WHAT TECHNOLOGIES TO IMPROVE HELICOPTER FLIGHT SAFETY ?

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ABSTRACT

Despite the very significant progress made in terms of aviation safety, some actions are still needed to improve helicopter flight safety as requested by ACARE. Statistics published in recent years on accidents of helicopters show a relative stagnation of progress in flight safety. The IHST objective of reducing worldwide helicopter accident rate by 80% between 2006 and 2016 will not be reached. Consequently the “Association Aéronautique et Astronautique de France”, has requested CTHC, its Helicopter Technical Commission, to identify embedded technologies that would improve the helicopter flight safety by drawing lessons from the past experience but also with a prospective view up to 2050. Its investigations were based on two main elements: results of a recent EHEST study and detailed analysis of the helicopter accident reports published by BEA, the French authority responsible for safety investigations.

To imagine technologies that will address the deficiencies in helicopter flight safety a detailed examination of accident reports is indeed necessary. For each accident, causes and possible solutions have to be considered in their operational context, by analysing precisely the accident scenario with its causal tree of situations/events as well as the system and human behaviours which conducted to the crash.

On the basis of actual accident cases, CTHC has investigated functions which could potentially improve flight safety. A list of 34 technical functions was initially defined in analysing accident scenarios.
In order to assess applicability of each function, CTHC applied some criteria : impact and relevance with respect to flight safety, regulatory constraints for on-board implementation, level of technology readiness, possible need of a third-party service (e.g. meteo data), requirements in training, and estimated costs.

Thus CTHC has selected 16 priority technologies divided in two groups: the 'mature' technologies which are a priori available, and the technologies 'to be developed' which require some efforts in research and development in order to achieve efficient technologies embeddable before 2050.

In addition, to provide a vision as complete as possible of the selected technologies, a specification form has been established for each of them. It includes the tentative definitions of its functional features, its implementation options, its technical characteristics and other needs and requirements that could be induced by its use in operation.

In conclusion, CTHC recommends that efforts of research, development and implementation of these prioritized technologies are conducted and supported as soon as possible. However, while it is clear that technology can have a significant beneficial effect on the safety of helicopter operations, it is also evident that technology cannot cover all safety aspects and resolve itself all the problems that can arise in flight. In fact, human factors play a very important role in safety as indicated in all analyses of helicopter accident reports.

Finally some comments expressed by helicopter operators about prioritized technologies for flight safety are also reported at the end of this paper.

1. ABBREVIATIONS and ACRONYMES

3AF	Association Aéronautique et Astronautique de France
ACARE	Advisory Council for Aviation Research and Innovation
ADREP	Aviation Data REporting Program (ICAO)
BEA	Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile

BEAD	Bureau Enquêtes Accidents Défense
CFIT	Controlled Flight Into Terrain
CS29	Certification Specifications n°29
CTHC	Commission Technique Hélicoptère 3AF
CTOL	Collision during Take-Off or Landing
DGAC	Direction Générale de l'Aviation Civile
EASA	European Aviation Safety Agency
EHEST	European HElicopter Safety Team
EHSAT	European Helicopter Safety Analysis Team
EHSIT	European Helicopter Safety Implementation Team
EGNOS	European Geostationary Navigation Overlay Service
EMS	Emergency Medical Services
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
F-POST	Fire/smoke post impact
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile communic.
HEMS	Helicopter Emergency Medical Service
HOMP	Helicopter Operation Monitoring Program
HTAWS	Helicopter Terrain Awareness and Warning System
HUMS	Health Usage and Monitoring System
ICAO	International Civil Aviation Organization
IHST	International Helicopter Safety Team
LALT	Low ALTitude operation
LOC-I	Loss Of Control - In flight
NTSB	National Transportation Safety Board
OWS	Obstacle Warning System
SAR	Search And Rescue
SCF-PP	System/Component Failure or malfunction (Power Plant)
SMS	Safety Management System
SVS	Synthetic Vision System
SPS	Standard Problem Statement
TRL	Technical Readiness Level
VRS	Vortex Ring State

2. INTRODUCTION and OBJECTIVES

The progress made in terms of aviation safety since the 1980s are highly significant. Based on lessons learned from previous accidents, actions were undertaken to reduce the likelihood that reproduces similar accidents and improves the safety of the flight.

Recently, safety goals have been set by ACARE for aviation and by IHST for helicopters. The ambitions of ACARE by 2050 are indeed [1] to obtain less than one accident per million flights, and for specific missions such as Search and Rescue to reduce by 80% the accidents in commercial aviation in comparison with the year 2000. Meanwhile, IHST displayed in terms of helicopter flight safety the objective of reducing overall 80% the rate of accidents worldwide between the years 2006 and 2016. However, after a period of significant progress in terms of helicopter flight safety, these recent years have been characterised by a relative stagnation in the number of accidents; therefore, the reduction targets set by IHST become now unreachable.

Moreover, the increasing complexity of missions, associated with changes in the cockpits of helicopters in terms of flight systems, automation and technology, modifies the piloting activities and consequently the risks and safety problems incurred by crews in operation.

In this context, the "Association Aéronautique et Astronautique de France" has requested CTHC to identify embedded technologies that would improve the safety of flight, not only in drawing lessons from the past experience but also with a vision for the future up to the year 2050.

The object of this paper is first to draw up a state of the current helicopter flight safety, to identify the causes of more symptomatic accidents, then to propose existing or new technologies for safety, with recommendations on priority technologies deemed the most relevant to meet the present and future problems of helicopter flight safety.

3. ACCIDENTOLOGY of HELICOPTERS

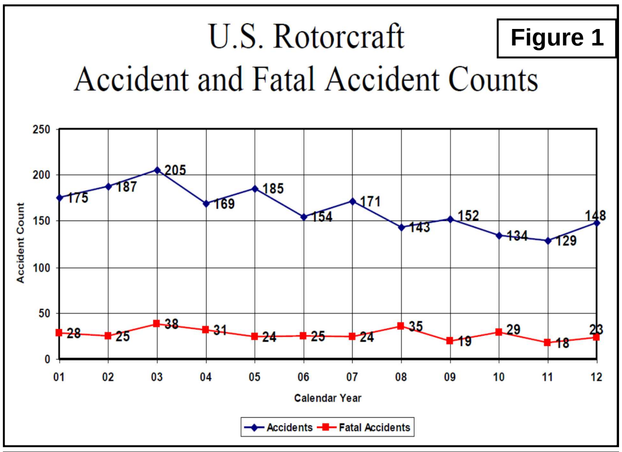
3.1. Statistics

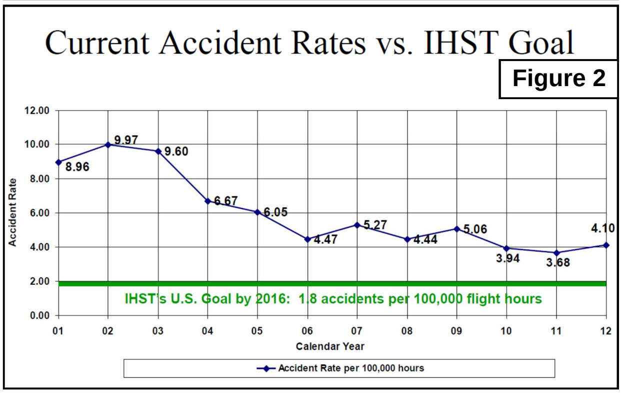
The current decay of accidents will not permit to achieve the objectives set out by international organisations, as evidenced by the statistics compiled in recent years, including in the United States.

3.1.1 US Statistics

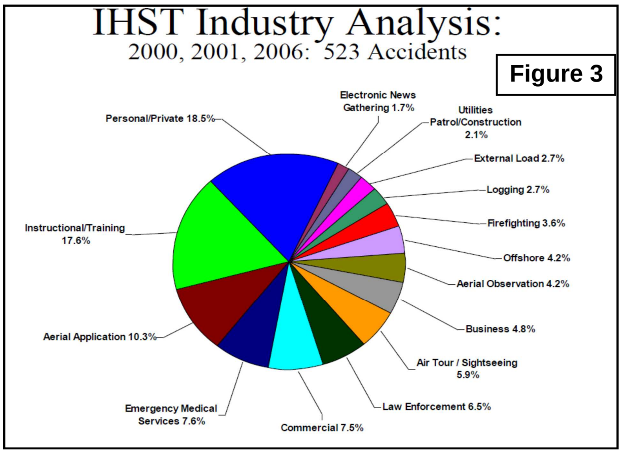
In 2013 FAA has published statistics about helicopter accidents in the United States, for all types of helicopters and civilian operations [5].
Figure 1 below shows the total number of accidents and the number of fatal accidents in the US over the period 2001-2012 while Figure 2 provides the accident rate, i.e. the number of accidents over the number of helicopter flight hours (to 10^5 hours) carried out during the year.

These two figures reflect that, after a period of fairly significant reduction in accidents, the actual improvement tends to stagnate in recent years. This observation is also true in terms of fatal accidents (red curve in figure 1). Statistics published in 2013 already showed that the target set by IHST, of obtaining in 2016 the rate of 1.8 accidents per 100,000 flight hours (green line in figure 2), would not be reached.

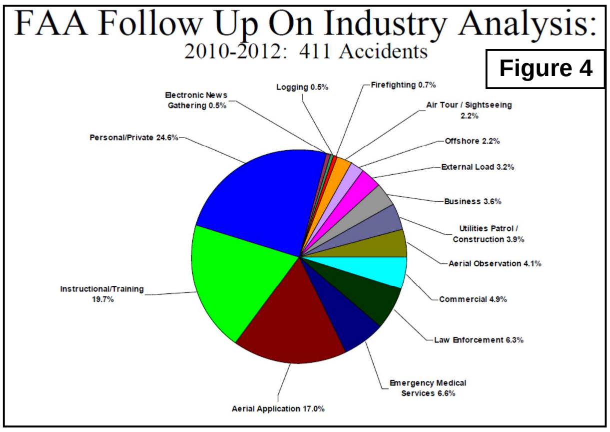




The figures 3 and 4 below describe the distribution of accidents according to the type of operation conducted with helicopters [5]. IHST establishes its statistics by distinguishing in great detail the helicopter operations.



Accidents are presented in considering respectively: the years 2000, 2001 and 2006 in Figure 3, and years 2010, 2011 and 2012 in Figure 4.
Comparison of these figures reveals a significant decrease in the total number of accidents between these two periods of 3 years each, thus confirming the trend shown in Figure 1. It indicates also that the operations the more conducive to accidents are in descending order: private general aviation flights, instruction or training flights, and aerial work. This trend is also confirmed in recent years (Figure 4) as the respective proportions of helicopter accidents listed for these three types of operation have increased.



Regarding progress in helicopter flight safety, current stagnation identified in the US is, in fact, a global problem that Europe is also facing as revealed by the statistics compiled by the EASA [2], the European Aviation Safety Agency.

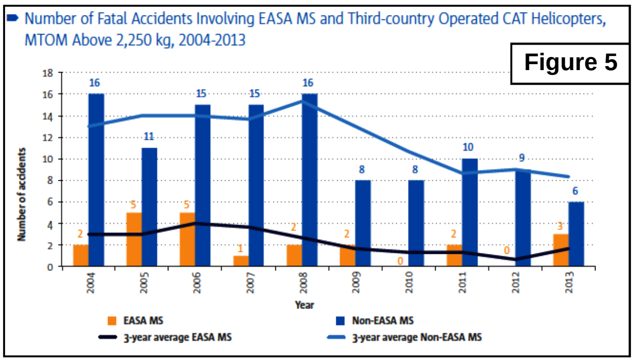
3.1.2 European statistics

Safety of helicopters is established by EASA by distinguishing only three categories of missions or operations: commercial transport, aerial work, and general aviation. From all listed accidents the EASA statistics count also fatal accidents, i.e. those which caused, at least, one death.

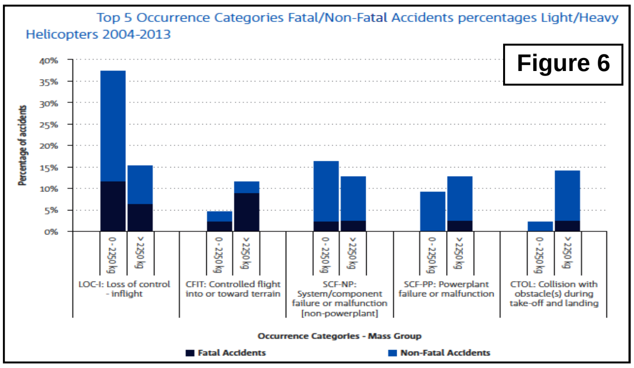
- ***Commercial Air Transport :***

This category covers passenger flights, including so-called EMS operations dedicated to medical emergencies, but also freight transport and ferry flights.
In 2013 in EASA member states 7 crashes of helicopters occurred in commercial transport operations [2], for all categories of mass, and 3 of them were fatal and led to 10 deaths.
Figure 5 below compares over the period 2004-2013 the fatalities in EASA countries with those of all the other countries for helicopters heavier than 2.25 tons.
These statistics are consistent with the trend noted previously. They reflect the lack of improvement in

safety obtained over these past five years in the European commercial transportation by helicopter.



On the 2004-2013 period, comparing the so-called heavy helicopters (M >2.25t) and the light ones (M < 2.25t), Figure 6 shows the most frequently encountered occurrences of an accident while distinguishing the number of fatal accidents from all accidents. The different occurrences mentioned correspond to the ADREP taxonomy [3] defined by ICAO, the international civil aviation organisation.
It can be seen in Figure 6, extracted from EASA report [2], that the loss of control in flight (LOC-I) occurs predominantly on light aircraft. This figure also indicates that impacts on the ground in controlled flight (CFIT) and collisions with obstacles during take-off or landing (CTOL) are more common on heavy aircraft than on the light ones. However, these differences are quite difficult to explain without analysing in detail the accident scenario and the actual causes leading to the crash.



- ***Aerial work :***

Aerial work includes all of the flights made for service activities in agriculture, construction, photography, surveillance, observation, inspection, civil security, or aerial advertising.
Table 1 below provides an overview of accidents which occurred in recent years for aeroplanes and helicopters of EASA countries [2]. Similar trends can be observed for these two types of aircraft. In particular, it can be noted the absence of any significant safety improvement, and even some deterioration in terms of mortality by accident in 2012 and 2013.

For helicopters, two types of occurrence are most frequent in this category of operation, namely loss of control in flight (LOC-I) but also low-level (LALT) operations.

Overview of Number of Accidents, Fatal Accidents and Fatalities by Aircraft Category and Operation Type, All Mass Categories, all EASA MS Registered Aerial Work Aircraft

Table 1

Aircraft category	Period	Number of all accidents	Fatal accidents	Fatalities on board	Ground fatalities
Aeroplanes	2002-2011 (average per year)	23.9	4.6	7.9	0
	2012	35	5	12	0
	2013	21	3	13	0
Helicopters	2002-2011 (average per year)	28.9	5.1	9.2	1.4
	2012	32	8	12	0
	2013	22	5	12	0

- ***General Aviation :***

General aviation covers all civil aviation operations other than those listed in the other two categories: commercial transport and aerial work.
For helicopters heavier than 2.25t, operating in different countries members of EASA in general aviation, the year 2013 recorded four accidents, none was fatal.
However, the category of light aircraft (M<2.25t), which is quantitatively more important, was much more dangerous since 52 accidents were counted, and 9 fatal accidents have led to the occurrence of 16 deaths. These figures of 2013 are indeed quite equivalent to average annual statistics for the period 2008-2012.They underline the character 'dangerous' in this category and therefore also confirm a stagnation of progress in flight safety in recent years.

For the period 2009-2013, statistics in EASA countries[2] related to the type of accidents in this category, indicate again that the loss of control in flight (LOC-I) is very common, and that it causes, unfortunately, the highest fatality. In second place comes the occurrence of engine failure (SCF - PP) but which is however slightly less deadly than the fire after impact (F-POST).

3.1.3 Conclusion on accident statistics:

In conclusion on the accidents of civil helicopters in EASA, for all categories of operations it turns out that the safety of flight did not progress significantly in recent years, and consequently targets expected by IHST or ACARE should not be met. Some efforts must be redoubled to improve safety.
However the statistics underline also clearly significant differences between the categories of operations. The characteristics of the different types of operations are involved in a meaningful way on helicopter flight safety; it should be analysed in detail to find out solutions.

It can be noticed however that to better assess the progress it would have been appropriate to get knowledge about the accident rates which take into account the number of flights or flight hours achieved in the year. These indicators are certainly more relevant to the extent they consider the magnitude of helicopter uses. Unfortunately, these data are not published by EASA, they are possibly not easily accessible, in particular for general aviation?

For the three categories of helicopter missions listed by EASA loss of control in flight is clearly the most frequent occurrence of an accident, including in fatal accidents. Among the 34 types of accident occurrence used and referenced in the ADREP taxonomy, statistics reveal also a significant number of accidents involving operations at low altitude (LALT), engine failure or system (CWS), impacts on the ground in controlled flight (CFIT), obstacle collisions at take-off or landing (CTOL) and fires after impact (F-POST).

The type of occurrence of an accident provides only a partial indication about the nature of the accident and does not allow identifying the causes. For the same type of occurrence, causes may be various (material, human or environmental) but also plural, consecutive of the superposition of several causal elements or the succession of contributing events.

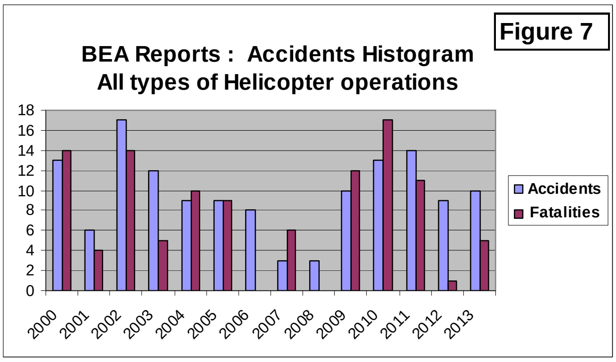
Imagine the technologies that will address the deficiencies in flight safety requires a more detailed examination of accidents caught in their own operational context, by studying precisely each scenario with its succession of situations and in analysing systems and human behaviours. With this in mind, the second part of this chapter deals with the existing reports of helicopter accidents that occurred in recent years in France.

3.2 Accident Reports Analysis

Each country member of EASA analyses the accidents occurring on its territory and publishes synthesis reports. In France, it is the BEA which is responsible for analysing and reporting on accidents in the civil field. These reports are available on the web via the address: http://www.bea.aero.

Over the period 2000-2013, the BEA published 136 reports of helicopter accidents which caused 108 deaths. Figure 7 below shows over this period the histogram of helicopters crashes analysed by the BEA and the fatalities that occurred in France. It shows a very strong annual variability of accidents as well as mortality, not leaving a tendency to the decrease, even in considering larger periods of time.

On the basis of different information collected (mechanical expertise, flight data records, testimonials...) every BEA report aims to reconstruct the events of flight and to determine the causes of the accident. These reports are a source of valuable information to identify technology solutions likely to avoid the crash and to assess the relevance of these solutions with regard to flight safety. This objective, however, requires a prior work of analysis on every accident report.



Tables 2-1 and 2-2 below are based on examination of the 136 BEA reports. A classification according to three categories of factors was carried out for each accident: its domain of activity (or type of operation), the human or cognitive factors involved in the accident, and the technical factors related to the helicopter or to environmental conditions. If every accident corresponds to a unique domain of activity, in contrast the accident is often the result of a sequence of several human and/or technical factors.

Table 2-1: BEA reports – Activity Domains

Activity Domains / Operation Types	
General Aviation	45
Aerial Work	43
Transport commercial	18
Training - Instruction	26
Rescue	4

Table 2-2: BEA reports – Causal Factors

Human Factors, Cognition	
Training, compliance to procedure	49
Lack of attention/ vigilance	41
Overconfidence	38
Decision making	28
Technical or Environmental Problems	
Power limits	19
Meteorology-Visibility	18
Wind	17
Autorotation	12
Maintenance	11
Surface conditions	7
Loss of control in yaw	6
Engine	4
Vortex	3

Although they have not been listed according to a detailed taxonomy, these indicative elements, identified on a substantial number of reports, helped to identify accident key factors. They have thus contributed to the reflection on embedded functions or technologies that could reduce the number of accidents. These elements extracted from the BEA reports will be also discussed in the §4 below. This chapter presents the work of EHSAT-France which has been dedicated to analysing accidents and their causes in using ADREP taxonomy where the Standard Problem Statement (SPS), i.e. the causal factors, are described according to a granularity compound of three distinct levels of definition.

4. EHSAT- France working group

4.1 Position of EHSAT-France in the overall organization:

Twelve others European countries have also created their own analysis working group (GB, A, E, I, NL etc.) and they applied the same methodology with the same tool.

4.2 Composition of the French group:

The French analysis team brings together experts from different backgrounds in the helicopter's world: differently sized operators, officials and state services, associations of operators, a research centre and a helicopter manufacturer.

4.3 Perimeter of EHSAT study

<u>Inclusion criteria:</u>

- Accident or serious incident (Annex 13, ICAO)
- Occurred between 01/01/2000 and 31/12/2010
- Occurred on the national territory.
- Mainly civilian events (some military events)
- Final accident report available (public access)

<u>Number of events included in the study:</u>

- EHSAT database: 121 events (25/09/2014)
- BEA : 117 (Included 12 in 2011 not used for the synthesis)
- BEAD-air : 7 events (Not used for the synthesis)
- Total: 98 events analysed and took into account for the preliminary results.

<u>Identified factors (SPS – HFACS)</u>

- List of standardised problems (SPS): 569 SPS factors identified for 98 events. These SPS are defined and structured according to a granulometry at 3 levels, SPS level 1 are more general while SPS level 3 are more detailed. For example, for an accident which occurred following a glare of the pilot by the sun, the identified SPS could be classified according to the 3 levels of following SPS : (1) 'Pilot Situation Awareness' ; (2) 'Visibility/Weather' ; (3)' Reduced visibility – sun/glare'.
- Analysis grid and classification of human factors aspects (HFACS): 371 HFACS factors identified for 98 events.

<u>Remarks :</u>

- Several SPS and HFACS factors identified by event.
- A given human factor problem can be coded with a SPS factor and a HFACS factor.

4.4 Analysis methodology

- Common analysis tool for all the regional teams: provided by EHEST.
- General information on the event: Usage of the ADREP 2000 taxonomy of ICAO.
- List of standardised problems (Classification SPS): List of potential problems described by flight phases.
- Analysis grid and human factors aspect classification (HFACS): Wiegmann & Shappell, 2001.

An analysis database was thus constituted for the helicopter accidents which occurred in France in the period 2000-2010. In addition to the inventory of standard problems (SPS, HFACS), this database included, for a given accident, the recommendations provided by the French experts group. When the work of the CTHC group took place, recommendations had been expressed and validated for 42 accidents of the database. These have been taken into account by the CTHC for identification of functional requirements and of technologies for safe flight.

4.5 Results of the French EHSAT analysis Vs Europe (% accidents)

In Figure 8 the most recurring SPS of level 1 are presented in percentage 8 in comparing results in France (in blue) and in Europe (salmon colour).

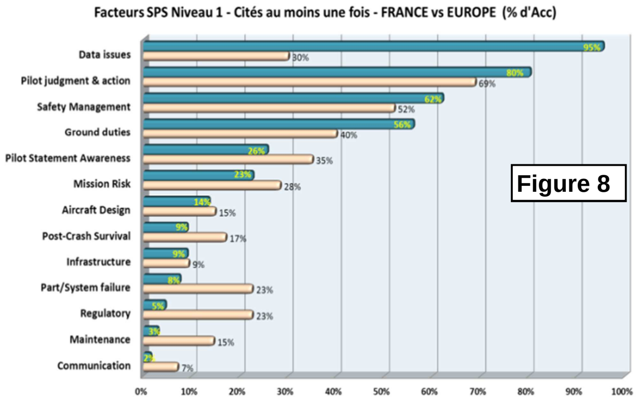


Figure 8

5. ACCIDENTS and TECHNOLOGIES

To propose functions or technologies that could improve flight safety of helicopters CTHC considered two different time horizons: an "immediate" vision corresponding to the current operations of helicopters, and a long-term vision taking into account expected developments and evolutions of these operations in 2050.

The CTHC Working Group based its discussions on two elements at its disposal:

- studies and results of the work of EHEST, in particular the report in reference [4],
- BEA accident reports accessible on its website.

EHEST study[4] highlights a panel of technologies at different levels of maturity in front of the main causes of accidents (SPS) identified previously by the European partners in EHSAT work which was presented above in the §4. After analysis and evaluation the EHSIT-ST Technology Group of EHEST, selected 15 priority technologies considered as very promising [4]. According to the criteria used by the European Group (its impact on safety and its applicability in terms of TRL and cost), these technologies are considered as the most likely to have an effective impact on the flight safety.

The 15 EHEST priority technologies[4] were selected from a panel of technologies established by the EHSIT-ST Technology group mainly on the basis of existing publications and information sources; and in itself, this group had no vocation to define other technologies outside this panel. This report, therefore, constituted a good starting point for the CTHC Working Group, and it deserved to be completed.

Meanwhile, the EHSAT-France group has established a data file from reports of helicopter accidents analysed by the BEA or BEAD-air (military aircraft), over the period 2000-2010. These data were studied according to the method described in the §4 to identify causes of accidents, the SPS factors. Following the analysis made by its experts, EHSAT-F expressed recommendations issued from 42 accidents of the database. Many of them formulate responses to human factor issues: on pilot training, on the culture of safety, on risk assessment by the pilot, etc. These considerations will be taken up then later in the document.

CTHC extracted from this data file the SPS at level 2 in the ADREP taxonomy. Level 2 has the advantage of being neither too general nor too detailed and represents a family of problems encountered in flight for which technological solutions seem possible.
These most recurrent SPS are presented in Appendix 1 with their number of occurrences identified in the 42 accident reports. Considering a given technology and its potential influence on SPS, this outcome contributes to qualify its impact on helicopter flight safety.
It will be noted that the last SPS is not in itself a causal factor, but it is considered important by the working group because this technology can facilitate and deepen the post-accident investigation work and therefore the experience feedback which is a strong means of improving the safety of flights.

However, it is also important to note that such data give only a partial view of the problem of the helicopter accidentology in the world. This is due to the specificity of the rotary wing fleet in France, that has very little class FAR/CS29 helicopter operators. In fact, in their vast majority accidents are related to operations of general aviation and aerial work. In France the commercial transportation of passengers (according to the EASA definition) is only present at a limited extent (some services from Issy les Moulineaux and Monaco).

On his side, the CTHC Working Group was interested in first to functional aspects. Starting from analyses of actual accident cases, functions were defined without necessarily implying the existence of a technology implementation, even if for most of these proposals it can exist some technical solutions at different stages of maturity. In the light of the elements identified in the accident report analyses, the Working Group has been able to determine, independently, a list of 34 technical functions offering a potential for improving flight safety in regard to their expected impact on the accident causes. The list of these 34 identified functions is presented in Appendix 2.

However, for helicopter operations, it is impossible to establish general recommendations. Many contextual elements deserve to be considered taking into account the intrinsic diversity of these operations, the regulations and requirements governing them, but also the structure and financial capability of the operators. Indeed, it is not realistic to ask a private owner of a light machine to apply what is due from a company with a fleet of helicopters providing passenger transport. The Working Group has therefore made a careful reading of the 136 helicopter accident reports issued by the BEA in order to contextualise as much as possible each accident case.

The applicability of the functions was evaluated against each of the 5 types of activity domains in Table 2-1, considering their own specificities.

According to EASA classification, training and rescue activities are not listed separately but fall into one of the first three categories. However, these activities have their own characteristics, their own type of flight operations as well as their own risk and hazard exposures. Thus, to analyse safety and accidents the Working Group decided to consider the 5 activity domains as defined in Table 2-1.

To assess the applicability of a function in air operations, it seems necessary to take into account the associated regulatory constraints. Indeed, according to the level of *criticality* of the function on flight safety, its certification may require more or less efforts. A good example is the Electronic Flight Bag, for which three levels of implementation can be envisaged:
- EFB on autonomous equipment like a tablet, that is unrelated to the aircraft,
- EFB presented in the aircraft system, but unrelated to the flight parameters,
- EFB presented in the aircraft system with integration of current flight data.

Take into account the criticality level of a function, as a criterion, seems important given its direct effect on the design constraints for its implementation (for example, the required level of redundancy), as well as on the constraints required into operations (for example, the obligations of updating a database). Such requirements may be dissuasive for some manufacturers or operators.

Another relevant criterion is the level of *technology readiness.* This criterion is not used to compare the relevance of functions between them, but only to differentiate the implementable functions in the short, medium or long term. Indeed, if a function has a very high potential for improving safety but its current technology readiness level does not allow its use in the short term, then certification authorities, manufacturers and research centres must push their developments to bring these technologies to the level required.

To complement the concept of applicability of a technology, it is also necessary to consider certain adjoining elements. The Group has considered:
- the concept of *third-party service*,
- the *training* elements related to the implementation of the technology into aircraft.

The concept of third-party service appears when a function needs calling to a service provider different from manufacturer/operator/authority. An example is the transmission of current weather conditions via a satellite service. This service exists in North America. It is integrated with many GPS receivers, but there is no equivalent central service provider in Europe. The lack of adequate third party can make inapplicable a technology.

Finally, *costs* were also assessed qualitatively. The cost estimated here is only relative to acquisition costs, excluding costs of development, maintenance, and the additional operating costs that may result from third-party services as mentioned previously. However cost evaluation can be very approximate especially when the technology readiness level is low.
Figure 9 schematically shows the process used to assess applicability of candidate technical functions or technologies.

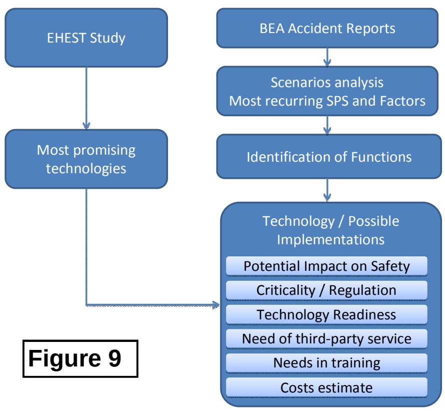


Figure 9

This methodology of assessment allowed bringing out a consensus in the Working Group to select priority functions for helicopter flight safety.

For each criterion (impact, criticality, cost, etc.) the Working Group has selected five levels of importance. The evaluation was conducted collectively inside the CTHC Working Group. Each member was bringing its own evaluation/rating criteria for the 34 candidate functions. Ratings of criteria were then taken over to deduce the interest of the function with regards to flight safety and operational use in a helicopter.

6. PRIORITY TECHNOLOGIES

A review of assessments permitted to identify 16 'priority' functions/technologies.

In Appendix 2 the CTHC priority technologies or functions are presented according to two distinct groups depending on their level of maturity or technology readiness.

Comparing outcomes of CTHC and EHEST studies it can be noted that 6 priority technologies are common or apparently similar. They are indicated with an asterisk (*) in the table of appendix 2.

6.1 Mature Technologies:

Technologies are considered as ‘Mature’ if they are a priori available to be readily implemented and usable on aircraft. These technologies may possibly require a few developments for their adaptation to the helicopter or to improve their performance so that they can respond effectively to operational requirements. However, the development work they require is considered as sufficiently limited to envisage their implementation on a helicopter in the short term.

In the table of Appendix 2 the functions or technologies indicated in green colour and with the ‘Mat’ priority index are the 6 ‘mature’ technologies selected by CTHC according to criteria rating.

6.2 Technologies to develop:

These technical functions require some research and developments in order to achieve an effective technology that will be integrated operationally on the helicopter in 2050. Some of them can generate several types of implementation and different characteristics, leading thereby to technologies with different levels of performance in terms of impact, and applicability.
In the table of Appendix 2 the 10 priority technologies to be developed that have been selected in accordance to criteria rating are those colored in blue and with the ‘To Dev’ priority index.

6.3 Specification forms:

Moreover, to provide a vision as complete as possible of each selected priority function/technology, one specification form has been established. Appendix 3 presents the form format used to specify the priority functions/technologies. It expresses the functions which are expected from the technology and includes also the tentative definitions of its features, its implementation options, its technical characteristics and other needs and requirements that could be required in operation.
CTHC group members have filled in the specifications for each of the selected functions or technologies, as accurately and completely as possible at this level of study. However, for a given technology all sections of the specification form are not necessarily relevant or easy to inform today.

7. CONCLUSIONS and RECOMMENDATIONS

To identify technologies for flight safety of helicopters the CTHC approach was mainly based on the analysis of accident scenarios. In a first step, the expression of technical needs was issued. These needs were then expressed in the definition of 34 technical functions (Appendix 2).

These functions were then assessed by the Group in a process (Figure 9) which involves a set of criteria relative to their estimated performance and applicability according to the implementation constraints of the technology.

From this assessment,16 technologies were deemed as major to improve helicopter flight safety. Among them, 6 technologies are considered to be sufficiently 'mature' (‘Mat’ index) and could be implemented in the relatively short term, while 10 other technologies (‘To Dev’ index) require efforts of research and development in order to make effective their use in flight before the year 2050.

If some technological functions contribute to the prevention of accidents by promoting safety actions before the flight (ex: installation of HUMS, or FDR/CVR recorder), most of the proposed embedded functions operate directly during the flight in order to avoid accident. Several technologies contribute particularly to improve the situation awareness of the pilot with respect to flight domain limits or to environmental conditions (for example functions: HTAWS, Rotor and tail proximity warning system; Active controls with force feedback; Obstacle avoidance system, etc.). But often they also contribute to lowering pilot workload in providing assistance to flight control or to decision making, especially in critical or complex situations. For example, this can be realized by providing to the

pilot a better understanding of the environment, knowledge about en route weather, or in providing assistance to the flight in autorotation, in improving his perception of the environment through an enhanced vision, etc.
The CTHC, therefore, recommends that efforts of research, development and implementation of these priority technologies are conducted and supported as soon as possible.

The current approach of flight safety relies mainly on the analysis of recent accidents in order to identify their causes. However given their current number, accident analyses do not provide themselves with all relevant items leading to an improvement of helicopter flight safety. This approach has reached its limits and it is definitely time to change this approach to safety management in order to lower the accident rate. To do this, it is necessary to extend the means of observation of the reality of helicopter operations to get the elements necessary to assess the real risks and make accordingly the relevant decisions. This development is comparable to that experienced by the commercial air transport of passengers, but must be managed specifically to the field of helicopters.

Thus, methods for analysing the experience feedbacks should be also developed and extended to the systematic analysis of the flights in order to monitor flight safety and its evolution according to operational conditions and aircraft uses. These analysis results will make it possible to obtain a more precise and objective assessment of its progress. They will also allow speeding up the necessary adjustments for its improvement. Improving flight safety should thus fit into a global and dynamic process that could be controlled in 'closed loop'.

While it is clear that technology can have a significant beneficial effect on the safety of helicopter operations, it is also evident that technology cannot cover all safety aspects and resolve itself all the problems that can arise in flight. In fact, some specific human factors play also a very important role in safety as indicated in the analysis of helicopter accident reports. Therefore, the development and implementation of technologies must be accompanied by specific actions relative to human factors: through increased training, awareness of crews about risks and hazards encountered in flight, through the development of a culture of safety, with the implementation of SMS among operators, etc. Such actions are fully in line with the recommendations that have been made by EHSAT. Finally, it should be recalled that human factors are also to be taken into account from the design phase of these technologies, in a 'human-centred design' process, especially to design the user interface of technology and modes of interaction between human and systems.

8. COMMENTS OF HELICOPTER OPERATORS

The CTHC Working Group presented its work to a panel of several helicopter operators. The audience members expressed their remarks and opinions on the technologies during the discussion which followed.

Remarks on some given technologies were noted, but in a general way, the operators expressed the opinion that the priority should be focused on systems which improve at the same time flight safety and operational efficiency. As such the systems which intervene on-line, 'to relieve' the control and navigation tasks of the pilot are considered as very interesting.

However, through the evolutions and developments that the technologies can bring, the operators recommended avoiding too strong standardisations of the processes and flight procedures. They consider that the pilot must keep the choice of its actions/decisions for controlling and managing flight. Aids to the pilot and assistance systems are deemed preferable to systems and\or procedures too strongly automated.

9. REFERENCES

[1] « Strategic Research & Innovation Agenda » , Volume 1 – ACARE, September 2012

[2] « Annual Safety Review 2013 » - EASA 06/2014

[3]http://www.icao.int/safety/airnavigation/AIG/Pages/ADREP-Taxonomies.aspx

[4] « The Potential of Technologies to Mitigate Helicopter Accident Factors – An EHEST Study » - NLR-TP-2014-311 v1.0

[5]https://www.aea.net/events/rotorcraft/files/Jan2013/FAA_Rotorcraft_Statistics.pdf

Appendix1: Occurrence of level 2 SPS identified by EHSAT-France

Main SPS - Level 2	Types of problem addressed	Nb of Occurrences
Pilot judgment & actions / Human Factors – Pilot's Decision	Compliance to procedures and flight rules Evaluation of pilot limits and abilities, decision-making	69
Ground Duties / Mission Planning	Flight planning: taking account of aircraft performances, terrain, wind...	49
Safety Management / Inadequate Pilot Experience	Inexperience of the pilot Insufficient knowledge	35
Pilot judgment & actions / Human Factors – Pilot/Aircraft Interface	Erreurs de jugement en perception, distraction, fatigue, manque de vigilance	27
Pilot judgment & actions / Flight Profile	Errors in judgement, in perception, distraction, fatigue, lack of vigilance	27
Pilot Situation Awareness / External Environment Awareness	Obstacles, Cables, Detection of traffic, recognition of the aircraft state, altitude…	20
Pilot Situation Awareness / Visibility & Weather	Degraded visibility (fog, night, Sun...), inadvertent entry into IMC, en route weather	17
Data Issues / Inadequate information in report	Incomplete or insufficient information in the report	97

Appendix 2 : The 34 candidate Technologies for Flight Safety

Priority Index	Technical Functions for Flight Safety
To Dev (*)	**Calculator/display of real-time performance at take-off and landing with alert. Taking into account: mass, centering, p_s, T°, H, terrain and obstacles, wind. Provide recommendations for takeoff procedure (e.g.: mini Vi HES)**
Mat	**Indications in flight on current power, and power limits**
Mat (*)	**HTAWS (using a database of terrain and fixed obstacles) – Intelligent system with adaptation to helicopter operations.**
To Dev	**Rotors and tail proximity warning system / obstacles (with 3D sound ?)**
-	Integration in the flight control system of a function preventing from rotor-airframe interferences
To Dev	**Embedded device to display weather conditions on the flight plan: - Indications of cloud masses, icing zones, wind... - Periodical updates online: GSM (satellite?), 3G or 4G, specific TD?**
To Dev (*)	**System to detect obstacles and cables (OWS): real-time active system, for cables of 1 cm in diameter.**
Mat (*)	**Cable cutter device**
To Dev (*)	**Aid to terrain knowledge: digital mapping including position of lines, with warning if risk of collision. Recommendation: cross-checking of different databases sources (e.g. IGN, ICAO, EDF... low voltage lines and other obstacles to low altitude helicopter flight).**
Mat	**Audible alarm in case of 'low rotor rate' to implement on all aircraft**
To Dev	**Loss of yaw control avoidance system**
-	Training tool in-service monitoring the pilot abilities (laptop software & simulator?)

-	Online aid to conduct flight procedures
-	« Eyes Out » Concept : allows the pilot to keep his look out of the cockpit
To Dev	**Low air speed measurement system**
To Dev	**Pilot assistance or automated system for autorotation flight**
-	Assistance to landing/ditching in emergency
-	Fonction de détermination de la hauteur sol, par exemple au moyen d'une radio sonde altimétrique fiable
To Dev	**Flight envelope protection functions (w.r. to VRS, engine or mast torque limits, BTP limits, NR limits,...) in using a force feedback control system.**
To Dev	**Enhanced or combined vision system for all weather flight**
-	System of on board supervision and monitoring comprising various functions, e.g.: online coherence analysis of various signals (failure detection, system degradation), recognition of the current flight phase and its incurred risks
-	Voice command system (emergency situations, aerial work, military operations)
-	Pilot activity monitoring, pilot surveillance (detection of deviations in pilot activities, output of control loop...)
-	Interconnection of helicopter with internet via broadband data link
-	System of remote sensing of atmospheric turbulence and wake vortex
-	Mid-Air Collision Avoidance System, including with respect to RPAS, gliders and very light aircraft
-	Navigation/Guidance using EGNOS technology
-	Facilitate employment of helicopter in IMC - IFR, generalization of the Autopilot
Mat (*)	**FDR / CVR / Datalink Recording system**
Mat	**HUMS with advanced techniques of data analysis**
-	Adaptive control laws
-	Experience Feedback Methodology: Systematic analysis of flight data, recordings
-	Automatic broadcast of emergency messages
-	Real-time tracking of 3D trajectories

(*) Priority technology common or similar to EHSIT-ST proposal [4]

Appendix 3: Specification form of a priority technology

FUNCTION : "NAME"

Description of the function / existing needs :

…

Possible Implementation(s):

….

Applicability by operation type:

Operation type	Relevance
Commercial Transport	High/Medium/Low
Aerial Work	
General Aviation	
Instruction - Training	
Rescue	

Mass: *class: 1/10/50/100kg ?*

Accessibility by aircraft category:

Aircraft Category	Accessibility
<1000kg, mono engine	Easy/Medium/Hard
<3150kg, mono engine	
<3150kg, twin engine	
>3150kg, twin engine	

Readiness/Present development state:

Possibly its efficiency was demonstrated in another frame that helicopter (airplane, military, etc.)?

Need for a specific third-party service:

….

Need for specific training:

….

Regulatory status: *Imposed by the certification or operational rules? In what case? Should it extend to other cases, in all cases? If technology is new: foreseeable impact in terms of certification effort? Possible recommendation by the group for proposing an amendment to existing regulations in order to take into account this function?*

Operational acceptability: *Point of view from helicopter operators or pilots?*

Possible adverse secondary effects: *For example: overconfidence*