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NLR-TP-2018-470 | November 2018

The potential of technologies to mitigate helicopter accident factors

Status update and way forward

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The potential of technologies to mitigate helicopter accident factors

Status update and way forward



Soucre: Airbus Helicopters

Problem area

Technology is not high on the list of highest ranking accident / incident factors, as it is merely the lack of technology that may have led to an accident. Technology provides a variety of solutions that can (directly or indirectly) address the identified safety issues and contribute to prevent various types of accidents or to increase survivability.

In 2011 EHEST's Specialist Team (ST) Technology was created with the objective to assess the potential of technologies to mitigate accident factors. The team identified 15 'highly promising' technologies that jointly can potentially mitigate 11 of the top 20 safety issues. Recommendations were given to industry, regulatory authorities, researchers and universities to act upon the conclusions. As the previous study dates back to mid-2014 the questions arose about the current status of those identified technologies and what other initiatives for safety promotion are being exploited.

Description of work

The European Plan for Aviation Safety (EPAS) 2018-2022 includes an action to promote technologies that will provide helicopter safety benefits. This action is a

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follow-up to the initial Research Action (RA) to identify promising helicopter technologies, which study led to the aforementioned 15 'highly promising' technologies. Starting from those identified technologies various sources have been consulted to find additional information regarding their status. In parallel several new, emerging technologies to enhance helicopter flight safety have been identified. EASA's Annual Safety Report 2017 has been used to distil the current safety concerns in order to lay the foundation for the EPAS action 'to promote technologies that will provide helicopter safety benefits'. A way forward regarding the EPAS action has been defined based on the lessons learned from previous work in the ST Technology and from other initiatives that are being exploited.

Results and conclusions

The 'highly promising' technologies have evolved towards a higher Technology Readiness Level. Other more recent safety enhancing technologies have been identified. Certain new or adapted regulations have been put in place. For the period 2012-2016 safety issues have been identified for operations related to Commercial Air Transport (both Offshore and Other), Specialised Operations and Non-Commercial Operations. Technological developments can help mitigate those safety issues. The ST Technology process provided traceable and unambiguous findings, but was quite challenging. Such a process will always be reactive as it is based on actual accident data. This will also make it challenging to anticipate on new technologies to mitigate future safety concerns. Various helicopter organisations and EASA deliver programmes to enhance helicopter flight safety through technical solutions, guidance material and training, or through rulemaking tasks, research projects and safety promotion. The study recommends to:

- Assess whether certain technologies that are being used in helicopter offshore operations can equally be adopted in other operations;
- Identify for which technical, operational and human factors related safety issues the application of technologies might be useful;
- Explore the possibilities to develop a proactive approach to enable an early focus on safety benefiting technologies for future safety concerns, initially concentrating on identifying areas for which technologies could be developed.

Applicability

The results of the underlying study, and especially the recommendations, provide the way forward for further investigations into technologies that can mitigate safety issues and lay the foundation for the EPAS action to promote technologies that will provide helicopter safety benefits.

GENERAL NOTE

This report is based on a presentation held at the European Rotorcraft Forum (ERF), Delft, The Netherlands, September 19-20, 2018.

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Summary

Technology is not high on the list of most important accident / incident factors, as it is merely the lack of technology that may have led to an accident. However, technology provides a variety of solutions that can (directly or indirectly) address the identified safety issues and contribute to prevent various types of accidents or to increase survivability. In mid-2014 the Specialist Team (ST) Technology, under the aegis of the European Helicopter Safety Team (EHEST) concluded that 15 'highly promising' technologies jointly could potentially mitigate 11 of the top 20 helicopter safety issues, that five technologies were highly promising for three or more safety issues, and that there were three safety issues for which no potential promising technology have been identified. The current European Plan for Aviation Safety (EPAS) 2018-2022 includes an action to 'promote technologies that will provide helicopter safety benefits', which action is attributed to the European Safety Promotion Network Rotorcraft (ESPN-R) as successor of the EHEST initiative. In light of this action the questions arose what is the current status of those 'highly promising' technologies, how can this EPAS action be targeting the right technologies, and what could be a viable way forward.

This paper presents an update regarding the status of the 15 identified 'highly promising' helicopter technologies. All of these have progressed towards a higher Technology Readiness Level (TRL) with various solutions being available on the market and being employed. Some additional safety enhancing technologies have been identified that in recent years either have been developed or became available on the market.

Furthermore the paper lays the foundation for the aforementioned EPAS action by distilling safety concerns for the period 2012-2016 from the EASA Annual Safety Report 2017. For various types of operation the key risk areas have been identified, which then have been translated into technical and/or operational and/or human factors safety issues. Technological developments can help mitigate those safety issues.

Finally it recommends the way forward for the EPAS action. This is not only based on the lessons learned from the former ST Technology, but also on other initiatives that have come to light. Various helicopter industry-wide (trade) organisations have developed programmes, including technical solutions, guidance material and training. And EASA concentrates on rulemaking tasks, research projects and safety promotion. It is recommended to:

- Assess whether specific technologies that are being used in Offshore operations can equally be adopted in other Commercial Air Transport and/or Specialised Operations;
- Identify for which technical, operational and human factors related safety issues the application of technologies might be useful;
- Explore the possibilities to develop a proactive approach to enable an early focus on safety benefiting technologies for future safety concerns through assessing the potential type of accident and contributing factors, not only for current but also for future operations, and the development of an associated and periodically updated roadmap.

It is the intention that these recommendations will be addressed by a new ST Technology.

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Abbreviations

ACRONYM	DESCRIPTION
ACRM	Aeromedical Crew Resource Management
AFCS	Automatic Flight Control System
APS	Accreditation Program of Safety
ASCENT	Active Simulator Cockpit Enhancement
CASA	Civil Aviation Safety Authority (of Australia)
CAT	Commercial Air Transport
CFIT	Controlled Flight Into Terrain
CIRS	Cockpit Information Recorder System
CPD	Collective Pull Down
CVFDR	Cockpit Voice and Flight Data Recorder
EAGLE	Eye for Autonomous Guidance and Landing Extension
EASA	European Aviation Safety Agency
EBS	Emergency Breathing System
ECG	Electro Cardio Gram
EEJ	Emergency Exit Jettison
EHAC	European HEMS & Air Ambulance Committee
EHEST	European HELicopter Safety Team
EHSAT	European Helicopter Safety Analysis Team
EHSIT	European Helicopter Safety Implementation Team
ELT	Emergency Locator Transmitter
ENG	Electronic News Gathering
EPAS	European Plan for Aviation Safety
ERF	European Rotorcraft Forum
ESPN-R	European Safety Promotion Network Rotorcraft
EU	European Union
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FCOM	Flight Crew Operating Manual
FDM	Fight Data Monitoring
FDR	Flight Data Recorder
FOQA	Flight Operations Quality Assurance
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HAI	Helicopter Association International
HEED	Helicopter Emergency Egress Device

ACRONYM	DESCRIPTION
HELLAS	HELIcopter LASer
HEMS	Helicopter Emergency Medical Services
HERO	Helicopter Emergency Release Operator
HFDM	Helicopter Flight Data Monitoring
HOFO	Helicopter OFFshore Operations
HOMP	Helicopter Operations Monitoring Programme
HTAWS	Helicopter Terrain Awareness and Warning System
HUMS	Health and Usage Monitoring System
IFR	Instrument Flight Rules
IWA	Immersive Witness Analyzer
IWI	Immersive Witness Interview
LOAM	Laser Obstacle Avoidance and Monitoring
MFD	Multi-Function Display
NCO	Non-Commercial Operations
NEHA	National E-N-G Helicopter Association
NLR	Netherlands Aerospace Centre
NTSB	National Transportation Safety Board
OCAS	Obstacle Collision Avoidance System
OPS	OPerationS
RES	RESearch action
RMT	Rule Making Task
SPA	SPecific Approvals
SPO	SPecialised Operations
SPT	Safety Promotion Task
ST	Specialist Team
STASS	Short Term Air Supply System
TAWS	Terrain Awareness and Warning System
TRL	Technology Readiness Level
UPAC	Utilities, Patrol and Construction Committee
VHF	Very High Frequency
VHM	Vibration Health Monitoring
WSPS	Wire Strike Protection System

1 Introduction

1.1 Background

The former European Helicopter Safety Team (EHST) contained two major sub-teams: the European Helicopter Safety Analysis Team (EHSAT) and the European Helicopter Safety Implementation Team (EHSIT). In March 2011 EHST created the EHSIT's Specialist Team (ST) Technology with the objective to assess the potential of existing and emerging technologies to mitigate accident factors. The results were published in report NLR-TP-2014-311 [1], which concluded that 15 'highly promising' technologies jointly can potentially mitigate 11 of the top 20 safety issues, that five technologies are highly promising for three or more safety issues, and that there are three safety issues for which no potential promising technology has been identified. Furthermore it was recommended to the industry to channel their technological development in line with the results of the study. The regulatory side should find ways to improve safety by adopting the technologies. Researchers and universities were encouraged to concentrate their efforts on developing the lacking technologies and the technologies which have a low Technology Readiness Level (TRL). Since 2017 the EHST initiative is continued under the umbrella of the European Safety Promotion Network Rotorcraft (ESPN-R). The European Plan for Aviation Safety (EPAS) 2018-2022 includes an action to 'promote technologies that will provide helicopter safety benefits' (thus providing an update of the previous study). As that previous study dates back to mid-2014, and in light of this EPAS action, the following questions arose: what is the current status of the 'highly promising' technologies; how can this action target the right technologies; and what will be the way forward?

1.2 Aim and objectives

This paper mainly aims to provide an update to the previously published report.

Chapter 2 provides an update to the previous report regarding the status of the 15 identified 'highly promising' helicopter technologies, and also regarding the status of the safety concerns for which technologies are lacking.

Chapter 3 lays the foundation for the EPAS action by distilling the current safety concerns from the EASA Annual Safety Report 2017, instead of basing it on the EHSAT analysis as was done in the past.

Chapter 4 recommends the way forward for the EPAS action based on the lessons learned from EHSIT's ST Technology and on other initiatives that have come to light.

Finally, chapter 5 contains the conclusions and recommendations.

2 Update on technologies

2.1 Highly promising technologies

Report NLR-TP-2014-311 [1] classified 15 technologies as being ‘highly promising’. This section lists these 15 technologies, together with a status update taken from various references.

Helicopter Terrain Awareness and Warning System (HTAWS) [2, 3, 4, 5]

TAWS is a new development of the traditional Ground Proximity Warning System (GPWS). The latter had several shortcomings, like it only being able to detect terrain directly below the aircraft and not detecting the aircraft closure rate to the ground. TAWS combines a worldwide digital terrain database with an accurate navigation system. TAWS is available from several manufacturers, for fixed wing aircraft as well as for helicopters.

Large helicopters (maximum weight over 3175 kg) with a passenger seating capacity of more than 9 and flying IFR are required to carry an HTAWS. FAA Rule 135.605 requires that after 24 April 2017 all helicopter air ambulances must be equipped with HTAWS.

HTAWS, to some level, can be acquired as bolt-on equipment. Some light helicopter types, like the Robinson R44 and R66 and the Bell 505 can be equipped with integrated glass cockpits with full HTAWS support. It is then up to the owner whether or not to fully implement HTAWS.

Digital range image algorithms for flight guidance aids for helicopter low-level flight [6, 7]

Common problems that arise when planning for terrain following flights is that the dynamics of the vehicle are difficult to model, the state space is only represented in an approximate manner and detailed calculations of the subject are computationally expensive. A new planning algorithm has been developed for the vertical component of terrain-following flight paths using methods of energy, where the path itself is modelled as an elastic band deformed by virtual forces to follow the terrain. Novel to the method presented here is that complicated limitations to the dynamics of the vehicle can be treated in an effective manner. This is achieved by an adaptive linear combination of different models for the internal elastic forces.

Another terrain following approach, aimed at drone applications, makes use of a monocular vision-based height estimation algorithm for terrain following flights. It consists of using optical flow to track features from videos obtained by the air vehicle, as well as its motion information, to estimate the flying height. The approach to estimate the height was inspired by the classical stereo vision technique, but uses images from a single camera acquired at different times. The proposed methodology was evaluated both in simulations and real experiments, and the results were satisfactory.

Laser radar obstacle and terrain avoidance system [8, 9, 10]

The primary obstacles detected by the HELicopter LASer (HELLAS) radar system are wind power turbines, trees, high voltage transmission lines and other wires that cannot be easily seen by the pilot. It is in use on a variety of helicopter types from the EC135 and larger.

The Laser Obstacle Avoidance and Monitoring (LOAM) system is able to detect thin obstacles like wires and to provide terrain mapping along the flight path. The system is in use on large helicopters only, like the EH101, CH47F and NH90, and has been flight-tested on smaller helicopters, like the EC130.

Other such systems are in use on small, unmanned aircraft systems for obstacle detection and collision avoidance. These specific systems are light-weight, but have a limited detection range. From the unmanned aircraft such systems may easily find their way to light (manned) helicopters.

Finally, laser-based systems are the leading technology for automobile collision avoidance systems and also are used in driver-less cars. Those systems have a limited detection range and only need to detect fairly 'large' obstacles. However, given the growth of that area, significant technology developments and improvements are expected.

Digital map

Digital maps are nowadays available in many forms, ranging from professional types presented on glass cockpit Multi-Function Display (MFD) screens, down to tablet-like computers that are allowed to be carried and operated on-board helicopters. When coupled to a satellite positioning system receiver the maps can show the actual (2D or even 3D) helicopter position. Many databases are available, including obstacle and terrain databases. Because of the low threshold entry level of tablet-based systems, digital (moving) maps have the potential to be effectively used on-board small helicopters.

Deployable Cockpit Voice and Flight Data Recorder (CVFDR) [11, 12]

The deployable CVFDR is a new development that deploys ('ejects') the crash-survivable memory unit in case of a crash or sinking. Such a system was first announced in mid-2017. The system will be lighter, more compact, and will provide new capabilities compared to current generation of recorders. Designed to float, the crash-protected memory module containing recorded cockpit voice and flight data will be equipped with an integrated Emergency Locator Transmitter (ELT) to help rescue teams to rapidly locate and recover flight recorders.

Another system, called a deployable flight incidence recorder set, combines a flight data recorder, a cockpit voice recorder and an ELT. This system can be installed on helicopters and fixed-wing aircraft. In the event of an accident, the beacon aerofoil unit is automatically triggered by on-board sensors, launching it from the platform, and emitting a distress signal as well as the aircraft's last-known latitude and longitude, making it easier for rescuers to find survivors quickly.

Passive tower-based Obstacle Collision Avoidance System (OCAS) [13, 14, 15]

OCAS consists of units, located on utility and power line towers, that detect air traffic entering a predefined warning zone and then activates warning lights to illuminate the obstacle. It aims to alert aircraft to the structures to which it is attached, while minimising the visual impact on the surrounding environment. Radars installed on the location scan the surrounding area for nearby aircraft. If an aircraft is detected, the radar system tracks its heading, speed and altitude and gauges whether or not the aviation lights on top of the obstacles should be turned on. Once the aircraft has safely passed the site, the lights are automatically switched off again. The system has been approved by aviation authorities in the USA, Canada, Norway and Sweden. In Norway the system was shut down in late 2013 due to poor access to spare parts, but it was reactivated again in late 2015.

A new development is the IntelliLight (an expanded product solution replacing OCAS), which so far gained authority approvals in the USA, Canada, Norway, Sweden, Finland and Germany. IntelliLight is based on the same operational principle as OCAS and delivers activation of obstacle lights when needed, avoiding continuous lighting.

Miniature Cockpit Voice and Flight Data Recorder (CVFDR) [16]

The Miniature CVFDR is intended to be smaller and cheaper than the conventional CVFDR. It can have all relevant sensors (pressure, gyros, GPS) integrated in case the (helicopter) platform itself does not provide the necessary data. The lightweight versions with fully integrated flight data recorder provide a combination of cockpit voice and flight data recording, an airborne image recorder and a data link recorder. This is a system with low weight and size, but specifically aimed at flight test or military installations. If data bus information is not available, additional sensors can be installed, such as a 3-axis gyro, a 3-axis G sensor, an air pressure sensor and an internal area microphone.

Wire Strike Protection System (WSPS) [17, 18]

WSPS is a passive, low cost, low weight and maintenance free system. Wire cutters are available as an option for more than 70 models of military and commercial helicopters of all major helicopter manufacturers around the world, nowadays even down to single engine helicopters in the size of the Robinson R66 Turbine.

Flight data evaluation and processing for accident/incident investigation [19]

The system comprises devices for voice, mission and flight data recording, but also transfer of data for post-mission analysis and includes Flight Data Monitoring (FDM). This web-based application allows accessing past and current flight data, generating detailed reports, and trending the safety improvements in the operations, by providing automated flight data and events analysis. The software is typically coupled to the Vision 1000 (see next technology) and flight path visualization software and therefore also can be used for flight data evaluation and accident/ incident investigation.

Cockpit Information Recorder System (CIRS) [20, 21]

Flight Data Recorders (FDR) can provide a wealth of useful information, but in many cases these systems are too expensive for general aviation applications. A different approach is provided by the CIRS, specifically aimed at smaller helicopters. The Vision 1000 system is a self-contained, light-weight and low-cost flight data recording solution, specifically aimed at light helicopters. The system only requires aircraft power and ground, and records attitude data, position and speed data, cockpit images and sounds (ambient and intercom). It is Airbus Helicopters strategy to fit each delivered helicopter with the Vision 1000 system and provide affordable retrofit solutions for the in-service fleet, especially the light range.

Full Authority Digital Engine Control (FADEC) [22, 23]

FADEC not only provides for efficient engine operation, it also allows the manufacturer to program engine limitations and to receive engine health and maintenance reports. FADEC finds widespread use on most modern turboshaft engines in helicopters. The new Bell 505 Jet Ranger X is equipped with a full FADEC on its turboshaft engine. Although the R66 engine lacks the FADEC, its manufacturer does receive alerts of any hot-starts or over-speed conditions through an electronic monitoring unit. That serves the same purpose without adding expensive “bells-and-whistles”. Such a system however does not prevent hot-starts or over-speed conditions.

On piston engines the FADEC system effectively replaces magnetos, carburettors, mixture control and prop control. Because FADEC maintains the fuel/air ratio on each individual cylinder within narrow tolerances, it bypasses the most common cause of engine failure: mismanagement of the mixture control. The use of FADEC-equipped piston engines is not (yet) common in helicopters.

Light Helicopter Operations Monitoring Programme (HOMP) systems [24, 25]

HOMP is a preventive flight data monitoring system with the aim of improving flight safety, based on the automatic detection of previously-defined events. It is an industry standard in North Sea offshore transportation, and is being

replicated in the USA and elsewhere as FOQA (Flight Operations Quality Assurance) and HFDM (Helicopter Flight Data Monitoring). Broader implementation of FDM in the helicopter industry will be up to those operators, customers, and insurance companies who understand it and see its value. Obstacles against broader implementation of FDM may be a lack of compatibility between systems (some multi-type fleets might need a ground station per helicopter type), and a general reluctance among operators to invest in expensive safety programs without a customer requirement or regulatory mandate. The additional cost is not huge, but operators are unlikely to incur it unless they can see the value proposition.

Efficient numerical approaches for on-board rotorcraft flight performance modelling [26, 27]

Modern flight systems allow on-board in-flight performance and mission planning. Research was conducted focussing on the development and evaluation of automation techniques for aircraft flight planning and decision control in complex 3D environments. The model-based approaches describe automatable processes which are capable of making critical decisions in real-time. Beside the basic functionality with its test methods, the system includes an extensive procedural control, higher automated modes and monitoring functions. An on-board monitoring component allows the use of planning modules which can adapt to the situation, e.g. to modify the route or the task ordering.

A decoupled planning approach has been developed to perform on-board flight path planning when flying through unknown environments. The approach involves roadmap-based global path planning and local path refinement with cubic splines. It allows the planning of safe, dynamically feasible and time-efficient flight paths with limited on-board processing power. The results demonstrate that close-to-optimal flight paths can be planned with a decoupled planning approach, if heuristics and simplifications for each planning step are carefully chosen.

Radar Altimeter (RadAlt) for altitude measurement [28, 29, 30]

RadAlts have become available as an option even for the smallest of helicopters. The system used on the Robinson R22 and R44 models is the lightest-weight, lowest-cost radar altimeter solution available, but still consists of various individual components (processing unit, indicator, power converter and two antennas).

The Micro Radar Altimeter is an all-in-one RadAlt intended for small unmanned and manned aircraft. It was derived from automotive radar designs. Real applications of the Micro Radar Altimeter in manned helicopters have not been found (yet).

Immersive visualisation [31, 32]

Visualization technologies are evolving rapidly, e.g. in augmented reality and virtual reality. Immersive visualization techniques already find widespread use in various areas, like in the design process, in educational applications and even for the control of dental anxiety during oral debridement (removal of dead, damaged or infected tissue). A new method called Immersive Witness Interview (IWI) has been developed to support accident analysis by taking eye witness statements into account. Information gained from interviewing multiple eyewitnesses or recorded videos from smartphones or observation cameras is used to reconstruct the (potential) flight path and aircraft attitudes in a 3D environment, including all potential errors. All information is processed with the Immersive Witness Analyzer (IWA) software to identify the level of accuracy. The results can then be exported into Google Earth or videos to show the approximate flight path from different angles.

Conclusions for highly promising technologies

For the 15 'highly promising' technologies progress has been made towards a higher TRL and various solutions are already available on the market. Some of those solutions are used on-board the helicopter, either as a standard fit or as an option. For the latter it becomes the choice of the owner/operator whether or not to install such a system, for

which an incentive may be required. Other solutions are not used on-board, nor are they intended to be used there. They will find application elsewhere, e.g. in accident analyses. In that way they can lead to ‘lessons learned’ and in doing so contribute to accident prevention.

2.2 Safety issues that (still) lacked technologies

The previous study identified three safety issues for which no potential promising technology has been identified. Not having identified technologies for certain safety issues is not necessarily a negative aspect, as other means of mitigation could very well be possible. Those three safety issues are as follows.

Safety management – Management [33]

In risk assessments the BowTie diagram finds widespread use to visualize the risk(s) in a single understandable picture. The diagram is shaped like a bow tie, thereby creating a clear differentiation between the proactive and reactive side of risk management. The BowTieXP software enables to easily create BowTie diagrams by visualizing complex risks in a way that is understandable, yet also allows for detailed risk-based improvement plans. BowTieXP provides an overview of multiple plausible incident scenarios and shows what barriers are in place to control these scenarios.

Regulatory - Oversight and Regulations

It is the mission of Aviation Authorities to promote the highest common standards of safety and environmental protection in civil aviation. During recent years certain new regulations have been put in place or existing regulations have been adapted with the aim of improving flight safety through technology:

- FAA Rule 135.605 [34]: After 24 April 2017 all helicopter air ambulances must be equipped with HTAWS.
- FAA Rule 135.607 [35]: After 23 April 2018 all helicopter air ambulances must be equipped with an FDM system that is capable of recording the aircraft’s state, condition and performance.
- EASA Notice of Proposed Amendment 2017-03 for ‘In-flight recording for light aircraft’ [36]. For helicopters this proposal only affects turbine helicopters with a maximum certified take-off mass of 2250 kg or more.
- EASA SPA.HOFO.160(c) [37] mandates a Class A HTAWS for helicopters used in Commercial Air Transport (CAT) operations with a maximum certificated take-off mass of more than 3175 kg or a maximum seating capacity of more than 9 and first issued with an individual Certificate of Airworthiness after 31st December 2018.

Preconditions; Condition of Individuals - Psycho-Behavioural Factors [38, 39]

The personal mental condition is of high importance for carrying out a safe operation. A person must be ‘fit for the task’, and if not he/she should step back or be forced to step back.

The European Commission is funding the project ASCENT (Active Simulator Cockpit Enhancement). The project is part of a wider research scheme to enhance cockpit simulators. The Nottingham Trent University’s Advanced Textiles Research Group will explore how smart textiles embedded in cockpit seats and pilot clothing can measure anxiety. Indicators of stress including a variable heart rate, perspiration and body temperature will be monitored with a range of sensors which are embedded into the yarns that are used to make clothing and textiles. As the heart rate is monitored via an Electro Cardio Gram (ECG) sensor system, it will also be possible to monitor fatigue and tell when a pilot is losing alertness.

Likewise, Formula 1 car races are considered one of the most dangerous forms of sports, but are also used to develop many new technologies. The latest new technology to be adopted is a smart biometric glove. The gloves will record biometric data such as heart rate and blood oxygen, which are made available to the teams after the race.

Conclusions for safety issues (still) lacking technologies

Some progress has been found regarding the three safety issues for which potential promising technologies were still lacking. This includes safety enhancing products from non-aviation applications, new regulations that have been put in place, or existing regulations that have been adapted.

2.3 Other safety enhancing technologies

In recent years several other safety enhancing technologies (including technologies that can increase survivability) have been developed or have become available on the market. These technologies were either not reported in the previous study or were not (yet) listed as highly promising e.g. due to their low TRL.

Collective Pull Down (CPD) [40]

A CPD has been developed as an aftermarket safety device that initiates the lowering of collective in an engine or drive system failure event. The CPD is triggered by the low rotor RPM warning signal, and is designed to immediately pull the collective down in less than half a second, eliminating pilot recognition and reaction times. The CPD can be easily overridden by the pilot at any time. It is lightweight, less than 2 lbs, easy to install and requires no software to operate. In 2016 this CPD received an FAA Supplemental Type Certificate for the Robinson R22, R44 and R44-II models.

Emergency breathing devices [41, 42]

Rebreathing systems have been used on-board offshore helicopters for a long time already, like e.g. the Emergency Breathing System (EBS) and the Short Term Air Supply System (STASS).

The Helicopter Emergency Egress Device (HEED) is a small emergency breathing device based on the most-sold scuba safety breathing device in the world. The third generation HEED III is known as the leading emergency breathing apparatus for egressing from ditched helicopters or smoke-filled environments. The bottle will supply about 2–3 minutes of air, just enough to allow the crew to escape the aircraft and swim to the surface. The device is easy to use, maintain and service.

Another safety device, called a hybrid re-breather, combines a life jacket with a very small aqualung. This is a life jacket with a rubber bag full of air that is continually re-breathed through a tube. This gives a few precious extra minutes in case of submersion in water.

Helicopter Emergency Release Operator (HERO) [43, 44]

The highly innovative HERO device has been designed to improve the survivability of helicopter crews and occupants in the event of a crash into the sea. HERO is the world's first dual-purpose personnel restraint/release survivability aid developed in response to the fatal crash of an Australian Army Black Hawk helicopter off the coast of Fiji in 2006. The system automatically disconnects helicopter aircrew and other occupants from their anchor points in the event of a crash into the sea. Equally applicable to civil and military operators, HERO can be fitted to any helicopter regardless of make or type. It has been approved by the Australian Civil Aviation Safety Authority (CASA).

Emergency exit training device [45]

The Emergency Exit Jettison (EEJ) training rig is a new training device. It simulates the emergency exits of various aircraft types, allowing the staff to carry out mandatory safety training by physically operating the emergency exits. The modular design of the unit means that it is future proof against any other types of aircraft.

High-speed data via satellite communication [46]

The Aspire 200 Satellite Communications System provides reliable high-speed data connectivity during flight, also beyond line of sight or beyond Very High Frequency (VHF) coverage area. The system can be used for a variety of applications, e.g. to reduce crew workload, to send real-time data quickly to and from the aircraft, or for aircraft tracking. The installation is FAA-approved for the Airbus Helicopters AS350, Sikorsky UH-60 Black Hawk and Bell 429, is EASA-approved for the Leonardo Helicopters AW139, and more rotorcraft are in the pipeline.

Eye for Autonomous Guidance and Landing Extension (EAGLE) [47]

The EAGLE project aims at improving safety and automation capabilities and is designed to be integrated on a variety of existing and future Airbus helicopter platforms. Airbus is developing the experimental on-board image processing management system to enable performing automatic approaches and landings in challenging conditions. The EAGLE system federates the entire helicopter's image processing functions into the avionics system, thus improving the crew's situational awareness and reducing the pilot's workload.

Late 2017 saw the in-flight validation of the EAGLE system on an H225 flying testbed. The trials have demonstrated the system's ability to select a small ground "target" from ranges of up to 2 miles and to automatically track it during the approach performed by the pilot. The flight tests have also validated the system's architecture and main components, such as the gyro-stabilized optronics package and the processing unit. The next steps of the testing campaign will focus on coupling EAGLE with the Automatic Flight Control System (AFCS) to fully automate approaches.

Conclusions for other safety enhancing technologies

Some additional safety enhancing technologies have been identified that in recent years have either been developed or become available on the market. Besides technical solutions, these also include survivability and training devices.

3 Current safety concerns

Safety concerns have previously been derived from the analysis performed by EHEST's analysis team, EHSAT, which covered incidents and accidents that took place in Europe in the period from 2000 till 2010. As no similar analyses have been performed for the period after 2010, the EASA Annual Safety Report 2017 forms the basis for the identification of the current safety concerns covering the period 2012-2016. Those safety concerns are summarised hereafter for the following types of operations:

- Commercial Air Transport (CAT) – Offshore
- CAT – other
- Specialised Operations (SPO)
- Non-Commercial Operations (NCO)

3.1 CAT - Offshore

This topic covers operations in the offshore helicopter domain and includes some initial input on offshore renewable energy operations in addition to the oil and gas industry. Four key risk areas are identified, being:

- Helicopter upset (loss of control)
- Terrain collision
- Ground damage
- Obstacle collision

These areas have been translated into technical, operational and human factors safety issues.

Technical:

- Diagnosis and tolerance of system failures/system reliability, with a specific need for improving system reliability for offshore helicopters and continually improve the ability to diagnose system failures early.

Operational:

- Flight planning and preparation, aiming at evidence-based training to improve the preparation of flight crew for the most relevant operational scenarios;
- Control of the helicopter flight path and use of automation, for which the focus is currently on reduction in human-factors caused rotorcraft accidents that are attributed to the rotorcraft design and evidence-based training to improve the preparation of flight crew for the most relevant operational scenarios;
- Handling of technical failures for which the focus is currently also on evidence-based training to improve the preparation of flight crew for the most relevant operational scenarios.

Human factors:

- Perception and situational awareness; current actions focus on training, and the introduction of the Flight Crew Operating Manual (FCOM) being implemented by the manufacturers.

3.2 CAT - Other

This topic covers all CAT operations involving helicopters other than offshore and includes passenger flights, air taxi and Helicopter Emergency Medical Services (HEMS). Four key risk areas are identified, being:

- Helicopter upset
- Obstacle collision
- Landing area excursion
- Terrain collision

These areas have been translated into technical, operational and human factors safety issues.

Technical:

- Diagnosis and tolerance of system failures/system reliability; as similar types of helicopter are used in offshore and other CAT helicopters operations this safety issue similarly aims to improve system reliability and continually improve the ability to diagnose system failures early.

Operational:

- Helicopter obstacle 'See and Avoid' involves the provision of the best equipment and strategies to help flight crew maintain safe clearance from obstacles during take-off and landing;
- Intentional low flying, closely related to the 'See and Avoid' safety issue above; in the domain of other CAT operations, there is routinely a requirement to fly at low altitude and the analysis identified that a disproportionately high number of occurrences takes place in the activity.

Human factors:

- Perception and situational awareness, similar to offshore focussing on training, and the introduction of the FCOM as implemented by the manufacturers.

3.3 SPO (aerial work)

This topic covers all helicopter aerial work/Part SPO operations and involves a wide range of different operational activities including aerial advertising, aerial patrol, agricultural, air shows, parachuting, construction/sling load operations and logging. Five key risk areas are identified, being:

- Obstacle Collision
- Helicopter Upset
- Terrain Collision
- Airborne Collision
- Landing Area Excursion

These areas have been translated into technical and operational safety issues.

Technical:

- Diagnosis and tolerance of system failures/system reliability, similar to the CAT issue aiming to improve system reliability and continually improve the ability to diagnose system failures early.

Operational:

- Intentional low flying; there are many operational situations where low flying is required and any operation has its specific considerations;
- Helicopter obstacle 'See and Avoid', closely linked to the low flying issue and similar to the CAT – Other category, requires the provision of the best equipment and strategies to help flight crew maintain safe clearance from obstacles during take-off and landing.

3.4 NCO (non-commercial)

This topic covers all non-commercial operations involving helicopters and includes traditional definition of general aviation as well as flight training and other non-commercial activities. Four key risk areas are identified, being:

- Helicopter Upset
- Terrain Collision
- Obstacle Collision
- Airborne Collision

These areas have been translated into operational and human factors safety issues.

Operational:

- Helicopter obstacle 'See and Avoid', linked to all 4 key risk areas;
- Intentional low flying; the nature of NCO helicopter operations includes low flying; this risk does not only contain the risk of collisions but also less response time in case of technical failures;
- Handling of technical failures; includes flying in spite of technical failures during which the pilot's workload increases requiring the pilot to focus on flying the aircraft first and then address the technical issues;
- Control of the helicopter flight path and use of automation; addressing the pilot's control of the helicopter flight path considering planning issues as well as ability/inability of the pilot to properly control the aircraft.

Human factors:

- Perception and situational awareness, an aspect involved in all operational safety issues; as helicopters land in a tighter area than fixed wing aircraft, the landing process requires even higher level of awareness than in conventional landing;
- Personal pressure and alertness, both aspects missing important information related to the current situation due to working under high pressure as well as the level of a pilot's alertness at the time of the occurrence.

Conclusions for current safety concerns

Safety concerns for the period 2012-2016 have been taken from the EASA Annual Safety Report 2017, for Commercial Air Transport – Offshore, Commercial Air Transport – Other, Specialised Operations and Non-Commercial Operations. For each operation the key risk areas have been identified, which then have been translated into technical and/or operational and/or human factors safety issues. Technological developments can help mitigate those safety issues.

4 Lessons learned, other initiatives and way forward

4.1 Lessons learned

The process applied in the previous study consisted of four steps:

- Identify main safety issues
- Develop assessment tool
- Identify and list potential promising technologies
- Rate each technology

For the identification of the main safety issues, results of the EHSAT analysis team were applied. Subsequently a specialist team including helicopter manufacturers, component manufactures, research establishments, universities and EASA, developed an Excel-based tool. Various sources were consulted to identify and list new (emerging) technologies, existing technologies that were not yet used on helicopters, and existing technologies that were used on large helicopters but not yet on small helicopters. To determine the most advantageous technology for each safety issue, scorings were applied. Based on expert judgement and available documents, the technology was rated on Impact and Applicability. Impact is a measure of how well the particular technology can mitigate the specific safety concern. Applicability is the measure indicating whether the technology can be utilised for a specific safety concern (taking into account its TRL) and against what (relative) cost.

This process provided traceable and unambiguous findings, and especially the rating results were found to be very intuitive, enabling a quick interpretation of the results. As it was a joint effort of organisations with varying backgrounds, the identified technologies were numerous and widespread (145 in 11 categories), and at various TRLs. Fifteen of the rated technologies were found to be highly promising, jointly mitigating more than half of the safety issues. This attributed to the finding that focusing on technologies for safety benefits is a useful process that is now continued under the EPAS.

On the other hand, the process proved to be challenging to find relevant background information, especially for low TRL technologies. This, amongst other aspects, contributed to the fact that it was a very time-consuming process. Due to the nature of the process, this will even more be true when trying to keep it up to date, as not only the already listed technologies should be revisited, but also newer technologies must be identified and rated. Furthermore, a follow up on the technologies is also a challenge as it should include an assessment on whether or not the technology potentially introduces a new safety issue. On that same line, it proved not to be possible to measure the actual impact and applicability of a specific technology as other factors (like training, procedures, regulations, etc.) could (also) have attributed to a change in accident data. Overall it is noted that this type of process will always be reactive as priorities and safety issues are set on the basis of actual accident and incident data. This, in combination with the long processing times, makes it challenging to anticipate new safety benefiting technological developments.

Conclusions for lessons learned

The process to identify technologies, as used by the former ST Technology, provided traceable and unambiguous findings, yet was quite challenging and time-consuming. Such a process will always be reactive as it will be based on actual accident and incident data. These combined aspects make it challenging to anticipate new technologies to mitigate future safety concerns.

4.2 Other initiatives

HeliOffshore [48] is the global, safety-focused association for the offshore helicopter industry. Through collaboration with and between the members, they are delivering an industry-wide programme to enhance safety, worldwide.

Safety progress is delivered through four work streams:

- System Reliability & Resilience, focused on enhancing the reliability and resilience of the human/machine system; among others, this has led to the implementation of Health & Usage Monitoring best practice guidelines;
- Operational Effectiveness, focused on enhancing operational effectiveness; this work stream is working with helicopter manufacturers to develop FCOMs;
- Safety Enablers, focused on the foundational activities that enable safe operations; protocols and agreements are in place relating to the sharing of safety information; these not only extend to all members, but also to others who may receive safety information generated or managed by HeliOffshore;
- Survivability, focused on enhancing the survivability of accidents; among others, this work stream touches upon enhanced flotation aids, emergency breathing systems and standardised underwater emergency training.

European HEMS & Air Ambulance Committee (EHAC) [49] is the trade association representing European organisations engaged in providing emergency medical services involving helicopters and ambulance aircraft. EHAC represents the concerns and interests of operators, emergency medical personnel and patients. The primary criteria include flight safety and medical efficacy. EHAC maintains a well-developed network between members, renowned experts, authorities, industry and other organisations. EHAC runs four working groups:

- Aeromedical Crew Resource Management (ACRM)
- Safety
- Flight OPS
- Medical

The innovative human factors ACRM training has been developed by EHAC and its partners to increase flight and patient safety. It is designed for pilots and HEMS Crew Members. It encompasses the technical abilities to fly an aircraft, and the non-technical abilities like team communication, capacity for teamwork, leadership behaviour, situative (i.e. occurring in relation to a specific situation) thoughtfulness and decision making.

Helicopter Association International (HAI) [50] is the trade association for the international helicopter community that provides support and services to its members and to the international helicopter community. HAI has benefited the entire industry, including manufacturers, suppliers, operators, pilots and mechanics. The association's initiatives have had a direct and positive impact on international helicopter activities. HAI is dedicated to improving hazard and risk identification, assessment and mitigation with the result of eliminating fatalities, accidents and incidents in the helicopter industry. HAI also advises, educates and consults with its members and the helicopter industry on safety issues to attain their primary objective. Safety-enhancing initiatives include:

- The HAI Accreditation Program of Safety (HAI-APS) is a voluntary program that helps helicopter operators to reduce accident and incident rates by improving their safety culture; to become an HAI-APS accredited operator, one needs to demonstrate that their operations are in compliance with internationally accepted standards of safety and professionalism;
- The HAI Utilities, Patrol and Construction Committee (UPAC) developed the 'Safety Guide for Operators' that offers general information and recommendations to mitigate associated risks for individuals and companies

involved in activities like utility patrol and inspection, power line construction and related maintenance operations; it also provides aid to utilities in selecting qualified contractors for these operations;

- The HAI Electronic News Gathering (ENG) Committee developed the 'E-N-G Aviation Safety Manual' to serve as a guide to assist operators in developing their own safety materials; this manual of recommended procedures and guidelines was developed through a cooperative effort with the National E-N-G Helicopter Association (NEHA) and in consultation with industry experts and representatives from the FAA and NTSB.

EASA's EPAS 2018-2022 document [51] details Rule Making Tasks (RMTs), Research Actions (RESs) and Safety Promotion Tasks (SPTs) related to Rotorcraft Operations. The RMTs drive the rulemaking process through which EASA contributes to the production of EU legislation and implementation material related to civil aviation safety and environmental compatibility. EASA's Basic Regulation permits the Agency to launch and finance research projects, initiated through RESs. Safety promotion activities are managed through SPTs, which are not limited to creating a product (e.g. leaflet), but also include dissemination and measurement activities, coordinated through the ESPN-R. Some of the EPAS tasks and actions are directly related to the analysis provided in the underlying paper, like e.g.:

- RMT.0708 Controlled Flight Into Terrain (CFIT) prevention with HTAWS; mandating HTAWS is expected to prevent between 8.5 and 11.5 CFIT accidents with fatalities or severe injuries within 10 years;
- RMT.0711 Reduction in accidents caused by failures of critical rotor and rotor drive components through improved vibration health monitoring systems; use of Vibration Health Monitoring (VHM) systems to detect imminent failures have been shown to greatly improve the level of safety of rotorcraft particularly for offshore operations;
- RES.020 Identify helicopter technologies with safety benefits; revise and update the study performed by NLR for EHEST on the safety benefits of technologies to assess and when relevant include new technologies addressing safety threats such as laser pointing, drones, bird strike, wire strike, etc.
- SPT.080 Implementation of Health and Usage Monitoring System (HUMS) best practice in offshore operations;
- SPT.082 Support the development and implementation of FCOM for offshore helicopter operations;
- SPT.095 Promote helicopter technologies with safety benefits.

Conclusions for other initiatives

Various helicopter industry-wide (trade) organisations and EASA make efforts to improve helicopter flight safety. The helicopter organisations have developed various programmes, including technical solutions, guidance material and training. EASA concentrates on rulemaking tasks, research projects and safety promotion.

4.3 Way forward

Based on the aforementioned lessons learned and other initiatives it is recommended to:

- Assess whether specific technologies that are being used in CAT Offshore operations can equally be adopted in CAT Other and/or SPO operations; an example is the technology that diagnoses the on-board systems aiming at an early detection of system failures; this technology is being developed and monitored through various initiatives;
- Identify for which technical, operational and human factors related safety issues the application of technologies might be useful; then concentrate on that/those aspect(s) of the safety issues by identifying and rating the technologies in a similar manner as done by the EHSIT ST Technology; however, a specific focus should be applied, as considering all safety issues and all technologies will be too time consuming;

- Explore the possibilities to develop a proactive approach to enable an early focus on safety benefiting technologies for future safety concerns; this requires an assessment of the potential type of accident and contributing factors, not only for current but also for future operations such as wind park servicing, drone interaction, autonomous passenger transport, etc.; such a process could be managed through a roadmap with feedback loops to verify and adapt the current focus where necessary.

5 Conclusions & recommendations

The former Specialist Team (ST) Technology was created with the objective to assess the potential of existing and emerging technologies to mitigate accident factors. Their report concluded that 15 ‘highly promising’ technologies jointly can potentially mitigate 11 of the top 20 safety issues, that five technologies are highly promising for three or more safety issues, and that three safety issues still lacked potential promising technology.

The European Plan for Aviation Safety (EPAS) 2018-2022 includes an action to promote technologies that will provide helicopter safety benefits. This action should provide an update to the aforementioned ST Technology results, for which three objectives have been defined:

- Provide an update to the team’s report regarding the status of the 15 identified ‘highly promising’ helicopter technologies and the status of the safety concerns for which technologies are lacking;
- Lay the foundation for the EPAS action (‘to promote technologies’) by distilling the current safety concerns from the EASA Annual Safety Report 2017;
- Recommend the way forward for the EPAS action based on the lessons learned from EHSIT’s ST Technology and on other initiatives that have come to light.

The technologies identified by the former ST Technology have been re-assessed. It is concluded that for the 15 ‘highly promising’ technologies progress has been made towards a higher Technology Readiness Level (TRL). Some of those solutions are already being used on-board helicopters, either as a standard fit or as an option. Other solutions will find application elsewhere, e.g. in accident analysis where they will lead to ‘lessons learned’ and as such can contribute to accident prevention. Some advancement can be found for the safety issues that were still lacking technologies, for which new products can also be taken from non-aviation applications. Certain new regulations have been put in place or existing regulations have been adapted. Finally some other safety enhancing technologies have been identified that in recent years have either been developed or become available on the market. These not only encompass technical solutions, but also survivability and training devices, and training courses.

Relevant safety issues were previously derived from helicopter accident analysis work, covering European incidents and accidents in the period from 2000 to 2010. As no subsequent accident analysis (for the period after 2010) has been performed, the EASA Annual Safety Report 2017 has been used for the identification of safety concerns covering the period 2012-2016. These safety concerns have been identified for operations related to Commercial Air Transport (CAT) – Offshore, CAT – Other, Specialised Operations (SPO), and Non-Commercial Operations (NCO). For each operation the key risk areas have been identified, which then have been translated into technical and/or operational and/or human factors safety issues. Technological developments can help mitigate those safety issues.

Lessons learned from the former ST Technology show that, although the process to identify technologies provided traceable and unambiguous findings, it was quite challenging and time-consuming. Such a process will always be reactive as it will be based on actual accident and incident data. These combined aspects make it challenging to anticipate new technologies to mitigate future safety concerns.

Various helicopter industry-wide (trade) organisations and EASA are making efforts to improve helicopter flight safety. The organisations have developed various programmes, including technical solutions, guidance material and training. EASA concentrates on rulemaking tasks, research projects and safety promotion.

Based on the lessons learned from the former ST Technology work and on the other initiatives that are being exploited, it is recommended to:

- Assess whether specific technologies that are being used in (CAT) Offshore operations can equally be adopted in CAT Other and/or SPO;
- Identify for which technical, operational and human factors related safety issues the application of technologies might be useful;
- Develop a proactive approach to enable an early focus on safety benefiting technologies for future safety concerns, through assessing the potential type of accident and contributing factors, not only for current but also for future operations, and the development of an associated and periodically updated roadmap.

It is the intention that a new ST Technology, under the aegis of the European Safety Promotion Network Rotorcraft (ESPN-R), will start working with these recommendations as a guideline for the work program.

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