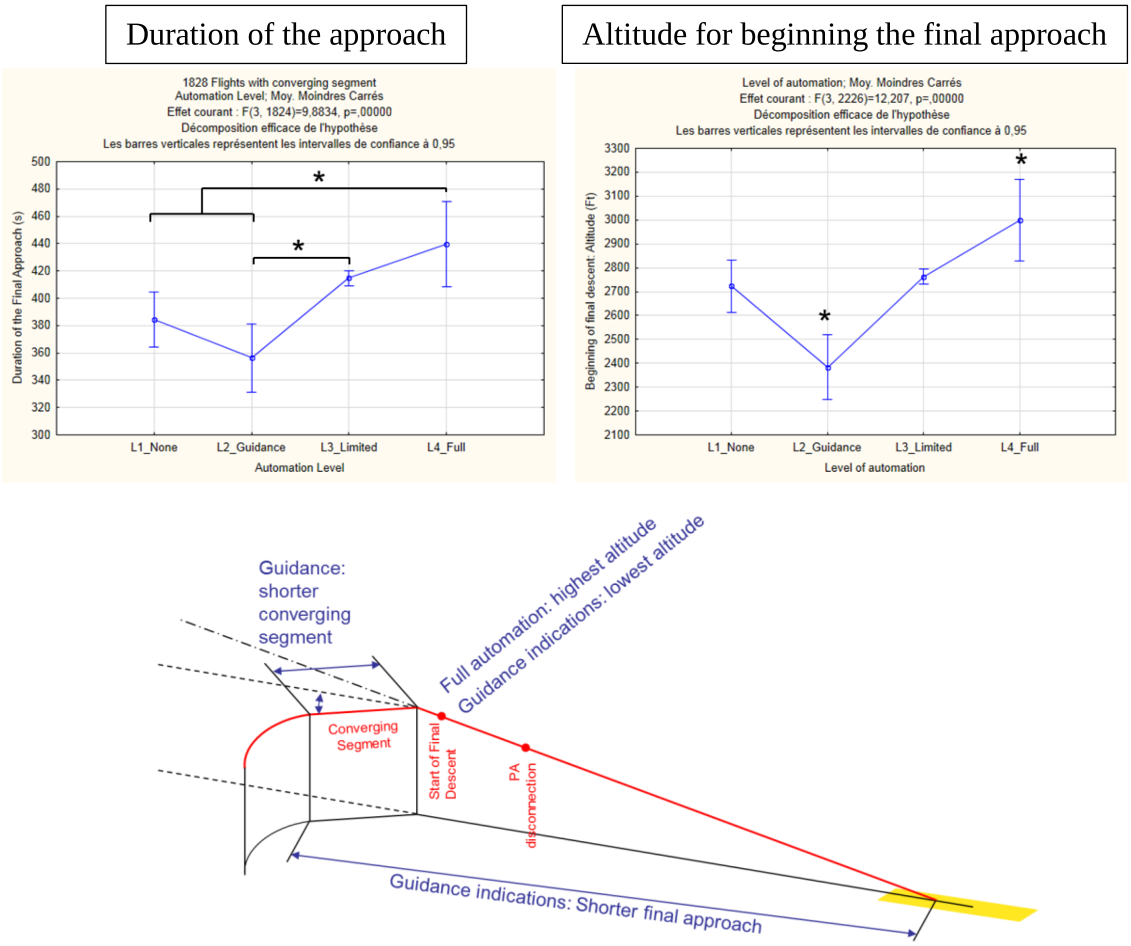

Figure 9: Impact of the level of automation on the duration of the final approach

This result also demonstrates that the use of this new methodology opens the way to the definition of new prescribed exceedances, more linked with the crew activity. It reverses the way some exceedances can be thought: instead of “is the aircraft stabilized at 1000Ft AGL?” we can now ask “at which altitude is the aircraft stabilized on the ILS slope?”

5. Conclusion and perspectives

In this paper, we propose an adaptation of the process used to analyze flight parameters recorded during routine operations. The main contribution is to introduce a model of the crew activity (flight profiles) that allows both the identification of how the standard operation procedures are used during flights, and the definition of new events closely related to the crew activity. It is an important step towards a better introduction of leading indicators in safety management systems.

The implementation of this new process in a dedicated tool and the analysis of a set of landing demonstrate some benefits of this methodology. To compare real flights with flight profiles raises new questions, promote the search for new emerging risks, and finally help to be in a more proactive safety management.

Potentialities of this new approach have not been widely studied yet and will be now investigated on flights with go-arounds. It should also be noted that this approach has also to be combined with researches on the use of data-mining algorithms for the safety management. Indeed, the use of flight profiles can allow the identification of parts of flights that make sense from a crew perspective and can then be mined to extract outliers.

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