Dynamic Decision-Support Application for in-flight Collision Risk Assessment

Konstanca Nikolajevic, Nicolas Belanger
Airbus Helicopters
Marignane, France
E-mail: konstanca.nikolajevic@airbus.com, nicolas.belanger@airbus.com

Abstract*—Avionics systems supporting emergency situations in-flight are a key challenge for safety. Facing the important lack of formalism of undesirable events and formal escape solutions, avionics designers' community often addresses the problematic by extremely preventive systems developed to keep the crews far upstream emergency situations. This is particularly true for operational accident scenarios like Controlled Flight Into Terrain (CFIT) for whom the complexity to build an efficient escape solution is dramatically increasing with the proximity of the event. This situation leads to a "discontinuity" in assistance systems aiming at preventing CFIT accidents, where the help does not come efficiently to the pilot once he has reached the breakdown point in the accident scenario. We are convinced that Knowledge Based Systems (KBS) are a promising approach to solve the problem of CFIT event diagnosis and prevention in line with well-designed escape solutions. In this paper, we intend to present a decision-support application for pilots based on a Risk Assessment Model for in-flight Safety Evaluation and Strengthening (RAMSES). RAMSES is a KBS that has been parameterized with pilots' knowledge through a formal elicitation process facing in-flight analysis of potentially dangerous situations leading to a crash. This knowledge representation approach has been supported by a strong modeling module of RAMSES which provides a major added value indicator: the deterioration across time of real time computed escape trajectories (5000 trajectories generated) projected in the 3D space frame, ahead and around the aircraft. This approach has permitted to extract new collision risk indicators for the helicopter, established in accordance with the pilots' perception of danger sight facing a CFIT accident scenario. In a second step, this knowledge has been used to parameterize the multicriteria tool PROMETHEE II (Preference ranking organization method for enrichment evaluation) in order to produce the best escape trajectory matching as close as possible the real reasoning of a pilot involved in such emergency situation.

***Keywords;* Path Planning; Decision aid making; Simulation; Optimization; Multi-criteria methods; Aerial Robotics**

I. INTRODUCTION

Reports on accident analysis and safety recommendations, published by the International Helicopter Safety Team (IHST) [1], and the European Helicopter Safety Team [2] provide an overview of the top factors in standard problem statements playing a role in helicopter accidents. It appears that "Pilot judgment and actions" and "Safety Management" take the lead. Besides, recognizing that the rate of helicopter accidents were too high, the IHST committed to a quite ambitious program [1] aiming at reducing the accident rate of civil helicopters by 80% in 10 years. Conscious of accident rates helicopter operators are more and more concerned about the safety and they are demanding innovative solutions to prevent accidents. Despite the existing embedded technologies in use, contributing to operational accident reduction is not a common thing and it requires to getting the full point of a typical accident scenario, encompassing all the logic there is beyond a simple chain of causes and contributing factors leading to a crash. Indeed, emergency situations inflight are various and not all very well formalized. There are no precise procedures for avoiding a complex undesirable event, be it of operational or technical nature. Of course, models for understanding accidents already exist such as the Reason's Swiss cheese model, the Domino model [6], and there is always a way to reconstruct and understand what happened from the official accident report. However, preventing the accident scenario from happening in-flight is a true challenge and it requires a fierce short-term risk management and decision making with respect to the aircraft's dynamic capabilities and maneuvers constraints. In order to prevent the accident scenarios from starting and taking place, it is necessary to have a method for estimating permanently the criticality of the current flight situation and translating it into risk values to trigger out alarms and escape maneuvers when necessary [5]. In this context, the first concern for the crew is securing the immediate trajectory of the aircraft. The study presented in this paper is based on the hypothesis that a collision threat is a function of the helicopter's dynamic capacities and of the immediate short-term environment situation, which may be assessed by a set of successive 3D positions reachable by the helicopter and forming an envelope of feasible trajectories computed ahead of the current 3D position as described in [3] [4]. The collision of this envelope of trajectories with the environment surrounding the helicopter provides a sight of danger convergence and allows quantifying the accident threat based on the remaining safe alternative trajectories to the current path.

Besides, the approach combines a mathematical model of parameterized trajectories to a decision-support model monitoring and sorting the alternative trajectories, as the risk of collision is getting closer. The system's operating model is similar to the existing TAWS (Terrain Awareness and Warning System)[1] in the sense that it provides an overview of the danger threat based upon the environment and the helicopter's dynamic capacities. However, from an operational point of view, the system described in this paper goes further as it ensures a continuity to the third order for the trajectories meant to serve as avoidance maneuvers, hence taking into account horizontal turns or composed movements like a turn combined to a climb rate, which contributes at decreasing at the same time the number of false collision alarms making the use of this system interesting for the crew both in terms of situation awareness, short term navigation, and decision-support.

The algorithms behind the decision-support application presented in this paper have been thought and designed upon thorough observations of real accidents and the actual crew's needs on board in operational type accident scenarios in order to provide a functional architecture generic enough and easily parameterized in line with the operated mission and the pilot's preferences. This paper is addressing dynamic autonomy issues for the specific case of operational accidents (like Controlled flight into terrain or loss of visibility) through a discussion and positioning over safety and risk management in-flight. Beyond this consideration, this paper will suggest a hierarchical approach for decision-making and risk assessment; and it will suggest new alerting rules for collision avoidance based on performance criteria derived from simulated collision approaches.

II. UNDERSTANDING THE ACCIDENT LOOP

The logic of an accident scenario is addressed through several accident models as stated before [6]. In all these cases, the accident happens because safety barriers have been overcome. Characterizing these safety barriers is very difficult. Often they rely on characteristic parameters of the mission, be it in aviation or not; and finding the accurate parameters to monitor in order to prevent the accident form occurring might be proper to the current situation. For that reason, it is of paramount importance to identify the moment when the accident scenario starts, and formalize this moment with facts, like for example the occurrence of a significant environmental constraint perturbing the mission, i.e. the incapacity of the aircraft to perform a certain number of escape maneuvers, the surrounding obstacle becoming closer, a degrading visibility etc.

The role of RAMSES function concept described in this paper is to provide the crew with an escape action before the current flight situation becomes too dangerous for the aircraft and its occupants. Fig. 1 illustrates a framework of the accident loop composed of separate undesirable events *E1, E2, E3, E4…* and of the final accident *A*. However, an accident scenario is not a simple chain of causes and contributing factors. It is much more complex for the family of accidents treated in this study because they are unpredictable in-flight. In CFIT accident scenarios, the pilot is not aware of the collision threat. These accidents remain difficult to prevent because the crash happens in full consent of the crew. Naturally, the accident reports published by official investigation boards[2] are often detailed and permit to reconstitute exactly how things happened before the accident; which means that for each report, it is often possible to derive a chain of significant undesirable events similar to the one presented in Fig. 1 in order to visualize how the undesirable events are sequenced. By contrast, the way an accident happens in-flight is often unique from a case to another, and even if characteristic trends could be extracted for operational accidents, they remain unnoticeable in real-time by the crew. For that reason, identifying autonomously the right moment to act in prevision of a crash is very hard in CFIT accident scenarios. A formal representation of this accident type does not exist. The avionics equipment like the TAWS (Terrain Awareness and Warning System) are used to prevent CFIT accident scenarios, however are not adapted for all the missions, especially when they require to go close to obstacles, or to navigate in hilly environments because the equipment generate a high rate of false alarms in these situations.

Typically, what happens in the case of a CFIT accident is that an environmental constraint or an inappropriate maneuver *E'*. (Fig. 1) pushes the aircraft into a danger loop leading to the accident; RAMSES function concept must find the best moment (principally based on new alerting rules and optimized decision-making capabilities) to trigger actions *E''* (Fig. 1) in order to get out of the danger loop and restore an acceptable safety threshold. Finding the right Decision Point requires working on the alerting rules of the avionics function concept and establishing a method for permanent in-flight autonomous and adaptive safety monitoring. Indeed, as the terrain elevation map changes during the flight, and the obstacle density evolves, the avionics function concept must be able to detect, according to the current flight situation whether there is a threat or not. If

[1] Terrain Awareness and Warning Systems aim at preventing Controlled Flight into Terrain (CFIT) accidents.

[2] The aircraft accident investigation boards (per country) are listed at http://aviation-safety.net/investigation/aaibs.php

the threat is real, then the function should be able to forecast it in order to leave enough time to the crew to take a corrective action, computed by RAMSES. In Fig. 1, the decision point is taken at the undesirable event *E2*; however, it could also be *E3*, *E4* etc. but not E1. In case a corrective action has been suggested by RAMSES and performed by the crew to get out of the accident loop at *E'';* then the aircraft should be able to reach its target position (final position of the mission or in-flight safe position).

Three degrees of safety are addressed through the study by analogy to the sequential division of traffic accidents [8]:

- Level 1: set of active safety actions that could be triggered before the accident occurs, which aim at avoiding the accident, i.e. set of avoidance maneuvers computed by the application and alarms,
- Level 2: set of preventive passive actions which intend to minimize the consequences of the crash, i.e. the application can predict when the accident is unavoidable in order to trigger immediate protective actions,
- Level 3: if the accident occurs the application can send the vehicle's relevant flight data and position to Search and Rescue teams.

In order to guide the study and confirm the accident trends published by the IHST [1], a survey has been conducted exclusively on the Airbus Helicopters fleet, over a period of 10 years. For a discretion concern the survey will not be revealed in this document, however it allows to confirm that operational accident scenarios require attention and represent a challenge for innovative avionics solutions to assist the crew in CFIT accident causes where a deviation from the safe flight trajectory is often observed [8].

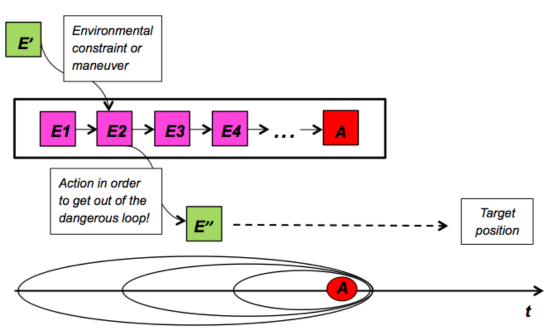


Figure 1. Accident loop made up of undesirable events *E1, E2, E3, E4*, etc. and provoked by an undesirable event *E'*

III. THE RAMSES FUNCTIONAL ARCHITECTURE

RAMSES Functional Architecture is composed of five principal Functional Blocs as shown in Fig. 4. Each functional bloc has a specific technical contribution meeting a formal requirement to prevent the CFIT (Controlled Flight Into Terrain) accident threat[3]. The idea is to monitor the danger proximity, prevent the danger sight and continually provide the crew with a set of feasible escape trajectories if the things go wrong. In the case of CFIT accidents, understanding the immediate environment ahead and around the helicopter is a key factor. The system must be able to evaluate possible future states of the aircraft and assess whether they are dangerous or not [5].

The RAMSES functional architecture displayed in Fig. 4. is composed of the following functional blocs:

- The *Trajectory Generation* functional bloc and more precisely the details of trajectories design have been described in previous works [3] [4] [5]. The trajectory generation functional bloc is at the beginning of the RAMSES concept chain. It computes three-dimensional trajectories compliant with the flight envelope of the aircraft and taking into account high kinematic constraints all along the trajectory and at its ends. The objective of the trajectory generation functional bloc is to make a projection of the possible future states of the aircraft in the surrounding environment. It creates a flexible envelope of feasible trajectories ahead and around the helicopter, with the goal to discretize the 3D reachable space within a given time, according to the current flight properties. An illustration is displayed in Fig. 2.

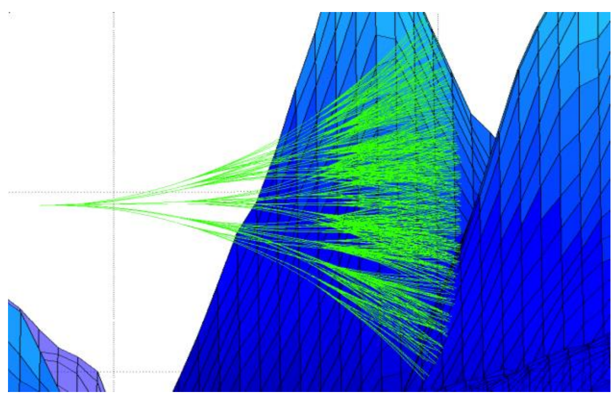


Figure 2. Example of an envelope of trajectories computed for a constant speed of 70 knots.

[3] This paper will focus on CFIT accident scenarios, however the RAMSES functional architecture has been thought and designed in order to meet preventive requirements of operational accidents in general as described in [5].

- The *Trajectory Evaluation* functional bloc takes as input the trajectories computed previously and evaluates their position with respect to the terrain elevation data bases or more generally speaking danger zones computed above the terrain [5] [10]. The idea is to evaluate the collision of the states composing a trajectory either with the terrain itself or with layers above the terrain to detect a gradual logic of progression towards the terrain as shown in Fig. 3.

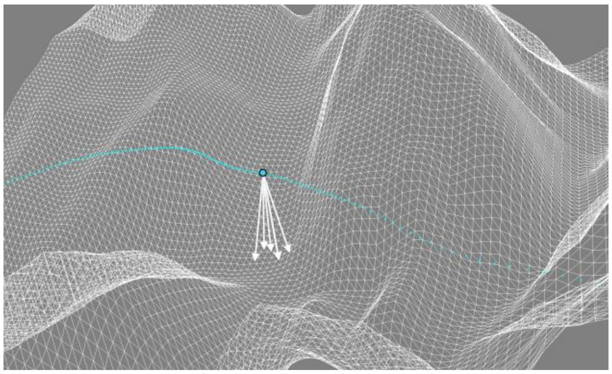


Figure 3. Evaluation of the position of a trajectory with respect to the terrain elevation data

- The *Risk Assessment* functional bloc (focus of this paper) monitors the safety of the current flight situation based on deterministic rules extracted from interviews conducted with Airbus Helicopters pilots and experts. The Risk Assessment functional bloc takes into account the remaining safe trajectories evaluated by the previous functional bloc. It ensures that the global safety thresholds are respected, otherwise it triggers warnings reported to the decision-making functional bloc. The risk assessment functional bloc estimates permanently the capacity of the system to recover from a degraded safety by evaluating the state of the discretized environment ahead of the current flight position. Hence it estimates if the collision is likely to happen. Practically, it could be said that the risk assessment functional bloc evaluates the capacity of the system to be resilient towards the danger threat. In this study, the notion of resilience is not developed or formalized further. However, the concept of resilience could be mentioned here like in the works of Belcastro [11], even if it is not going to be thoroughly studied, in the sense that a similar way for preventing the undesirable events is used: the RAMSES avionics function concept analyses the future state of the aircraft in order to adjust the current state and predict whether the current situation could recover from the corresponding degraded safety. Accordingly, the risk assessment functional bloc provides indicators of the current situation awareness to the crew.

- The Classifier and Decision-Making functional blocs collect the information computed and provided by the previous functional blocs in order to choose the best avoidance trajectory available to prevent a possible collision. These last two functional blocs are not going to be detailed in this paper, as they are not implied directly in the in-flight collision risk assessment capability of the function. However they remain of paramount importance in the decision-support chain of RAMSES.

    - The Classifier functional bloc is based on a known multicriteria method: PROMETHEE II (Preference ranking organization method for enrichment evaluation) parameterized according to the pilots interviews [5] [9].

    - The Decision-Making functional bloc acts as the final decision-maker of the chain. It is in charge of managing the information between the pilots and the system via an interface like a HMI (Human Machine Interface); and it acts as the link between the autopilot, potentially, and the rest of the RAMSES functional blocs. In order to convey the operational reality of the current in-flight situation, the decision making functional bloc relies on the elicitation of the pilot's knowledge put in emergency situations.

- The interfaces between the RAMSES functional blocs and the external systems or devices, displayed in Fig. 4, are used to ensure a link between the RAMSES system and a possible simulation environment or a more global avionics system in the case RAMSES is part of it.

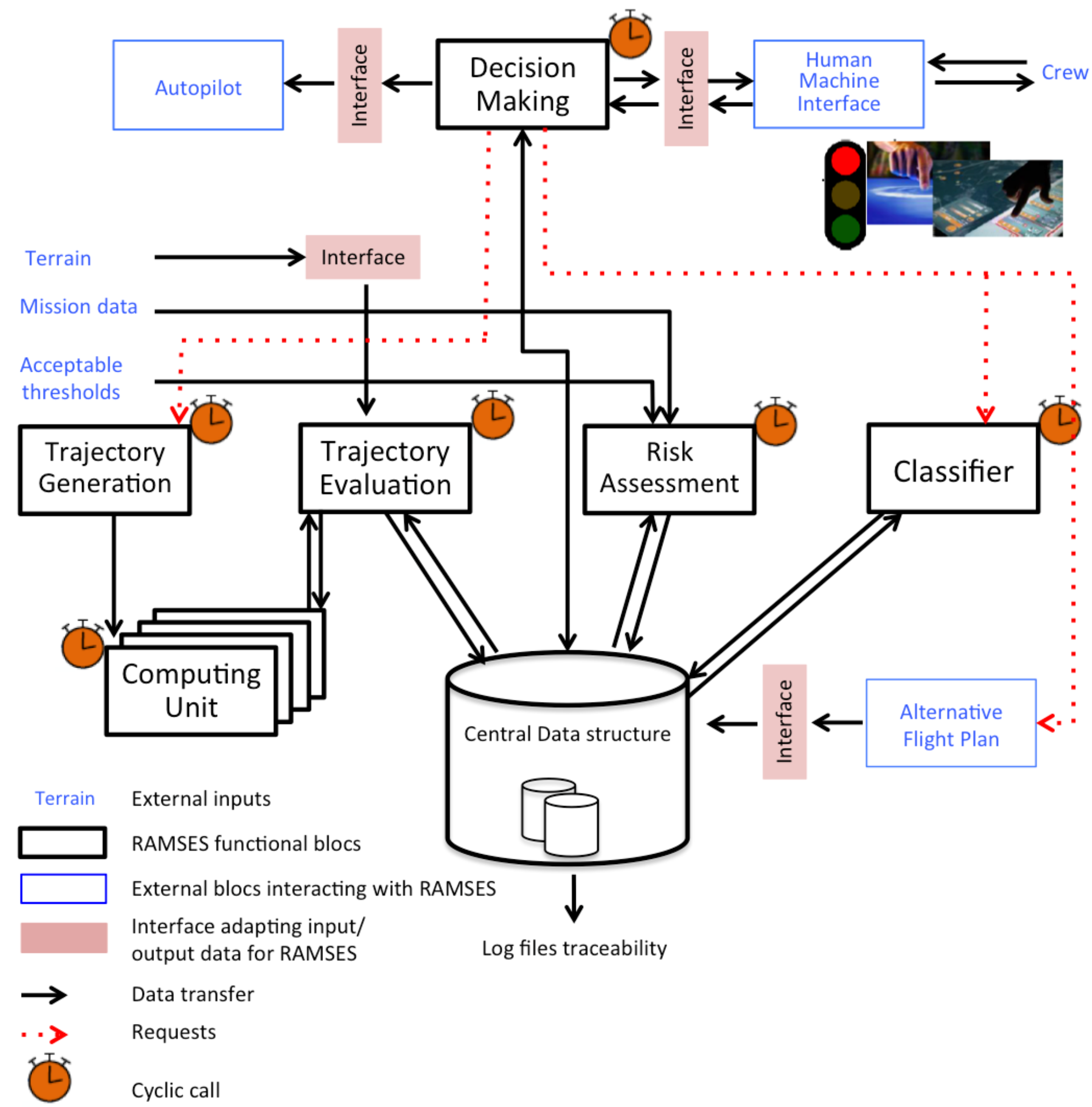


Figure 4. RAMSES functional architecture

IV. FOCUS ON THE RISK ASSESSMENT

In the present work we propose to objectivize the potential of achievable maneuvers by the helicopter in the current environment in order to assess the risk in-flight in a manner close to pilots' reasoning. This idea relies on the simple concept that "a danger only exits in regards of the potential of reaction of the system". Following this idea we had to imagine a new way to measure the distance to the undesirable CFIT event, not by the means of time or meters, but by a composite measurement where the capability to avoid the accident is represented in terms of variety of solutions. This major criterion is tuned and mixed up with other criteria identified by flight tests pilots involved in CFIT in-flight emergency situations analysis. This knowledge engineering approach allowed us to build up new warning rules that we validated on new cases which did not serve in the corpus used to build them up.

Based on the current state of the aircraft and the surrounding environment, the Risk Assessment functional bloc provides a forecast of the current flight situation in the near future by estimating the risk of collision of the aircraft ahead of the current position. The calculations are based on the drop of remaining safe trajectories and their properties rendered through performance criteria. The criteria, characterizing the trajectories, necessary to the identification of localized risk of collision in the environment, are derived from observations of simple operational emergency situations when the helicopter flies close to the ground, at low altitude. They allow characterizing the diagnosis of the current risk of collision in a deterministic way by quantifying the aircraft's approach to the ground in the three-dimensional space frame. However, this information does not constitute the final alarm indicator, relevant for the crew. These criteria ensure that the sorting of the available trajectory solutions and the choice of the best avoidance trajectory solution, developed further, are compliant with the operational reality of the flight.

When a helicopter flies in a hilly terrain, close to the ground, at low altitude, the safe areas are not always reachable in short time periods. Actually, in these situations, the helicopter navigates in a confined space between the hills or the mountains. Therefore, the distribution of available safe avoidance trajectories may change from one flight point to another, with respect to the terrain elevation. Accordingly the trajectories composing the envelope (cf Fig. 2) computed by the Trajectory Generation functional bloc might not be fully safe for the helicopter. As an example, Fig. 5 illustrates this phenomenon with a case when the helicopter goes towards a cliff. At the beginning, many safe (green) trajectories are available, but as the helicopter approaches the cliff, they collide with the terrain elevation and become unsafe (red) (as displayed in Fig. 6.

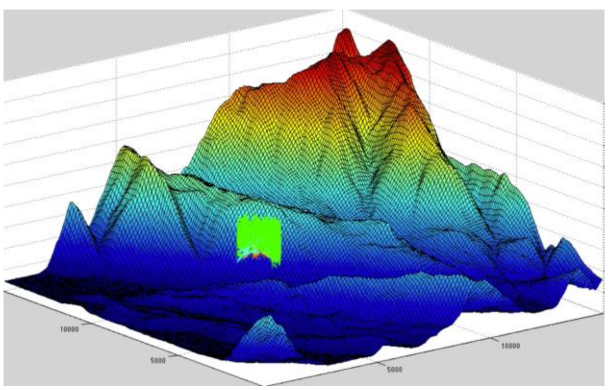


Figure 5: Safe flight situation with many safe (green) trajectories available.

It is possible to observe trends or patterns in the drop of trajectories composing the global set of trajectory solutions with respect to angle of approach to the terrain. Hence, in Fig. 6, it is possible to notice a group of safe trajectories on the top right side of the global envelope. As a consequence, even if there is an important drop in the number of remaining safe trajectories for the helicopter, there still might be some of them who are safe enough for avoiding the collision. The risk assessment functional bloc detects these behaviors and generates collision risk indicators in accordance with the remaining number of valid trajectories in the 3D space frame. Indeed, as stated above, formalizing the situation awareness of the helicopter is of paramount importance in CFIT accident scenarios and this paper suggests a way to do so based on performance criteria extracted from various terrain approaches observations, in the form of preliminary use cases.

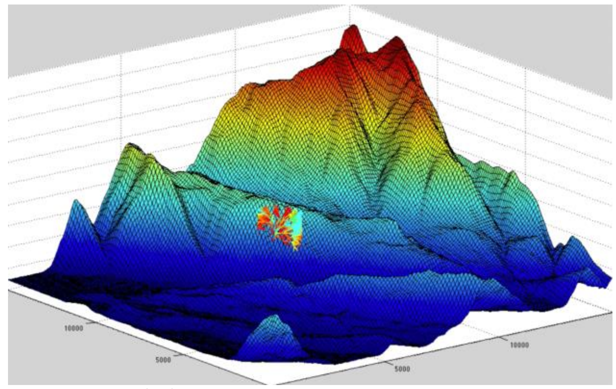


Figure 6: Unsafe flight situation with many trajectories collide with the terrain elevation (red)

In order to formalize the approaches we have tested the collision of the envelope of trajectories with the terrain elevation but also with danger zones computed above the terrain database with a method inspired of the distance fields [10]. An example of a computed danger zone 150 meters above the terrain is displayed in Fig. 7.

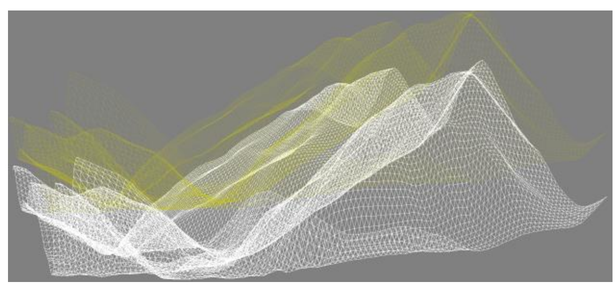


Figure 7: Danger zone (yellow) computed 150 meters above the terrain elevation data (white).

Four danger zones have been computed above the terrain elevation for the following heights:

- 50 meters,
- 150 meters,
- 250 meters: if the envelope of trajectories does not collide with this danger zone, then the flight situation is considered safe.

In this paper we intend to formalize the approach of the helicopter towards the terrain in order to objectivize the risk of collision of the aircraft. For that reason, firstly, we discretized the space reachable by the helicopter in the near future with an envelope of trajectories composed of the possible future states of the helicopter.

In a second step, we studied the collision of this envelope with the terrain elevation and with danger zones computed above the terrain. When the envelope of trajectories enters in collision with the danger zones, the simulation shows the progression of the helicopter towards the terrain through the drop in the remaining safe trajectories.
The two use cases described below detail this phenomenon, and the process of transfer of the cardinal of trajectories between the different sets of trajectories bounded by the danger zones.

1. Preliminary case study: helicopter flies towards a cliff

This use case illustrates the simulated approach presented in Figs. 5, 6 and 8. The helicopter flies towards the cliff and the envelope of trajectory solutions accounts of the progression. Indeed, as the helicopter comes close to the cliff, the number of remaining trajectory solutions drops as shown in Fig. 9.

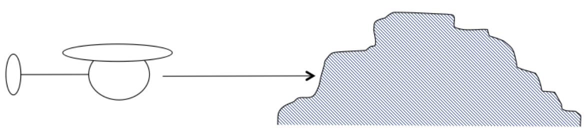


Figure 8: Helicopter flies towards a cliff

At the beginning of the simulation (cf Fig. 9), all the trajectory solutions are valid at least 150 meters above the ground. Then we observe a transfer of the cardinal (number of trajectories) of trajectories from those 250 meters above the ground to those 150 meters above the ground.
At point 1 in Fig 9, the transfer of the cardinal from trajectories 250 meters above the ground to the trajectories 150 meters above the ground becomes less important than the transfer from the 150 meters above the ground to the trajectories 50 meters above the ground. Potentially, this shows that the first level of security has been overcome.
At point 2, the number of non-solutions (below 50 meters) overcomes the number of remaining safe solutions.
At point 4, no more trajectories are available. The accident is unavoidable if the helicopter continues in the same direction. By analogy to the sequential division of traffic accidents, the point from which the accident is unavoidable is called the accident situation [7].
Points 5 and 6 mark the moment when no more safe solutions are available respectively above 250 meters and 150 meters.

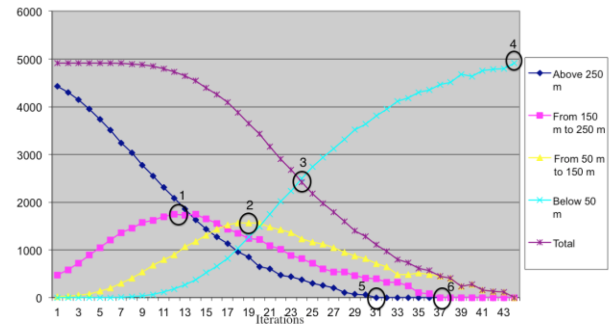


Figure 9: Drop in the number of remaining safe trajectories when the helicopter flies towards a cliff

2. Preliminary case study: helicopter flies towards a cliff and moves away

On the same scheme, the case when the helicopter flies towards a cliff and moves away (Fig. 10) is very interesting for the risk assessment functional bloc as it gives useful indicators in terms of possible new alerting rules. Indeed, this case represents a situation when equipment like the HTAWS may generate nuisance collision alarms, as they don't take into account the current flight state of the helicopter, *i.e.* when it is performing the turn.

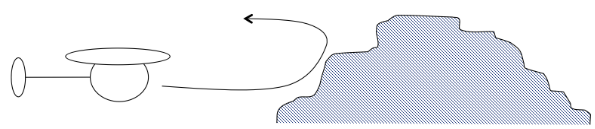


Figure 10: Helicopter flies towards a cliff and moves away.

Point 1 in Fig. 11, attests of the moment when the helicopter starts moving away of the cliff, and the trajectories forming the discretized environment around the helicopter become safe again. This explains why the cardinal of trajectory solutions above 250 meters suddenly increases again.

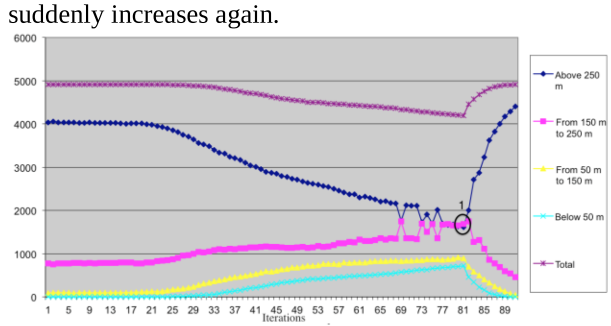


Figure 11: Drop in the number of safe trajectories when the helicopter flies towards the cliff and moves away

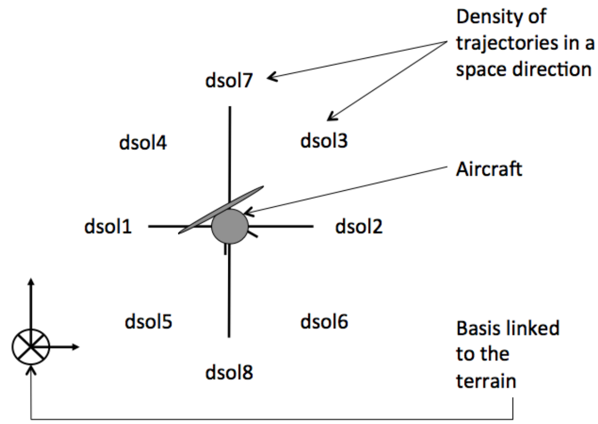
On Fig. 11 we can see that the total amount of escape trajectories decreases slightly between 5000 and 4000 and then increases suddenly again to the maximum in a very short period of time (8 iterations which corresponds to 80 milliseconds). This demonstrates that during the whole analyzed period of flight, a lot of maneuvers (including safe ones) were constantly available to avoid the accident. This example shows how important it is to evaluate the global capability of maneuvers of the helicopter at each point of flight. With this evaluation we see that in our example, there is no risk raised at any point of the flight. Taking into account only one particular trajectory to build up an alerting indicator would lead to a more restricted view of the reality. In an obstacles dense environment, the ratio of false alarms could then increase dramatically with a single trajectory evaluation for risk analysis. Our approach guaranties that the flight situation is analyzed in terms of maneuvers capability in a global way and thus that the risk evaluation is closer to the perception of a pilot. This has been demonstrated by the interviews we performed during which the pilots also took into account the global set of available maneuvers to assess the risk of collision.

3. Extraction of performance criteria and suggestion of new warning rules

In the previous paragraph we introduced the importance of evaluating the risk linked to a flight situation in a global way compared to existing indicators based on a single trajectory evaluation. The importance of this global approach has been validated by our interviews performed with flight tests pilots analyzing CFIT cases. This knowledge elicitation phase demonstrated the importance to evaluate the global capability of maneuvers of the helicopters and introduced other performance criteria. It can be noticed here that the performance criteria validated by the pilots were introduced to both evaluate the risk assessment of the flight situation and the selection of the best appropriate maneuver to escape the risky situation. Indeed the interviews were conducted in a spirit of continuous analysis: we did not intend to separate the risk analysis from the way to escape the risky situation as those analyses are strongly linked. As a matter of fact, the lector will see that the introduced criteria are not all part of the established warning rules. Two of them are used for those rules as all of them are used for the selection of the most appropriate escape maneuver.

The criteria are:

- **The time to obstacle:** which is the computed time associated to the extrapolated current trajectory of the helicopter
- **The density of trajectory solutions**: which is the number of available solutions available in different regions of space



- **The maneuverability:** which is a criterion representing the easiness to perform a maneuver
- **The dynamic solicitation:** which is a representation of the maneuver compared to the maximum dynamic capability of the helicopter (load factor, elevation speed…)

The established warning rules are presented on the chart below. They have a restricted field of application as we used CFIT cases with a small subset of feasible trajectories (64 trajectories) and applied a constant speed to objectivize those rules with the experts:

Warning level 1	Warning level 2
Time to obstacle < 20 seconds AND $dsol_i < 32$ OR Time to obstacle < 15 seconds OR $dsol_i < 20$	Time to obstacle < 10 seconds AND $dsol_i < 32$ OR $dsol_i < 10$

Pilots chose two levels of warnings that shall be sequential whatever the environment and the flight situations. At this stage of the work, this is something that still needs to be strongly tested as the variety of topographies and flight contexts can vary to infinity. Anyway, those rules, which at the end seem simple, are promising to assess the risk associated to a CFIT situation. By this way we objectivize the situation awareness associated to the current in-flight situation, the decision making process is not described here. Time to obstacle mixed up with density of solutions exploded in space regions seems to be commonly agreed by the pilots as performing criteria to assess the risk. Thresholds were proposed and agreed without reserves to finally be integrated in the warning rules. The warnings levels were then validated in new studied cases.

V. CONCLUSION

The present work introduced the decisional system RAMSES which aims to bring a new approach to assess the risk associated to a flight situation for CFIT scenarios, and proposes the most appropriate maneuver to escape the risky situation. We focused the paper on a new risk assessment approach and RAMSES architecture. To objectivize the risk associated to a flight situation for CFIT scenarios, we used a knowledge engineering approach involving flight tests pilots. It helped us to extract the mandatory criteria to be used in warning rules. Our approach demonstrated that the distance to an undesirable CFIT event is strongly linked to the available maneuvers projected in the environment. A discretization of this set of maneuvers has been chosen with around 5000 possible maneuvers generated at the current flight point and taking into account the initial flight parameters. The observation of the degradation of this maneuvers set over time is an extremely powerful criterion to build up an efficient risk assessment. It demonstrates that a global approach is more appropriated than a single trajectory evaluation because pilots seem to reason in a global manner to evaluate the risk of a flight situation. On top of that, reasoning in a global way (in terms of valid maneuvers) leads to avoiding false alarms in obstacles dense environments. Time to obstacle criterion has also been integrated to build up new warning rules for CFIT event. This is a preliminary work and we need now to make those warning rules robust in front of a huge amount of CFIT scenarios. To do so, we will still use a knowledge engineering approach until we stabilize the warning rules and make them independent to the topography or the flight situation. This knowledge convergence process is mandatory and its results in terms of iteratively updated warning rules have to be questioned about its added value. Once the stabilized warning rules built up from a wide CFIT corpus are established, we will have to bench their added value compared to existing systems particularly in obstacles dense environments.

References

[1] U.J.H.S.A. Team. The compendium report: The u.s. jhsat baseline of helicopter accident analysis. Technical report, IHST, 2011.

[2] EHEST. Ehest analysis of 2000 – 2005 european helicopter accidents Technical report, EHEST, 2010. ISBN 92-9210-095-7.

[3] K. Nikolajevic, N. Belanger, D. Duvivier, R. Ben Atitallah, and A. Artiba. A method to compute efficient 3d helicopters flight trajectories based on a motion polymorph-primitives algorithm. In Proceedings of the International Conference on Control and Automation Systems (ICCAS 2015), Amsterdam, The Netherlands, Aug. 2015.

[4] K. Nikolajevic and N. Belanger, “A new method based on motion primitives to compute 3D path planning close to helicopters’ flight dynamics limits”, in International Conferenceon Mechanical and Aerospace Engineering (ICMAE), IEEE, 2016.

[5] K. Nikolajevic, “Dynamic Autonomous Decision-Support Application for piloting a Helicopter in Emergency Situations”, Ph.D dissertation, LAMIH, University of Valencienne and Henaut-Cambresis, 2016.

[6] J. Reason. Human error: models and management. *Bmj* (British Medical Journal), 320(7237):768–770, 2000.

[7] T. Fernandez and T.Brenac. L’étude déatilllée d’accidents orientée vers la sécurité primaire: méthodologie de recueil et de pré-analyse. Presse de l’Ecole Nationale des Ponts et Chaussées 1995.

[8] https://www.airbushelicopters.com/website/docs_wsw/pdf/IN2255-I-00-REV1-FR.pdf. Accessed: 2015-12-2.

[9] http://www.promethee-gaia.net/assets/bibliopromethee.pfd. DOI: 10.13140/RG.2.1.1704.392; Accessed 2015-12-14.

[10] D.E. Swinhart, A.F. Barfield, E.M. Griffin, R.C. Lehmann, S.C. Whitcomb, B. Flynn, M. Skoog, K.E. Processor, et al. Automatic ground collision avoidance system design, integration & flight tests. Aerospace and Electronic Systems Magazine, IEEE, 26(5):4-11, 2011.

[11] C.M. Belcastro. Aircraft loss of control : Analysis and requirements for future safety-critical systems and their validation. In Control Conference (ASCC), 2011 8th Asian, pages 399-406. IEEE, 2011.