The Potential of Technologies to Mitigate Helicopter Accident Factors – An EHEST Study

Customer

National Aerospace Laboratory NLR

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UNCLASSIFIED

EXECUTIVE SUMMARY

The Potential of Technologies to Mitigate Helicopter Accident Factors – An EHEST Study

Problem area

In 2005 the International Helicopter Safety Team (IHST) was launched with the objective to reduce the helicopter accident rate by 80% worldwide by 2016. The European Helicopter Safety Team (EHEST) is committed to the IHST objective, with emphasis on improving the European safety.

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 that can contribute to prevent various types of accidents or to increase survivability. The EHEST's Specialist Team (ST) Technology was created in March 2011 with the objective to assess the potential of existing and emerging technologies to mitigate accident factors.

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This report is based on a presentation to be held/held at the Helitech Safety Workshop, Amsterdam, 16 October 2014.

Description of work

The ST Technology work consists of listing technologies and linking them with accident causes and contributing factors as identified in EHEST analyses, and then to assess the potential of those technologies to mitigate safety issues. The top 20 safety issues have been identified from EHEST accident analyses. To assess the potential of technologies the team has developed a tool, the so-called technology matrix. The work continued by identifying individual technologies and finally the process of evaluating (rating) these technologies was defined and carried out.

Results and conclusions

The final version of the technology matrix includes 145 technologies divided over 11 categories, of which 93 have been rated. There are 15 'highly promising' technologies, and 50 are 'moderately promising'. There are 5 technologies that are highly promising for three or more safety issues:

- Enhanced Ground Proximity Warning System / Terrain Awareness and Warning System
- Digital range image algorithms for flight guidance aids for helicopter low-level flight
- Laser radar obstacle and terrain avoidance system
- Digital Map
- Deployable Voice and Flight Data Recorder

It is concluded that the 15 'highly promising' technologies jointly can potentially mitigate 11 of the top 20 safety issues.

Applicability

The technology matrix is a powerful tool to prioritise technological solutions from a safety perspective and identify development needs. At a glance the scored results can be interpreted and the effort be focussed on developing the most promising technologies.

The industry is highly recommended 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 are encouraged to concentrate their efforts on developing the lacking technologies and the technologies which have a low Technology Readiness Level.

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PROVISIONAL ISSUE

The Potential of Technologies to Mitigate Helicopter Accident Factors – An EHEST Study

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Customer

National Aerospace Laboratory NLR

This report is based on a presentation to be held/held at the Helitech Safety Workshop, Amsterdam, 16 October 2014.

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Summary

The work presented in this report has been carried out under the aegis of the European Helicopter Safety Team (EHEST).

EHEST is the helicopter component of the European Strategic Safety Initiative (ESSI) and the European branch of the International Helicopter Safety Team (IHST). EHEST is committed to contribute to the IHST goal of reducing the helicopter accident rate by 80 percent by 2016 worldwide, with emphasis on improving European safety. EHEST brings together helicopter and component manufacturers, operators, regulators, helicopter and pilots associations, research institutes, accident investigation boards and some military operators from across Europe.

Within EHEST two major teams have been defined: the European Helicopter Safety Analysis Team (EHSAT) and the European Helicopter Safety Implementation Team (EHSIT). One of the EHSIT sub-teams is the Specialist Team Technology (ST Technology) which was created to assess the potential of technologies to mitigate safety issues. Technologies can provide a variety of solutions that can (directly or indirectly) address the safety issues identified in the EHSAT analysis and that can contribute to prevent different types of accidents or to increase survivability. The main goal of the team is to list technologies and link them with incident / accident causes and contributing factors as identified in the EHSAT analyses. The team developed a tool that links the results of the EHSAT analysis (accident / incident factors called Standard Problem Statements (SPSs)) to R&D and technological developments. The tool contains a list of technologies (technology database) and a technology – safety matrix providing rows with technologies and columns with SPS items. As the total number of SPS items is rather large, the matrix only includes the top 20 (level 2) SPS items as revealed by the EHSAT analysis of more than 300 accidents.

Various sources have been consulted to identify and list technologies/concepts with the potential of improving rotorcraft safety. The basic criteria for the selection of technologies are:

- new (emerging) technologies
- existing technologies, not yet used on helicopters
- existing technologies used on large helicopters, but not yet on small helicopters

As of mid-2014 the tool includes a total of 145 ‘individual’ technologies, grouped in 11 categories (the number of listed technologies per category is shown in between brackets):

- Aircraft Design (9)
- Avionics (25)

- Crashworthiness (10)
- Data Monitoring (18)
- Dynamic System (9)
- Maintenance (7)
- Operational Support (2)
- Situational Awareness (50)
- Vibrations (4)
- Workload (4)
- Other (7)

To determine the most advantageous technology for each safety issue, a scoring (or rating) system has been introduced. The scoring process involves two rating elements: Impact and Applicability, each on a scale from 0 to 5:

- Impact is a measure of how well the particular technology can mitigate the specific SPS
- Applicability is the measure indicating whether the technology can be utilised for a specific SPS (taking into account its TRL) and against what (relative) cost

The individual ratings for Impact and Applicability are automatically summed to arrive at a total score ranging from 0 to 10. A total scoring of 0 to 3 is considered not or slightly promising, 4 to 6 is considered moderately promising and 7 to 10 is considered highly promising. Out of the 145 entries a total of 93 have been rated, equalling to 64% of the total. There are various reasons why certain technologies have not been rated. In about two-thirds of the cases the documentation describing the technology is rather old (more than 8 years) and therefore the current TRL (which is the basis for the applicability rating) is unknown. Other documentation is lacking sufficient information to enable a justifiable rating.

There are 15 'highly promising' technologies (in order of decreasing number of safety issues for which they are 'highly promising'):

- Enhanced Ground Proximity Warning System / Terrain Awareness and Warning System
    - system providing warnings of obstacle hazards such as ground and towers.
- Digital range image algorithms for flight guidance aids for helicopter low-level flight
    - set of algorithms for terrain following or contour flight.
- Laser radar obstacle and terrain avoidance system
    - system using an eye-safe laser capable of detecting objects as thin as wires, thus making it useful for wire strike prevention.

- Digital Map
    - system displaying digital maps; moderns versions also provide elevation and obstacle information.
- Deployable Voice and Flight Data Recorder
    - recorder that gets deployed (‘ejected’) in case of a crash or sinking; equipment is floatable and contains Emergency Locator Transmitter and Underwater Locator Beacon.
- Passive tower-based Obstacle Collision Avoidance System
    - units located on utility and power line towers detect air traffic entering a predefined warning zone and activates warning lights to illuminate the tower; does not require any installations in the helicopter.
- Miniature Voice and Flight Data Recorder
    - miniature recorder, intended to be smaller and cheaper, and can have all relevant sensors (pressure, gyros, GPS) integrated inside.
- Wire Strike Protection System
    - system basically consisting of cutters placed on the roof and bottom of the rotorcraft.
- Flight data evaluation and processing for accident incident investigation
    - system comprising devices for voice, mission and flight data recording and data transfer; it also includes support equipment for conducting investigations and comprehensive flight data analysis.
- Cockpit Information Recorder
    - cheap alternative for the flight data recorder, especially aimed at smaller helicopters; it consists of a colour camera, microphone and GPS.
- Full Authority Digital Engine Control
    - system that controls the engine(s); it also automatically starts recording certain parameters when the engine exceeds some kind of limit, thereby providing vital information about failures.
- Light helicopter HOMP systems
    - flight data monitoring system for light helicopters, being a preventive system for improving safety.
- Efficient numerical approaches for on-board rotorcraft flight performance modelling
    - flight system allowing aviators to complete performance/mission planning on-board the aircraft, automatically taking into account performance boundaries and other limits.

- Radar Altimeter for altitude measurement
    - system aimed at small helicopters, consisting of one single unit containing both transmitter and receiver antennas as well as processing unit.
- Immersive visualisation
    - new technique to support accident analysis, taking into account eye witness statements; witness reports are used to reconstruct the(3D) flight path of an observed aircraft, including all potential errors.

The first five technologies in the above listing are highly promising for three or more SPS's:

1. Enhanced Ground Proximity Warning System / Terrain Awareness and Warning System; mitigating the following 5 SPS's (the number in square brackets denotes the SPS ranking number within the top 20 SPS's):
    - Pilot judgment & actions - Human Factors Pilot's Decision [1]
    - Pilot situation awareness - External Environment Awareness [2]
    - Pilot judgment & actions - Flight Profile [4]
    - Unsafe Acts / Errors – Judgment & Decision-Making Errors [8]
    - Mission Risk – Terrain / Obstacles [10]
2. Digital range image algorithms for flight guidance aids for helicopter low-level flight; mitigating the following 3 SPS's:
    - Pilot situation awareness - External Environment Awareness [2]
    - Pilot judgment & actions - Flight Profile [4]
    - Unsafe Acts / Errors – Judgment & Decision-Making Errors [8]
3. Laser radar obstacle and terrain avoidance system; mitigating the following 3 SPS's:
    - Pilot situation awareness - External Environment Awareness [2]
    - Mission Risk – Terrain / Obstacles [10]
    - Pilot situation awareness – Visibility / Weather [16]
4. Digital Map; mitigating the following 3 SPS's:
    - Pilot situation awareness - External Environment Awareness [2]
    - Pilot judgment & actions - Flight Profile [4]
    - Mission Risk – Terrain / Obstacles [10]
5. Deployable Voice and Flight Data Recorder; mitigating the following 3 SPS's:
    - Part/system failure – Aircraft [5]
    - Maintenance – Performance of Maintenance Duties [18]
    - Regulatory - Accident Prevention [20]

There are three safety issues for which no potential promising technology has been identified:

- Safety management – Management
- Regulatory - Oversight and Regulations (Regulatory)
- Preconditions; Condition of Individuals - Psycho-Behavioural Factors

Not having identified technologies for these issues is not necessarily a negative aspect, as other means of mitigation could very well be possible.

The concept of a technology-safety issues matrix is a powerful tool to prioritise technological solutions from a safety perspective and identify development needs. At a glance the scored results can be interpreted and the effort be focussed on developing the most promising technologies.

The industry is highly recommended 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 are encouraged to concentrate their efforts on developing the lacking and low TRL technologies.


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Abbreviations and acronyms

Acronym	Description
ACE-3D	Airframe Condition Evaluation - 3 Dimensional
ADIRS	Air Data Inertial Reference System
ADIRU	Air Data Inertial Reference Unit
ADS	Air Data system
AFCS	Automatic Flight Control System
AHRS	Attitude-Heading Reference System
AHS	American Helicopter Society
AIAA	American Institute of Aeronautics and Astronautics
AIN	Aviation International News
ANDI	Adaptive Nonlinear Dynamic Inversion
ANN	Artificial Neural Network
ANVIS	Aviator's Night Vision Imaging System
APM	Auto-Pilot Mode
APMS	Auto-Pilot Mode Selector
ARTIS	Autonomous Rotorcraft Testbed for Intelligent Systems
ATC	Air Traffic Control
ATM	Air Traffic Management
ATP	Altitude and ground Track Predicting
ATR	Advanced Technology Rotor
AVCS	Active Vibration Control System
BOSS	Brown-Out Symbology System
CBM	Condition-Based Maintenance
CEAS	Council of European Aerospace Societies
CFIT	Controlled Flight Into Terrain
CIR	Cockpit Image Recorder
CIRS	Cockpit Image Recording System
COSA	COgnitive System Architecture
CS	Certification Specification
DGLR	Deutsches Gesellschaft für Luft- und Raumfahrt
DLR	Deutsches Zentrum für Luft- und Raumfahrt
D/NAW	Day/Night All Weather
DTED	Digital Terrain Elevation Data
DVE	Degraded Visual Environment

DVFDR	Deployable Voice and Flight Data recorder
EADS	European Aeronautic Defence and Space Company
EASA	European Aviation Safety Agency
EGNOS	European Geostationary Navigation Overlay Service
EGPWS	Enhanced Ground Proximity Warning System
EHEST	European Helicopter Safety Team
EHSAT	European Helicopter Safety Analysis Team
EHSIT	European Helicopter Safety Implementation Team
ELT	Emergency Locator Transmitter
ERF	European Rotorcraft Forum
ESSI	European Strategic Safety Initiative
EU	European Union
FADEC	Full Authority Digital Engine Control
FCD	Fluidic Control Devices
FDR	Flight Data recorder
FHS	Flying Helicopter Simulator
FLI	First Limit Indicator
FMS	Flight Management System
FOG	Fibre-Optic Gyros
FPM	Flight Path Marker
FSD	Flight safety Digest
GA	General Aviation
GBAS	Ground-Based Augmentation System
GCAS	Ground Collision Avoidance System
GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GSA	Global Navigation Satellite Systems Agency
HALAS	Hubschrauber-Außenlast-Assistenz-System
HFDM	Helicopter Flight Data Monitoring
HGS	Head-Up Guidance System
HIPS	Helicopter Integrated Pictorial Symbology
HOMP	Helicopter Operations Monitoring Program
HTF	Helicopter Terrain Following
HUD	Head-Up Display

HUMS	Health and Usage Monitoring System
ICAS	International Council of the Aeronautical Sciences
IEEE	Institute of Electrical and Electronics Engineers
IFPG	Intelligent Flight Path Guidance
IFR	Instrument Flight Rules
IHST	International Helicopter Safety Team
IMA	Integrated Modular Avionics
IMD	Integrated Mechanical Diagnostic
IMDS	Integrated Mechanical Diagnostic System
IR	Infra-Red
ITFV	Integrated Three-Function Valve
LADAR	LAser Detection And Ranging
LIDAR	Laser Imaging Detection And Ranging
LZ	Landing Zone
MARS	Mobile Aircrew Restraint System
MFS	Manned Flight Simulator
MRO	Maintenance, Repair and Overhaul
NAA	National Aviation Authority
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organization
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
NVD	Night Vision Device
OCAS	Obstacle Collision Avoidance System
OCL	Obstacle Contour Line
OEI	One Engine Inoperative
OEM	Original Equipment Manufacturer
ONERA	Office National d'Etudes et Recherches Aérospatiales
OWS	Obstacle Warning System
PAVE	Pilot Assistant in the Vicinity of hElipads
PIO	Pilot Involved Oscillation
P-LIVE	Piezo- Liquid Inertia Vibration Eliminator
R&D	Research & Development
RDT&E	Research, Development, Test & Evaluation
RFID	Radio Frequency Identification
RNLAF	Royal Netherlands Air Force
RPM	Revolutions Per Minute

SBAS	Satellite-Based Augmentation System
SEMA	Smart Electro-Mechanical Actuator
SE-SVS	Sensor Enhanced-Synthetic Vision System
SHM	Structural Health Monitoring
SMAAS	Surface Movement Awareness & Alerting System
SME	Small and Medium Enterprise
SMS	Safety Management System
SPIE	Society of Photographic Instrumentation Engineers
SPS	Standard Problem Statement
SRTM	Shuttle Radar Topography Mission
ST	Specialist Team
SVS	Synthetic Vision System
TA	Technology Application
TAWS	Terrain Awareness and Warning System
TCAD	Traffic Collision Awareness Device
TCAS	Traffic Collision Avoidance System
TRL	Technology Readiness Level
TV	Television
UAV	Unmanned Aerial Vehicle
ULB	Underwater Locator Beacon
UV	Ultra-Violet
VDL	VHF Data Link
VFDR	Voice and Flight Data recorder
VLA	Visual Landing Aid
VRS	Vortex Ring State
VTOL	Vertical Take-Off and landing
WAAS	Wide Area Augmentation System
WSPS	Wire Strike Protection System

1 Introduction

Launched on November 2006, the European Helicopter Safety Team (EHEST) (Ref. 1) brings together manufacturers, operators, research organisations, regulators, accident investigators and a few military operators from across Europe. EHEST is the helicopter component of the European Strategic Safety Initiative (ESSI), and also the European branch of the International Helicopter Safety Team (IHST). EHEST is committed to contribute to the IHST goal of reducing the helicopter accident rate by 80 percent by 2016 worldwide, with emphasis on improving European safety. The main European stakeholders are represented in the Team. EHEST is built on the concept of partnership between industries and authorities.

Within EHEST two major teams have been defined: the European Helicopter Safety Analysis Team (EHSAT) and the European Helicopter Safety Implementation Team (EHSIT). Within EHSIT several Specialist Teams (ST's) have been created, including the ST Technology. The EHEST organization is schematically visualized in Figure 1-1.

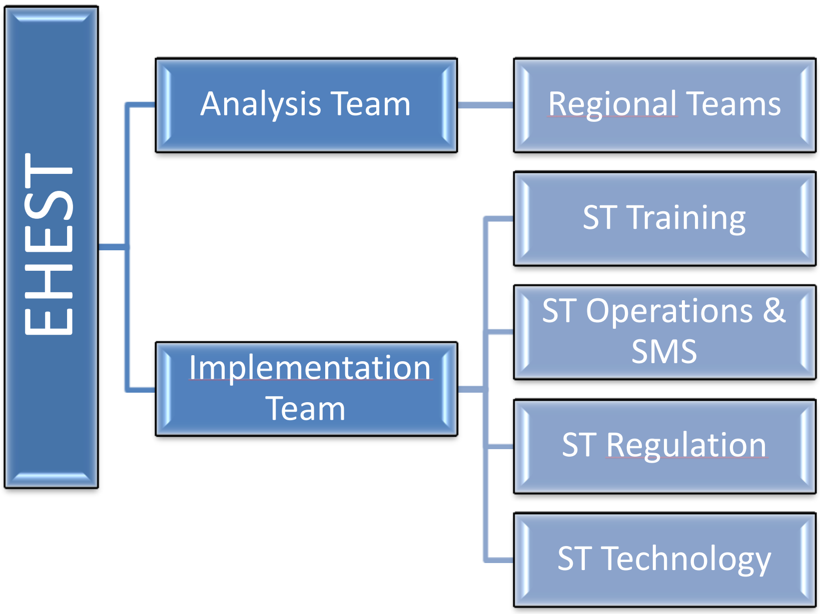

Figure 1-1 EHEST organisation

Analysis of safety issues and implementation of safety enhancements are linked. EHSAT performs the first step in that process: the analysis of occurrences. So far, nine EHSAT regional teams have been created to analyse helicopter accidents and derive recommendations for interventions. It is estimated that the current nine regional analysis teams cover more than 90% of the civil European helicopter fleet. The analysis results of the different regional teams are consolidated on a European level. The EHSAT process is data driven: recommendations are developed from analysing accidents documented in accident reports, using a methodology adapted from IHST.

EHSIT was formed with the purpose of developing safety enhancements addressing the accident factors identified in the EHSAT analysis and the intervention recommendations suggested by the EHSAT using an agreed process. The EHSIT brings these suggestions forward and develops safety actions that come in various forms: safety leaflets, videos, manuals and guidance for operators, suggestions for rulemaking, etc. Most of these actions by the way are not of regulatory nature, but are safety promotion actions.

The EHSIT Specialist Team Technology (ST Technology) was created on a suggestion by the EHSAT to assess the potential of technologies to mitigate safety issues. Technology is not high on the list of highest ranking safety issues. Technology provides a variety of solutions that can (directly or indirectly) address the safety issues identified in the EHSAT analysis and that can contribute to prevent different types of accidents or to increase survivability.
The ST Technology consists of a range of stakeholders, with various expertise and backgrounds. The main goal of the team is to list technologies and link them with accident / incident causes and contributing factors as identified in the EHSAT analyses. The team developed a tool that links the results of the EHSAT analysis (accident / incident factors called Standard Problem Statements (SPS's)) to R&D and technological developments. The tool contains a list of technologies (technology database) and a technology – safety matrix providing rows with technologies and columns with SPS items. As the total number of SPS items is rather large, the matrix only includes the top 20 (level 2) SPS items as revealed by the EHSAT analysis of more than 300 accidents.

More information about the ST Technology can be found in Chapter 2. The methodology developed by ST Technology is described in Chapter 3. Then the various results are presented in Chapter 3.5. Finally, chapter 5 touches upon the challenges and the possible follow-up of this work. The final chapter 6 provides the conclusions.

2 EHSIT Specialist Team Technology

This chapter introduces EHSIT's Specialist Team Technology (ST Technology) by describing its background (2.1), its objective (2.2) and the partner organisations forming the Specialist Team (2.3).

2.1 Background

The historic and current helicopter accident rate is (too) high. The International Helicopter Safety Team (IHST) (Ref. 2) was launched in 2005 with the objective to reduce the helicopter accident rate by 80% worldwide by 2016. The European Helicopter Safety Team (EHEST) contributes to this effort.

Rotorcraft technological developments have not been as fast as, for instance, fixed wing jet fighter developments. Current technologies are focussing on 3rd generation rotorcraft versus 5th generation fighter aircraft. Lack of investments has hampered technological breakthroughs. Technologies that may have been in use on fixed wing aircraft for many years are transferred to rotorcraft at a (much) later date. Only few technologies have been developed specifically for rotorcraft.

An interesting question was asked at the 2009 edition of the European Rotorcraft Forum (ERF): *"What kind of safety benefits can we expect from (existing and new) technologies and how can the EHEST results be used to assess the safety importance of technologies and contribute to orienting their development?"* This question sparked the creation of a Specialist Team on Technology. Also The European Aviation Safety Plan 2012-2015 (Ref. 3), issued by the European Aviation Safety Agency (EASA) contains an action to assess the impact of technologies in mitigating helicopter safety issues (action HE1.4). That action was allocated to the Specialist Team Technology of the EHEST.

2.2 Objective

Technology is not high on the list of highest ranking accident / incident factors (see also 3.1), as it is merely the lack of technology that may have led to an accident. Technology however provides a variety of solutions that can (directly or indirectly) address various identified safety issues and contribute to prevent various types of accidents or to increase survivability. Technology can be a powerful means to improve safety, as it brings solutions to known safety issues, including those of operational nature.

Therefore, the ST Technology has been created with the objective to:

Assess the potential of technologies to mitigate safety issues

This is done by listing technologies, linking them with safety issues (Standard Problem Statements (SPS's)) as identified in the EHSAT analyses and assessing their safety potential. This process is further described in chapter 3.

2.3 Partners

EHEST's Specialist Team Technology is led by the National Aerospace Laboratory, NLR and consists of members from approximately 15 different organisations including helicopter manufacturers, component manufactures, research establishments, universities and EASA. In the subsequent paragraphs each organisation is briefly introduced, for which use has been made of the organisations respective websites.

2.3.1 Helicopter manufacturers

AgustaWestland

www.agustawestland.com

AgustaWestland, the Anglo-Italian helicopter company owned by Italy's Finmeccanica, is a total capability provider in the vertical lift market. Through its rotorcraft systems design, development, production and integration capabilities, its experience in the training business and its customer focused Integrated Operational Support solutions, the Company delivers unrivalled mission capability to military and commercial operators around the world.

This expertise, backed by technological excellence and innovation, makes the Company a leader in a number of the world's most important helicopter markets offering the widest range of advanced rotorcraft available for both commercial and military applications.

AgustaWestland operates globally in the vertical lift market through a number of joint ventures and collaborative programmes with major European and American helicopter primes where the company has leading or primary roles. There are also partnerships with a number of other leading aerospace and defence companies to deliver mutually beneficial programmes. This network of alliances strengthens the Company's product range, increases its global reach, and enhances business opportunities.

Team member: Dino Paggi.

Airbus Helicopters

www.airbushelicopters.com

Airbus Helicopters, formerly Eurocopter, is a subsidiary wholly owned by the Airbus Group, a global aerospace and defence leader. Eurocopter Group was created in 1992 with the merger of the rotorcraft divisions of Aerospatiale (France) and Deutsche Aerospace (Germany). In January 2014, the company was rebranded Airbus Helicopters, opening a new chapter in its history.

By a process of successive integrations, Airbus Helicopters has become the world-leading rotorcraft manufacturer with a turnover of 6.3 billion euros. At present, the company is composed of three entities: the parent company, Airbus Helicopters; the German subsidiary, Airbus Helicopters Deutschland; and the Spanish subsidiary, Airbus Helicopters España. Employing approximately 23,000 people worldwide, the company's fleet in service includes 12,000 helicopters operated by more than 3,000 customers in approximately 150 countries.

Airbus Helicopters' international presence is marked by its subsidiaries and participations in 24 countries, and its worldwide network of service centres, training facilities, distributors and certified agents. Airbus Helicopters' range of civil and military helicopters is the world's largest; its aircraft account for one third of the worldwide civil and parapublic fleet.

Team member: Detlef Gabriel.

2.3.2 Component manufactures

Cassidian

www.cassidian.com

Cassidian, an EADS company, is a worldwide leader in global security solutions and systems, providing Lead Systems Integration and value-added products and services to civil and military customers around the globe: air systems (aircraft and unmanned aerial systems), land, naval and joint systems, intelligence and surveillance, cyber security, secure communications, test systems, missiles, services and support solutions. As of 1 January 2014, the defence and space businesses of the EADS Group are consolidated into one new division, Airbus Defence and Space while EADS is rebranded into "Airbus Group".

Team member: Marcel Mämpel.

Diehl Aerospace

www.diehl.com/en/diehl-aerosystems/company/company-profile/diehl-aerospace.html

Diehl Aerospace is the leading supplier of avionics systems and lighting concepts for civil and military aircraft. With core competencies from the cockpit through to the cabin, Diehl Aerospace sets global standards with impressive cutting-edge technology and consistent focus on its customers. Diehl Aerospace's wide range of products and services includes developing, manufacturing, and supporting systems and components for equipping commercial and military aircraft from the cockpit to the cabin. Diehl Aerospace provides a wide range of top-quality services, from product and system development through to worldwide customer service.

Team member: Gian-Marco Cabibbe.

Rockwell Collins

www.rockwellcollins.com

Rockwell Collins is a pioneer in the design, production and support of innovative solutions for our customers in aerospace and defence. Our expertise in flight-deck avionics, cabin electronics, mission communications, information management and simulation and training is strengthened by our global service and support network spanning 27 countries. Working together, our global team of nearly 20,000 employees shares a vision to create the most trusted source of communication and aviation electronics solutions.

Our aviation electronics systems and products are installed in the flight decks of nearly every air transport aircraft in the world. Our communication systems transmit nearly 70 percent of U.S. and allied military airborne communications. Whether developing new technology to enable network-centric operations for the military, delivering integrated electronic solutions for new commercial aircraft or providing a level of service and support that increases reliability and lowers operational costs for our customers throughout the world, we deliver on our commitments.

Team member: Etienne Gomez.

Silkan

www.silkan.com

SILKAN designs and develops high performance simulation solutions supporting the whole life cycle of complex systems. SILKAN takes on projects where safe operations require a combination of system behaviour analysis, complex control design, specific training and operation readiness.

This leads to SILKAN's strong presence in such sectors as aerospace & defence, transportation and energy industries.

To achieve the seamless integration of its solutions, SILKAN has developed inventive technologies such as TUTOR (a Simulator Integration Environment) and Arion 100 (a deterministic time stamped Ethernet bus for real-time data acquisition and processing). Optimization and other performance enhancement environments are put to contribution to meet application requirements.

SILKAN's solutions are innovative, cost-effective, and are developed in-house using technical and industrial expertise. This know-how is complemented by a network of partners who provide privileged access to the most advanced and innovative technologies, as well as a network of operational experts complementing our own team.

Team member: Bernard del Ghingaro.

Thales

www.thalesgroup.com

Thales is the only company in the world with leadership positions in both on-board equipment (cockpit and cabin solutions) and ground equipment (radar, air traffic management systems, etc.). The Thales group is contributing to the future prosperity of the civil aerospace sector by providing equipment, systems and services — both in the air and on the ground — to support aircraft manufacturers, airlines, air traffic controllers, airports and civil aviation authorities in meeting the challenges of growth, safety, economic and environmental performance, security and passenger comfort.

Thales is also the only company with the capability to provide end-to-end mission support to military customers offering a combination of ground and air solutions designed to increase operational effectiveness and flexibility, improving situational awareness while reducing the workload of the crew.

Team members:

- Joel Flinois
- Stéphane Moulene

2.3.3 Research establishments

Deutsches Zentrum für Luft- und Raumfahrt, DLR

www.dlr.de

DLR is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space programme. DLR is also the umbrella organisation for the nation's largest project management agency.

DLR has approximately 8000 employees at 16 locations in Germany: Cologne (headquarters), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Goettingen, Hamburg, Juelich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stade, Stuttgart, Trauen, and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

Team member: Jens Wolfram.

Nationaal Lucht- en Ruimtevaartlaboratorium, NLR

www.nlr.nl

The National Aerospace Laboratory (NLR) is the independent knowledge enterprise in the Netherlands on aerospace. The overall mission is making air transport and space exploration safer, more sustainable and more efficient. NLR's multidisciplinary approach focuses on developing new and cost effective technologies for aviation and space, from design support to production technology and MRO (Maintenance, Repair and Overhaul). With its unique expertise and state of the art facilities NLR is bridging the gap between research and application.

NLR covers the whole RDT&E (Research, Development, Test & Evaluation) range, including all the essential phases in research, from validation, verification and qualification to evaluation. By doing so, NLR contributes to the innovative and competitive strength of government and industry, in the Netherlands and abroad.

NLR employs a staff of approximately 650 at offices in Amsterdam and Marknesse.

Team members:

- Jos Stevens
- Joost Vreeken

Office National d'Etudes et Recherches Aérospatiales, ONERA

www.onera.fr

Onera is the French national aerospace research centre. It is a public research establishment, with eight major facilities in France and about 2,000 employees, including 1,500 scientists, engineers and technicians.

Onera was originally created by the French government in 1946, and assigned six key missions:

- Direct and conduct aeronautical research
- Support the commercialization of this research by national and European industry
- Construct and operate the associated experimental facilities
- Supply industry with high-level technical analyses and other services.
- Perform technical analyses for the government
- Train researchers and engineers

Team member: Pierre-Marie Basset.

2.3.4 Universities

Aix-Marseille University

www.univ-amu.fr

Aix-Marseille University was established by decree No. 2011-1010 of August 24, 2011. It officially opened on January 1, 2012, replacing the University of Provence, University of the Mediterranean and Paul Cézanne University. Today, as well as being one of the youngest universities in France, it is also the largest in terms of its student body, its faculty and staff, and its budget in the whole of the French-speaking world. These factors combine with the remarkable results already achieved in teaching and research to make Aix-Marseille University a top class higher education and research institution.

Team member: Sylvain Leduc.

Cranfield University

www.cranfield.ac.uk

Cranfield University is world-leading in its contribution to global innovation. With our emphasis on the aerospace, automotive, defence and security, health, environment, management and manufacturing sectors, we have changed the way society thinks, works and learns. We generate and transform knowledge, translating it to the benefit of society. Our partners, from micro SME's to the largest blue-chip multinationals, from governments across the world to NGO's and charities, tell us this is what they value about Cranfield.

Innovation is part of Cranfield's 'corporate DNA', evolved over 60 years of commitment to this agenda. Our work informs policy for governments and produces new technologies and products for the world of commerce. We draw on this pool of research and consultancy to provide our students with a distinctive 'real-world' learning environment, allowing them to develop as professionals and transfer their new knowledge to the global economy. This has always been the 'Cranfield way' but it has never been more important than in today's world.

Team member: Matthew Greaves.

2.3.5 EASA

http://easa.europa.eu/

The European Aviation Safety Agency (EASA) is the centrepiece of the European Union's aviation safety system comprised of the Agency, the European Commission and the National Aviation Authorities (NAA's). Its mission is to promote the highest common standards of safety and environmental protection in civil aviation.

Air transport is one of the safest forms of travel. As air traffic continues to grow, a common endeavour is needed at the European level to keep air transport safe and sustainable. The Agency develops common safety and environmental rules. It monitors the implementation of standards through inspections in the Member States and provides the necessary technical expertise and training to the system. The Agency works hand in hand with NAA's, which have their own role to play in the EU system.

EASA co-chairs the EHEST together with Airbus Helicopters and the European Helicopter Operators Committee.

Team members:

- Clément Audard
- Michel Masson
- Jeremie Teahan

3 Methodology

In order to assess the potential of technologies to mitigate safety issues the following actions have been performed:

1. Identify the main safety issues
2. Develop an assessment tool
3. Identify and list potential promising technologies
4. Rate each technology

These steps are further described in the following paragraphs.

3.1 Identify the main safety issues

For the identification of the main safety issues use has been made of the results produced by EHEST's analysis team, the EHSAT. The total number of safety issues (Standard Problem Statements, SPS's) identified by the EHSAT is rather large. Therefore only the Top 20 (level 2) SPS items as revealed by the EHSAT analysis of more than 300 accidents / incidents that took place in Europe in the period from 2000 till 2010 are being used. Table 3-1 provides an overview of these top 20 SPS's in decreasing ranking order. More information can be found in Ref. 4.

Rank	SPS Level 1	SPS Level 2	Number of occurrences
1	Pilot judgment & actions	Human Factors Pilot's Decision	64
2	Pilot situation awareness	External Environment Awareness	38
3	Ground Duties	Mission Planning	35
4	Pilot judgment & actions	Flight Profile	31
5	Part/system failure	Aircraft	30
6	Unsafe Acts / Errors	Skill-based Errors	29
7	Safety Management	Inadequate Pilot Experience	28
8	Unsafe Acts / Errors	Judgment & Decision-Making Errors	27
9	Pilot judgment & actions	Procedure Implementation	26
10	Mission Risk	Terrain / Obstacles	26
11	Pilot judgment & actions	Landing Procedures	25
12	Safety Management	Management	23
13	Maintenance	Maintenance Procedures / Management	23
14	Regulatory	Oversight and Regulations	23
15	Preconditions; Condition of Individuals	Cognitive Factors	22

16	Pilot situation awareness	Visibility / Weather	20
17	Aircraft Design	Aircraft Design	19
18	Maintenance	Performance of Maintenance Duties	19
19	Preconditions; Condition of Individuals	Psycho-Behavioural Factors	19
20	Regulatory	Accident Prevention	18
	Total number of occurrences		**545**

Table 3-1 Top 20 SPS Level 2 (2011)

Appendix A of this report provides a qualitative description of this top 20 so as to give insight into what is included in each one of them. Furthermore each SPS description is elucidated with a short narrative of a typical accident scenario for which the named SPS was a major issue.

3.2 Develop an assessment tool

The assessment tool that has been developed by the ST Technology consists of an Excel file with two main tab sheets. One sheet contains a list of technologies (technology database). Besides a short description of each technology, this sheet also contains the Technology Readiness level (TRL, a definition of which is provided in Appendix B) and a link to the source documentation. The other sheet (see Figure 3-1) contains a technology – safety matrix providing rows with all listed technologies and columns with Standard Problem Statements (SPS). On this latter sheet a rating will be provided for each combination of technology and SPS.

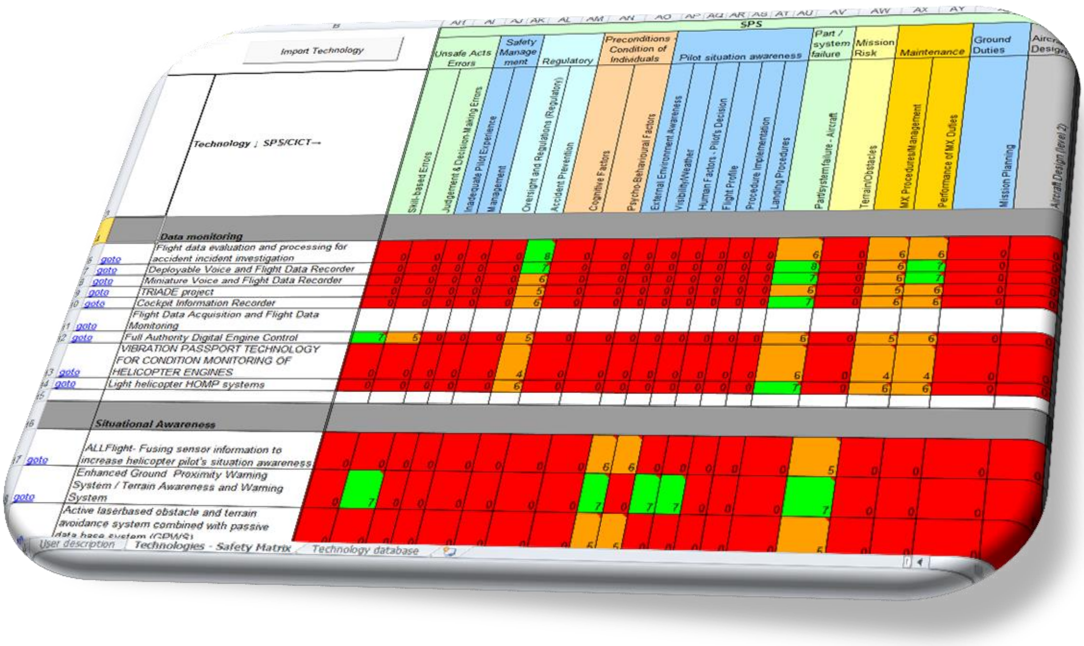

Figure 3-1 Screen shot of rating page in matrix tool

3.3 Identify and list potential promising technologies

The basic criteria for the selection of technologies are:

- new (emerging) technologies
- existing technologies, not yet used on helicopters
- existing technologies used on large helicopters, but not yet on small helicopters

Various sources have been consulted to identify and list technologies/concepts with the potential of improving rotorcraft safety. To enable this consultation process a list of possible search terms was created. The (non-exhaustive) list of sources that have been consulted includes the following ones:

- proceedings from relevant forums and symposia, like those of the American Institute of Aeronautics and Astronautics (AIAA), the European Rotorcraft Forum (ERF), the American Helicopter Society (AHS), the International Council of the Aeronautical Sciences (ICAS), the Deutsche Gesellschaft für Luft- und Raumfahrt (DGLR) and the Council of European Aerospace Societies (CEAS)
- manufacturers brochures and press releases, both from rotorcraft manufacturers as well as from system/component manufacturers
- libraries from renowned institutions, like the NASA Technical Report Server and the AIAA database
- internet pages and fora
- ST Technology partner's own knowledge/information

A complete overview of the technologies that have been identified is provided in Appendix C. In the Appendix the technologies are listed in order of decreasing TRL. Each identified technology is also assigned to one of several (mutually exclusive) categories. As of mid-2014 the tool includes a total of 145 technologies in 11 categories (the number of listed technologies per category is shown in between brackets):

- Aircraft Design (9)
- Avionics (25)
- Crashworthiness (10)
- Data Monitoring (18)
- Dynamic System (9)
- Maintenance (7)
- Operational Support (2)
- Situational Awareness (50)
- Vibrations (4)

- Workload (4)
- Other (7)

In addition, four other references are listed that have been used 'for information only'. These could not be rated as they were more general overview papers rather than useful specific technology descriptions.

A brief qualitative description of each of these categories, including some examples of relevant technologies and of their (potential) safety benefits, is provided in Appendix D.

3.4 Rate each technology

To determine the most advantageous technology for each safety issue, it is necessary to provide scorings. The process for this evaluation involves two rating elements: Impact and Applicability, each on a scale from 0 to 5:

- Impact is a measure of how well the particular technology can mitigate the specific SPS
- Applicability is the measure indicating whether the technology can be utilised for a specific SPS (taking into account its TRL) and against what (relative) cost

Table 3-2 shows the possible ratings for Impact and Applicability.

Impact: How well can this particular technology mitigate the specific SPS?
0 - None
1 - Slightly effective
2 - Moderately effective
3 - Quite effective
4 - Completely effective, but with limited applicability (e.g. only for Aerial work, GA, etc.)
5 - Completely effective
Applicability: with respect to specific SPS (including consideration of costs and TRL)
0 - Not applicable now, nor in the (near) future
1 - Not applicable now, possibly in the future (> 5 years)
2 - Not applicable now, possibly in the near future (<5 years), at relative high cost
3 - Not applicable now, possibly in the near future (<5 years), at relative low cost
4 - Applicable now (TRL ≥ 8), at relative high cost
5 - Applicable now (TRL ≥ 8), at relative low cost

Table 3-2 Impact and Applicability scoring

With respect to applicability, the difference between 'relative high cost' and 'relative low cost' is not quantitatively defined. To rate such items, questions like (if this technology would become available for a specific helicopter type) would the cost of it be proportionally to the helicopter type? For example, applying HTAWS to an AW101 helicopter could be achieved at relative low cost while applying it, for example, to a Robinson R22 would involve relative high costs. In most cases it was clear whether the technology was envisaged for large or small helicopter types.

The individual ratings for Impact and Applicability are automatically summed and colour-coded to arrive at a total score ranging from 0 to 10 (see Table 3-3). If either one of the ratings is zero, the overall score also becomes zero. A total scoring of 0 to 3 is considered not or slightly promising, 4 to 6 is considered moderately promising and 7 to 10 is considered highly promising. This method is considered intuitive, enabling a quick interpretation of the results. It can be used to identify which category of technology addresses which generic safety issues, which technologies best addresses specific safety issues and which safety issues are not (yet/sufficiently) addressed by technology.

Score	Colour	Meaning
0-3	(red)	Not or slightly promising
4-6	(orange)	Moderately promising
7-10	(green)	Highly promising

Table 3-3 Scoring colour codes and meaning

3.5 Usability of results

Once the scores are available, the results on the technology – safety matrix tab sheet can be used in three ways:

- *Which technology (best) addresses a specific safety problem.* This can easily be determined by identifying the technology/technologies with the highest ratings associated with a specific SPS. By scanning the coloured cells one can easily identify the highest rated technologies. This has the clear benefit of identifying specific technologies with the highest potential in mitigating a certain (or the most) safety issues. These technologies can then be promoted to make them more widely available.
- *Where can safety benefits be expected from a technology.* If a new technology is introduced it is predominantly aimed at a specific problem. By rating this technology against the top SPS's it could become clear that the technology also can be used to mitigate other (lesser known) safety issues. For instance, a manufacturer has developed a sensor aiming to mitigate visibility / weather related problems. Through this rating system other safety issues can come to light that, to a varying degree, could be mitigated by this sensor (e.g. mitigate unsafe flight profiles and aid landing procedures).
- *Which safety issues are not (sufficiently) addressed by technology.* Once the matrix is filled with rated technologies, safety issues lacking (technological) mitigation means stand out as a result of the colours used. Once these blanks are identified

manufacturers, research organisations and alike can be supported to address these specific safety issues. This could create new incentives and justification to perform research and to develop mitigating technologies.

4 Results

4.1 Rated technologies

The technology database contains 149 entries, of which 145 entries describe ‘individual’ technologies and 4 entries provide a combined overview of various technologies. Out of these 145 entries a total of 93 have been rated, equalling to 64% of the total (see Table 4-1). There are various reasons why certain technologies have not been rated. In about two-thirds of the cases the documentation describing the technology is rather old (more than 8 years) and therefore the current TRL (which is the basis for the applicability rating) is unknown. Other documentation is lacking sufficient information to enable a justifiable rating.

When looking at the technology categories (which are mutually exclusive), about half of the categories have a rating percentage of 67% or above (green cells), about half of the categories have a rating percentage between 33% and 67% (orange cells), and one category has a rating percentage of 22% (red cell).

Technology category	Total	Rated	Non-rated	% rated
Aircraft design	9	6	3	67%
Avionics	25	9	16	36%
Crashworthiness	10	6	4	60%
Data monitoring	18	17	1	94%
Dynamic system	9	2	7	22%
Maintenance	7	3	4	43%
Operational support	2	1	1	50%
Other	7	5	2	71%
Situational awareness	50	39	11	78%
Vibrations	4	2	2	50%
Workload	4	3	1	75%
(for information only)	(4)	(0)	(4)	
Totals	145 (149)	93	52 (56)	64%

Table 4-1 Overview of rated/non-rated technologies

Table 4-2 shows the rating details per technology category. For each category it is indicated how many technologies within that category have a highest rating being green, orange or red. E.g. within the ‘Aircraft design’ category there is one technology with the highest rating for that technology being ‘green’ (highly promising), 3 technologies with the highest rating being ‘orange’ (moderately promising), and 2 technologies with the highest rating being ‘red’ (not or slightly promising). From the row with the totals it is apparent that there are 15 highly promising technologies.

Technology category	# of rated technologies	# of techno’s with highest rating green	# of techno’s with highest rating orange	# of techno’s with highest rating red
Aircraft design	6	1	3	2
Avionics	9	1	7	1
Crashworthiness	6	0	1	5
Data monitoring	17	6	9	2
Dynamic system	2	0	2	0
Maintenance	3	0	2	1
Operational support	1	0	1	0
Other	5	1	2	2
Situational awareness	39	6	21	12
Vibrations	2	0	1	1
Workload	3	0	1	2
Totals	93	15	50	28

Table 4-2 Rating details per technology category

4.2 Most promising technologies

There are various ways of looking into the most promising technologies. Three methods will be described in the following paragraphs.

4.2.1 Top 15 highly promising technologies

As a first step only the ‘green’ cells in the rating sheet are taken into account. These are the technologies that are highly promising and have a high TRL level. This leads to the following list of the top 15 highly promising technologies (in order of decreasing number of ‘green’ cells):

1. **Enhanced Ground Proximity Warning System / Terrain Awareness and Warning System.**

   Although not a predominant feature of helicopter operations, in-flight collision with other aircraft is inevitably catastrophic and in busy offshore operating areas where air traffic services, communications and weather may be variable, the risks undoubtedly increase. Landing on a helideck is a challenging task, which currently relies heavily on the skill of the pilot and the helideck environment. The risks can be reduced by improving helideck design, standardising take-off and landing profiles and procedures, and by introducing new equipment. Risks can also be mitigated by installing technological advances such as Enhanced Ground Proximity Warning System (EGPWS), generically known as a Terrain Awareness and Warning System (TAWS). Such systems can also provide a warning of fixed, land-based obstacle hazards such as towers. Fitment of collision avoidance systems can undoubtedly be justified in busy offshore environments, where the risk of mid-air collision rises.

Only looking at the 'green' cells this technology is useful to mitigate the following 5 SPS's (the number in square brackets denotes the SPS ranking number within the top 20 SPS's):

- Pilot judgment & actions - Human Factors Pilot's Decision [1]
- Pilot situation awareness - External Environment Awareness [2]
- Pilot judgment & actions - Flight Profile [4]
- Unsafe Acts / Errors – Judgment & Decision-Making Errors [8]
- Mission Risk – Terrain / Obstacles [10]

2. Digital range image algorithms for flight guidance aids for helicopter low-level flight.

Low-altitude and terrain-following flights are needed for both civil and military rotorcraft. Carrying out such tasks at low altitude and in poor visibility, whether in daylight or at night-time, can be extremely hazardous. Studies have shown that Controlled Flight into Terrain (CFIT) accidents, including wire strikes, have been of major concern for both civil and military helicopter users. Extensive simulation and flight tests were conducted to develop and test a complete set of algorithms for terrain following or contour flight, and more particularly to improve means of computing a reference Obstacle Contour Line (OCL) for terrain-following flights. All practical experimentation was performed using two actual LIDAR OWS (Obstacle Warning Systems). In addition, a wire detection algorithm was designed and simulation tested using real flight test data.

Only looking at the 'green' cells this technology is useful to mitigate the following 3 SPS's:

- Pilot situation awareness - External Environment Awareness [2]
- Pilot judgment & actions - Flight Profile [4]
- Unsafe Acts / Errors – Judgment & Decision-Making Errors [8]

3. Laser radar obstacle and terrain avoidance system.

Wire strikes have been a major concern for both civil and military helicopters. In addition to wire strike protection devices, there are a number of devices that warn the pilot about the proximity of wires. This specific system uses an eye-safe laser which is mounted on the fuselage to provide the pilot with the information about the surrounding environment using both optical display and aural warning. By using a laser the system can sense objects as thin as wires.

Only looking at the 'green' cells this technology is useful to mitigate the following 3 SPS's:

- Pilot situation awareness - External Environment Awareness [2]
- Mission Risk – Terrain / Obstacles [10]
- Pilot situation awareness – Visibility / Weather [16]

4. Digital Map.

Digital moving maps provide a fast, clear and precise information medium. They are capable of displaying moving maps based on all relevant formats and scales. Consequently, the armed forces, border patrol, police, rescue services and other organisations were amongst its first users. Nowadays, the benefits of digital map preparation are also used in land, maritime and air traffic. Modern systems can also provide terrain elevation and obstacle information to the pilot. Systems can be either standalone or integrated within the avionics suite.

Only looking at the 'green' cells this technology is useful to mitigate the following 3 SPS's:

- Pilot situation awareness - External Environment Awareness [2]
- Pilot judgment & actions - Flight Profile [4]
- Mission Risk – Terrain / Obstacles [10]

5. Deployable Voice and Flight Data Recorder.

Voice and Flight Data Recorders (VFDR) acquire and store cockpit voice and flight data. They have been around for a long time and have proven to be valuable tools in the accident investigation process. But after a crash they normally stay inside the wreckage, which may hamper the investigative process. The Deployable VFDR (DVFDR) is a rather new development. The crash-survivable memory unit gets deployed ('ejected') in case of or shortly before a crash, or in case of sinking of the helicopter. The equipment can float and also contains an Emergency Locator Transmitter (ELT) and/or Underwater Locator Beacon (ULB) to ease localization and retrieval.

Only looking at the 'green' cells this technology is useful to mitigate the following 3 SPS's:

- Part/system failure – Aircraft [5]
- Maintenance – Performance of Maintenance Duties [18]
- Regulatory - Accident Prevention [20]

6. Passive tower-based Obstacle Collision Avoidance System.

The Obstacle Collision Avoidance System (OCAS) consists of units located on utility and power line towers and detects all air traffic entering a predefined warning zone and activates warning lights that illuminate the tower. The fact that the OCAS does not require any installations in the helicopters can make it attractive to helicopter operators. It is also attractive to utilities in spite of its cost. However, the lights on the utility towers can normally be turned off. The OCAS has potential to prevent wire strikes.

Only looking at the 'green' cells this technology is useful to mitigate the following 2 SPS's:

- Pilot situation awareness - External Environment Awareness [2]
- Mission Risk – Terrain / Obstacles [10]

7. Miniature Voice and Flight Data Recorder.

Voice and Flight Data Recorders (VFDR) have proven to be valuable tools in the accident investigation process. They can provide information that may be difficult or impossible to obtain by other means. Large commercial aircraft and some smaller commercial, corporate, and private aircraft are required to be equipped with VFDRs. Existing solutions however are too cumbersome and expensive for 'light' helicopters. The Miniature VFDR is intended to be smaller and cheaper, and can have all relevant sensors (pressure, gyros, GPS) integrated in case the helicopter platform itself does not provide the necessary data.

Only looking at the 'green' cells this technology is useful to mitigate the following 2 SPS's:

- Part/system failure – Aircraft [5]
- Maintenance – Performance of Maintenance Duties [18]

8. Wire Strike Protection System.

A US Army study found that fatalities associated with wire strikes decreased by nearly half after helicopters were equipped with a Wire Strike Protection System (WSPS), also called wire cutters. The system basically consists of cutters placed on the roof and bottom of the rotorcraft. These can cut through wires in case of collision and thus prevent an accident. The system is already installed on many (but not all) civil helicopters, so there is room for improvement.

Only looking at the 'green' cells this technology is useful to mitigate the following 2 SPS's:

- Mission Risk – Terrain / Obstacles [10]
- Aircraft Design - Aircraft Design [17]

9. Flight data evaluation and processing for accident and incident investigation.

The system comprises devices for voice, mission and flight data recording and data transfer which are indispensable for post-mission analysis. As such it provides the interface between aircraft and ground station for both mission data upload and mission and maintenance data download. But it also includes the required support equipment for conducting investigations as well as comprehensive flight data analysis, such as the one required for accident / incident investigations.

Only looking at the 'green' cells this technology is useful to mitigate the following SPS:

- Regulatory - Accident Prevention [20]

10. Cockpit Information Recorder.

Flight Data Recorders (FDR) can provide a wealth of useful information to operators, flight instructors, maintenance engineers and accident investigators. But in many cases these systems are too expensive for general aviation applications. A radically different approach to the standard FDR is a Cockpit Image Recording System (CIRS) which only uses a high resolution camera, an area microphone and a collection of internal sensors (like GPS) to build a picture of the flight path of the aircraft. The camera is directed at the aircraft instrument panel where it can 'see' the information being presented to the pilot and to also observe the pilots operation of switches / controls. The microphone records background noise and the pilot's communications.

Only looking at the 'green' cells this technology is useful to mitigate the following SPS:

- Part/system failure – Aircraft [5]

11. Full Authority Digital Engine Control.

The latest designs of (large) helicopters have Full Authority Digital Engine Controls (FADEC), sometimes linked through the Flight Management System (FMS) to a 4-axis autopilot, which also minimises the mishandling of the engine controls. The FADEC starts recording automatically when the engine exceeds some kind of limit (for a limited period of time) and can give vital information about the cause of failure and may result in future prevention.

Only looking at the 'green' cells this technology is useful to mitigate the following SPS:

- Unsafe Acts / Errors – Skill-based Errors [6]

12. Light helicopter HOMP systems.

The Helicopter Operations Monitoring Program (HOMP) is a preventive system for improving safety. Data recorded during the flight is systematically analysed on the ground, and used to identify and quantify risks related to operations. The principle is based on the automatic detection of previously defined events. A more in-depth analysis then leads to the implementation of corrective actions through training programs or changes to operational procedures. The system has first been used for Oil & Gas operations. Nowadays helicopter manufacturers are also offering flight data recording and analysis systems that are adapted to other sizes of helicopter.

Only looking at the 'green' cells this technology is useful to mitigate the following SPS:

- Part/system failure – Aircraft [5]

13. Efficient Numerical Approaches for On-Board Rotorcraft Flight Performance Modelling.

Modern flight systems allow aviators to complete performance/mission planning on-board the aircraft during flight. Previously, the aviator planned their performance and mission as a pre-mission exercise using either paper charts and pencil, or using specialized software on a personal computer. On-board flight performance models answer such questions as: what is the available power, what is the power required to hover or cruise, what is the maximum (flight / hover) weight, what is the maximum flight speed, how much fuel is required or what is the best rate-of-climb that can be achieved. These models are composed of data and equations that are used to calculate many performance parameters. Also included in these models are the boundaries and limits for each of these parameters. These models must be efficient in both size and speed while maintaining accuracy for on-board systems, particularly when the flight performance model is used for pilot guidance such as terrain following. A number of numerical approaches have been used to maintain the accuracy of the flight performance model while being efficient for both size and speed. These approaches include the use of non-dimensional data, higher order interpolation and pre-processing of derivatives and derived results.

Only looking at the 'green' cells this technology is useful to mitigate the following SPS:

- Pilot judgment & actions - Flight Profile [4]

14. Radar Altimeter for altitude measurement.

A radar altimeter used on aircraft measures the actual altitude of that aircraft above the terrain by timing how long it takes a beam of radio waves to reflect from the ground and return to the plane. As such the system provides the pilot with real time and accurate information. Recent developments of the equipment consist of a single unit containing both transmitter and receiver antennas as well as the processing unit, thereby providing a low-cost solution that can be easily installed, also on 'light' helicopters.

Only looking at the 'green' cells this technology is useful to mitigate the following SPS:

- Pilot situation awareness - External Environment Awareness [2]

15. Immersive Visualisation.

The analysis of accidents can be complicated and often smaller aircraft and helicopters are not equipped with a Flight Data Recorder. Radar data can be inadequate due to terrain reflections when the aircraft flew in very low altitude. This means that in some cases little information can be available and taking witness testimonies into account can be time and cost consuming. A new method called Immersive Witness Interview (IWI) has been developed to support the analysis of accident investigation, taking witness statements into account. Based on the witness reports that are transformed in three dimensional, a flight path of an observed aircraft can be reconstructed including all potential errors. IWI has been evaluated in the beginning of 2009 within a test in real circumstances.

Only looking at the 'green' cells this technology is useful to mitigate the following SPS:

- Regulatory - Accident Prevention [20]

As is apparent from the above listing, the first five of those 15 technologies are highly promising for three or more SPS's. These are:

- Enhanced Ground Proximity Warning System / Terrain Awareness and Warning System
- Digital range image algorithms for flight guidance aids for helicopter low-level flight
- Laser radar obstacle and terrain avoidance system
- Digital Map
- Deployable Voice and Flight Data Recorder

4.2.2 Top 10 high-ranking technologies using weighted sums of ratings

As a second step the rating values have been combined with the ranking order of the SPS's. The rating sheet contains the top 20 SPS's, which altogether appear 545 times in various accidents. Each individual SPS will appear a number of times in various accidents, which number can be expressed as a percentage of the total number of appearances (being 545). The technologies being the most beneficial to the highest ranking SPS's should get a higher 'score' than the other ones. For each individual technology this is accomplished as follows:

- Multiply each rating value with the percentage appearance of its SPS (when the rating for a certain SPS is 8 and that SPS represents 7% of the appearances, the score is 8*0.07 is 0.56)
- Sum all results for that technology across all 20 SPS's

This method takes into account 'green' cells as well as 'orange' cells. Therefore this also includes technologies which, for a certain SPS, may have a low Impact combined with a high Applicability, or vice versa. In doing so the top 10 technologies turns out to be as follows (in decreasing order of ‘weighted sum scoring’):

1. Digital range image algorithms for flight guidance aids for helicopter low-level flight.
2. Enhanced Ground Proximity Warning System / Terrain Awareness and Warning System.
3. Passive tower-based Obstacle Collision Avoidance System.
4. Testing of new terrain following guidance algorithms for rotorcraft displays.
5. Laser radar obstacle and terrain avoidance system.
6. Predictive ground collision avoidance using digital terrain referenced navigation.
7. Full Authority Digital Engine Control.
8. Engine backup system.
9. Practical regime prediction approach for HUMS applications.
10. PAVE: A prototype of a helicopter pilot assistant system.

Five of these (numbers 1, 2, 3, 5 and 7) also appeared in the top 15 highly promising technologies and have been described there (see para 4.2.1). The other five, although lacking any ‘green’ cells, do appear in this top 10, because they have a (considerable) number of ‘orange’ cells for high ranking SPS’s. For these 5 technologies informative descriptions are provided below:

4. Testing of new terrain following guidance algorithms for rotorcraft displays.

New terrain following algorithms specific to rotorcraft navigation were developed and tested on a fixed base simulator. Guidance and cueing were accomplished through a Synthetic Vision System (SVS) and the Altitude and ground Track Predicting Flight Path Marker (ATP-FPM) from prior work. Pilots flew two separate courses that were designed to replicate real world environments as well as test key components of the algorithms. Experimental data showed significant improvement in the Maximum Descent and Climb algorithms in comparison to the base line algorithms with no additional perceived workload.

6. Predictive ground collision avoidance using digital terrain referenced navigation.

Basic Ground Collision Avoidance Systems (GCAS) only take into account the terrain actually being overflown and do not consider the actual flight path. The proposed system overcomes these shortcomings by using a digital ground navigation database for predictive ground collision avoidance. Based on the actual flight path and the terrain elevation (and obstacles) ahead of the aircraft, a warning is generated if the projected flight path will not clear the terrain with a sufficient margin.

8. Engine backup system.

A hybrid helicopter that combines a turboshaft engine with an electric motor has been successfully tested. This marks a new milestone in the innovation roadmap that opens the way for further enhancements in rotary-wing aircraft safety. For this initial breakthrough in exploring the hybrid concept, use is made of a supplemental electric system to increase manoeuvrability of a single-engine helicopter during entry into and performing the autorotation landing. In the event of an engine failure, the electric motor provides (a limited amount of) power to the rotor, allowing the pilot to better control the helicopter during the descent to a safe touchdown.

9. Practical regime prediction approach for HUMS applications.

A number of aircraft parameters such as attitude, altitude, airspeed, torque, etc. are currently collected and used by Health Usage Monitoring Systems (HUMS) to identify flight regimes. For each regime, the Original Equipment Manufacturer (OEM) has assigned a damage factor to each component that has usage. Thus, regime recognition can improve flight safety and/or reduce maintenance burden by predicting if the aircraft will be flown in a damaging way. For that it is important that the regimes can be recognized correctly during the flight to avoid either underestimated or overestimated damages for the aircraft. A number of studies have shown the effectiveness of some newly developed regime recognition algorithms.

10. PAVE: A prototype of a helicopter pilot assistant system.

The main function of the helicopter pilot assistant system is the capability to generate an optimal plan according to different constraints like setting waypoints, defining speed, altitude, and time of arrival constraints at waypoints. A 4-dimensional trajectory planner generates an accurate trajectory, based on the helicopter performance data, helicopter state, actual weather and helicopter flight envelope. A functional prototype of such a system for helicopter operations has been developed within the scope of a project entitled PAVE (Pilot Assistant in the Vicinity of hElipads). PAVE concentrates especially on safe take-off and landing phases even in very difficult visual conditions. Besides today’s standard procedures or emergency procedures in case of an engine failure the research is also being done for the definition of noise abatement procedures and – for future ATM applications – of time based procedures.

4.2.3 Top 10 high-ranking technologies using non-weighted sums of ratings

The third method is an alternative to the previous one, also taking into account 'green' and 'orange' cells, but without weighing the ratings against the ranking order of the SPS's. For that, all rating values for each individual technology are simply summed. This leads to the following top 10 listing (in decreasing order of 'non-weighted sum scoring'):

1. Digital range image algorithms for flight guidance aids for helicopter low-level flight.
2. Passive tower-based Obstacle Collision Avoidance System.
3. Testing of new terrain following guidance algorithms for rotorcraft displays.
4. Laser radar obstacle and terrain avoidance system.
5. Enhanced Ground Proximity Warning System / Terrain Awareness and Warning System.
6. Full Authority Digital Engine Control.
7. PAVE: A prototype of a helicopter pilot assistant system.
8. Predictive ground collision avoidance using digital terrain referenced navigation.
9. Practical regime prediction approach for HUMS applications.
10. Flight testing of rotorcraft IFR steep approaches using SBAS and GBAS guidance.

It is to be noted that these are the same technologies as the ones in para 4.2.2, but in a different order (apparently the result is more or less independent of the analysis strategy).

4.3 Promising technologies that are not yet mature

Paragraph 4.2.1 provided an overview of the 15 most promising technologies, that is to say technologies that have a high overall rating ('green' cells). In this paragraph attention will be given to technologies that only have 'orange' cells, more specifically to the ones with an Impact rating of 3 or 4 (quite effective to completely effective) and an Applicability rating of 2 or 3 (not applicable now, possibly in the near future). The combination of Impact = 5 with Applicability = 1 does not occur in the rating sheet. These technologies have a good potential to mitigate safety issues, but are not yet mature and thus require further development. This list could be a driver for Industry to concentrate their efforts on the listed technologies.

Technologies with impact = 4 (completely effective, limited applicability) and applicability = 3 (possibly applicable in near future at relative low cost)

- (none listed in the rating sheet)

Technologies with impact = 4 (completely effective, limited applicability) and applicability = 2 (possibly applicable in near future at relative high cost)

- Low level flight solutions for civilian missions
  - efficient algorithms enabling to compute obstacle contour line and flight path during low-level flight

Technologies with impact = 3 (quite effective) and applicability = 3 (possibly applicable in near future at relative low cost)

- TRIADE project
  - structural health monitoring sensing devices
- Vibration passport technology for condition monitoring of helicopter engines
  - high frequency vibration monitoring for engines
- ALLFlight- Fusing sensor information to increase helicopter pilot's situation awareness
  - intuitive display to minimize the workload
- Testing of new terrain following guidance algorithms for rotorcraft displays
  - new terrain following algorithms specific to rotorcraft navigation
- Improved predictor-tunnel-configuration for a three dimensional flight guidance display
  - 3D tunnel display including a predictor system telling the pilot where his aircraft will be in the near future
- Low-cost obstacle warning
  - obstacle detection system using automotive radar sensors
- Predictive ground collision avoidance using digital terrain referenced navigation
  - system that uses a digital ground navigation database for predictive ground collision avoidance
- Helicopter slung load stabilization using a flight director
  - flight director effectively damping the load pendulum motion and allowing manoeuvring without exciting oscillatory load modes
- PAVE: A prototype of a helicopter pilot assistant system
  - system aiding the pilot by generating an accurate 4D trajectory taking into account all kinds of (external and internal) limitations
- Helicopter windshield spherical
  - large spherical windshields with high resistance against bird strikes
- Engine backup system
  - after engine failure, an electric motor provides some power to the rotor enabling a better control of the helicopter during autorotation

Technologies with impact = 3 (quite effective) and applicability = 2 (possibly applicable in near future at relative high cost)

- Helicopter integrated pictorial symbology for 4-D re-routable approach-to-landing
  - novel display concept for Helicopter Integrated Pictorial Symbology (HIPS) for curved and descending approach-to-landing and touch-down
- Active laser-based obstacle and terrain avoidance system combined with passive data base system (GPWS)

- system combining active obstacle and terrain avoidance system with passive data base

4.4 Safety issues lacking technologies

For three SPS no promising technologies were identified. These are listed hereunder and their respective ranking is indicated between brackets (see also 3.1):

- Safety management – Management [12]
- Regulatory - Oversight and Regulations (Regulatory) [14]
- Preconditions; Condition of Individuals - Psycho-Behavioural Factors [19]

For the SPS on cognitive factors [ranked 15] only one technology was identified with a 'slightly promising' rating and for the SPS on Inadequate Pilot Experience [ranked 7] only one 'moderately promising' and one 'slightly promising' technology was identified.

As indicated before it cannot be ascertained that all potentially relevant technologies are identified (because of the methodology used to identify technologies). This means that it cannot be stated that there are no technologies for these issues. Furthermore, not having identified a potential promising technology is not necessarily a negative aspect, as other means of mitigation could very well be possible (or already in place). These mitigations could be found in aspects as regulations, training, operations, maintenance, etc.

5 Challenges

Although the work of the ST Technology has been finalized, 2 main challenges remain.

First of all, the work itself can never be finished. New technologies will be developed, technologies already under development will have their TRL improved and become more mature, existing technologies will become lighter/smaller/cheaper, and additional accident analyses may lead to changes in the ranking of SPS's. Therefore the technology matrix tool should be constantly updated. Who will do this and how this will be done is (currently) still an open question. And EHEST should deliberate on how to continue the work of the ST Technology.

The second challenge is to translate the results of this study into concrete technology developments and (subsequent) technology implementation. In this respect the ST Technology is limited as to how much they can do in this area. In this light, the results of the study will be disseminated as much as possible through publications and presentations throughout the helicopter community and beyond. And then it is up to that community to pick up the challenges to improve safety through the use of technologies. The industry is highly recommended 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 are encouraged to concentrate their efforts on developing the lacking and low TRL technologies. One effective way to do so could be the inclusion of such technologies in EC funded research topics as well as dedicated call for proposals.

6 Conclusions

In March 2011 the Specialist Team Technology was tasked to answer the following question, raised at the 2009 European Rotorcraft Forum:
“What kind of safety benefits can we expect from (existing and new) technologies and how can the EHEST results be used to assess the safety importance of technologies and contribute to orienting their development?”

In order to assess the potential of technologies to mitigate safety issues an assessment tool has been developed. In this tool the potential promising technologies are listed and rated against the main safety issues. As of mid-2014 the assessment tool includes a total of 145 technologies in 11 categories.

The rating process involves two elements: Impact (how well can the technology mitigate the specific safety issue) and Applicability (can the technology be utilised for a specific safety issue). The individual ratings for Impact and Applicability are automatically summed and colour-coded. This method is considered intuitive, enabling a quick interpretation of the results.

The results on the technology – safety matrix tab sheet can be used in three ways:

- Which technology (best) addresses a specific safety problem. This becomes apparent by identifying the technology/technologies with the highest ratings associated with a specific safety issue.
- Where can safety benefits be expected from a technology. As each technology is rated against a range of safety issues it becomes clear where (multiple) safety benefits can be expected.
- Which safety issues are not (sufficiently) addressed by technology. Once the matrix is filled with rated technologies, safety issues lacking (technological) mitigation means clearly stand out.

The technology database contains 145 individual technologies, of which a total of 93 have been rated. Fifteen technologies are rated as ‘highly promising’, and 50 as ‘moderately promising’. The 15 ‘highly promising’ ones are as follows (in order of decreasing number of safety issues for which they are ‘highly promising’):

- Enhanced Ground Proximity Warning System / Terrain Awareness and Warning System
    - system providing warnings of obstacle hazards such as ground and towers.
- Digital range image algorithms for flight guidance aids for helicopter low-level flight

  - set of algorithms for terrain following or contour flight.
- Laser radar obstacle and terrain avoidance system
  - system using an eye-safe laser capable of detecting objects as thin as wires, thus making it useful for wire strike prevention.
- Digital Map
  - system displaying digital maps; moderns versions also provide elevation and obstacle information.
- Deployable Voice and Flight Data Recorder
  - VFDR that gets deployed ('ejected') in case of a crash or sinking; equipment is floatable and contains Emergency Locator Transmitter (ELT) and Underwater Locator Beacon (ULB).
- Passive tower-based Obstacle Collision Avoidance System
  - units located on utility and power line towers detect air traffic entering a predefined warning zone and activates warning lights to illuminate the tower; does not require any installations in the helicopter.
- Miniature Voice and Flight Data Recorder
  - miniature VFDR is intended to be smaller and cheaper, and can have all relevant sensors (pressure, gyros, GPS) integrated inside.
- Wire Strike Protection System
  - system basically consisting of cutters placed on the roof and bottom of the rotorcraft.
- Flight data evaluation and processing for accident and incident investigation
  - system comprising devices for voice, mission and flight data recording and data transfer; it also includes support equipment for conducting investigations and comprehensive flight data analysis.
- Cockpit Information Recorder
  - cheap alternative for the FDR, especially aimed at smaller helicopters; it consists of a colour camera, microphone and GPS.
- Full Authority Digital Engine Control
  - system that controls the engine(s); it also automatically starts recording certain parameters when the engine exceeds some kind of limit, thereby providing vital information about failures.
- Light helicopter HOMP systems
  - flight data monitoring system for light helicopters, being a preventive system for improving safety.
- Efficient numerical approaches for on-board rotorcraft flight performance modelling

- flight system allowing aviators to complete performance/mission planning on-board the aircraft, automatically taking into account performance boundaries and other limits.

- Radar Altimeter for altitude measurement
    - system aimed at small helicopters, consisting of one single unit containing both transmitter and receiver antennas as well as processing unit.
- Immersive visualisation
    - new technique to support accident analysis, taking into account eye witness statements; witness reports are used to reconstruct the(3D) flight path of an observed aircraft, including all potential errors.

The combination of these 15 technologies can potentially mitigate the following safety issues:

- Pilot judgment & actions - Human Factors Pilot's Decision
- Pilot situation awareness - External Environment Awareness
- Pilot judgment & actions - Flight Profile
- Part/system failure - Aircraft
- Unsafe Acts / Errors - Skill-based Errors
- Unsafe Acts / Errors - Judgment & Decision-Making Errors
- Mission Risk - Terrain / Obstacles
- Pilot situation awareness - Visibility / Weather
- Aircraft Design - Aircraft Design
- Maintenance - Performance of Maintenance Duties
- Regulatory - Accident Prevention

It is to be noted that the top five individual technologies above are highly promising for three or more (up to five) safety issues.

There are three safety issues for which no potential promising technology has been identified:

- Safety management – Management
- Regulatory - Oversight and Regulations (Regulatory)
- Preconditions; Condition of Individuals - Psycho-Behavioural Factors

Not having identified technologies for these issues is not necessarily a negative aspect, as other means of mitigation could very well be possible.

The results of this study show which technology can (potentially) mitigate which safety problem(s). It is concluded that 15 highly rated technologies jointly can mitigate 11 of the top 20 safety issues.

The challenge on how to implement these technologies lies with the industry. This message, accompanied by the results, will be disseminated as much as possible through publications and presentations throughout the helicopter community and beyond.

- The industry is highly recommended 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 are encouraged to concentrate their efforts on developing the lacking and low TRL technologies.

Finally, as new technologies will be developed, technologies already under development will have their TRL improved and become more mature. On the other hand additional accident analyses may lead to changes in the ranking of safety issues. The technology matrix tool should be constantly updated. And EHEST should deliberate on how to continue the work of the ST Technology.

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Appendix A Top 20 SPS Level 2 descriptions

This appendix provides a qualitative description of the top 20 Standard Problem Statements (SPS's) so as to give insight into what is included in each one of them. Each SPS is elucidated with a short narrative of a typical accident scenario for which the named SPS was a major issue (partly based on Ref. 5). It is to be noted however that those accidents may also involve other SPS's.

1. Pilot judgment & actions - Human Factors Pilot's Decision

Human factors and decision making are important assets in accident prevention. Available resources must be used as planned (resource management). Cues that should have led to termination of current course of action or manoeuvre must be taken seriously. Aircraft limitations, rules and procedures must be adhered to. And last but not least: a pilot must know his own limitations and capabilities, and make use of them in his decision making process.

The commercial helicopter pilot was flying a passenger on an air taxi flight to a remote site in an area surrounded by snow-covered, flat, featureless terrain. Low fog, reduced visibility and flat light conditions reduced his ability to discern a horizon or terrain. The pilot elected to make a precautionary landing to wait for better visibility. After about 10 minutes, he decided to continue flight. After take-off, flat light conditions again reduced ability to recognize topographical features on the snow-covered terrain. He reported that in attempting to establish a stable hover, and erroneously believing that the helicopter was not moving, the right skid struck the snow-covered terrain. The helicopter rolled onto its right side.

2. Pilot situation awareness - External Environment Awareness

A pilot must constantly be aware of the external environment, like the aircraft position and altitude, aircraft state and flight envelope, surrounding hazards and obstacles. He must be able to detect and/or avoid conflicting traffic. Aiding systems, like enhanced vision systems or thermal imaging, may be used in appropriate environmental conditions. Also sufficient knowledge of the aircraft's aerodynamic state must be in place. Only then can the pilot build, update and maintain situation awareness and act accordingly (which may include changing course of action).

The pilot reported that while en-route to a field for an aerial application, he was distracted by a radio call from another pilot. The pilot looked down at a map to verify a field location, and when he looked back up, he did not see the power lines that he knew were there and which he had flown over on earlier flights. The helicopter collided with the power lines and fell to the ground.

3. Ground Duties - Mission Planning

The planning of the mission is an important part of the flight preparation, one in which latent, and thus potentially dangerous, risks can be identified and mitigated. Proper consideration must be given to aircraft operational limits, performance, fuel planning and weather and wind conditions, thereby making use of actual operational data and mission requirements. A lack of sufficient experience may lead to inadequate planning, for instance inadequate consideration of obstacles. A pre-flight Risk Assessment tool developed by the EHEST supports this important mission planning phase.

> The pilot with four passengers departed on a local area revenue sightseeing flight in a skid-equipped helicopter. While in cruise flight the fuel pump warning light illuminated, and the pilot began a precautionary landing approach to a vacant parking lot. While on final approach the engine flamed out. The pilot initiated an autorotation, but the helicopter landed hard. An examination of the helicopter revealed that it had flown 1.5 hours before the accident. The helicopter's fuel gauge, annunciator system, fuel pump, and fuel system, functioned normally. The fuel tank contained about 40 ounces of fuel.

4. Pilot judgment & actions - Flight Profile

The flight profile must always be chosen such that it is safe for various aspects. These include conditions like altitude, airspeed, take-off and approach, rotor RPM and power margins.

> During a local flight to pick up personnel, the helicopter was launched during a snowstorm. The weather was moderate snow, partial obscuration, 1/4-mile visibility, winds 12 knots with gusts to 20 knots, and a temperature/dew point of 28/27 degrees Fahrenheit respectively. Limitations in the flight manual require that both a particle separator and deflector be installed on the engine for flight in snow to prevent engine flame out. A deflector was not installed. During cruise flight at approximately 200 feet above ground level, the engine lost all power and the pilot performed a downwind autorotation landing. During touchdown the helicopter rolled on its side.

5. Part/system failure – Aircraft

Pilots can hardly prevent random failures, but may play an essential role in managing their consequences in flight. Airframe components can fail due to inadequate design, manufacturing defects, overstressing, poor maintenance or lack thereof, lubrication starvation or external influences (called “Particular Risks” in System Safety Assessment) like lightning strikes or bird strikes. Failures may affect items like rotor blades, rotor hubs, drive train components, landing gear, etc. Also rotorcraft systems can fail, such as the hydraulic, electrical, fuel or flight control system, or the avionics or data recording equipment.

During cruise flight the pilot lost control of the helicopter and an uncontrolled forced landing was made onto the top of a two-story industrial warehouse. The pylon mounted actuator support assembly had separated from the transmission case. All of the studs showed progressive fatigue cracking from multiple origins.

6. Unsafe Acts/Errors – Skill-based Errors

Errors based either on insufficient experience or skills, or on the activation of contextually inappropriate routines, are called skill-based errors. Such errors can result in inadvertent operations, checklist errors or procedural errors, in breakdowns in the visual scan or in various forms of over-control, under-control or inadequate control manoeuvres.

During take-off, when transitioning from hover to forward flight the helicopter started descending. One of the skids touched the ground, after which the helicopter rolled and pitched nose down. The main rotor blades hit the ground and the helicopter rolled over. It is plausible that the helicopter was not controlled in a coordinated way. When pitching nose down, the resulting descend was not correctly compensated by selecting more power. The following yawing moment was not adequately countered with the pedals.

7. Safety Management - Inadequate Pilot Experience

An important component of safety management is the pilot’s competency and experience in relation to the operation. Inadequate pilot experience, in general or regarding the operation and/or mission of interest, may lead to inappropriate decisions and actions before and/or during the flight.

During the initial approach the speed increased slightly. This was corrected by raising the nose and reducing the torque. The crew failed to timely notice the rapid decrease in airspeed and increase in vertical descent speed. Sometime later it was noted that the speed decreased rapidly and the pitch angle increased to 15 degrees. At that moment the pilot in command / pilot non flying applied full collective but could not prevent the helicopter from briefly hitting the water. The two cockpit crew members both flew two different types of helicopters and did not have recent experience on the type involved.

8. Unsafe Acts/Errors – Judgment & Decision-Making Errors

During an operation a proper risk assessment is essential. This also includes the appropriate prioritisation of tasks. Necessary actions must be taken on time, and not being rushed, delayed or ignored. And the pilot must pay sufficient attention to decision-making during operation.

The helicopter struck a pole adjacent to a hangar during take-off. The helicopter was configured to seat four occupants with four seatbelts. There were five occupants on-board at the time of the accident, and a child, who was not seat belted, was ejected from the helicopter. The pilot did not calculate the centre of gravity, and only calculated the weight prior to the flight using passenger weights as understood by the pilot. During the investigation actual passenger weights were used and the centre of gravity was found to be out of limits. In addition, the take-off gross weight was found to be above the maximum gross weight limit.

9. Pilot judgment & actions - Procedure Implementation

A pilot's ability to correctly implement procedures is very important to prevent accidents or incidents from happening. A pilot can act improperly due to misdiagnosis or he may exhibit control / handling deficiencies. A response to loss of tail rotor effectiveness may be inadequate. Also energy and power management during the complete mission is crucial. The pilot may improperly recognise and respond to a potential dynamic rollover. Fuel monitoring must be carried out adequately, etc. Plus there may be all kinds of procedure implementation mishaps.

The pilot of the medevac helicopter reported that, during lift-off at the remote site, he encountered a loss of visual reference due to a "brown out" condition created by blowing dust. He then attempted to land the helicopter without any visual reference. A rolling motion to the left was created and, after the left skid contacted the ground, a dynamic rollover ensued.

10. Mission Risk - Terrain/Obstacles

Certain missions can be very risky due to the nature of the terrain or the presence of obstacles. This may include flying near other vehicles, obstacles and wires. But it may also include remote landing sites or flying over unsuitable emergency landing terrain. Flying at high density altitudes can also pose a problem, as do operations with limited power margins. Therefore lack of operating site reconnaissance or unforeseen obstacles can spoil the day.

The pilot was assigned to fly in high-level rugged desert conditions. Once airborne (density altitude was about 9000 feet) he was instructed to land and hold for a period of time. A witness observed the helicopter make a 45 to 60 degree bank turn, lower its nose down almost vertically, and then reduce its nose low pitch to approximately 45 degrees as it disappeared from sight. Post-accident examination of the engine revealed that the engine had functioned for a time at a temperature level well above its limits. The probable cause(s) of this accident was determined as the pilot's loss of aircraft control due to abrupt flight manoeuvring. Contributing factors were the high density altitude weather condition, the total loss of engine power after over-temping the turbine section, and the lack of suitable terrain for the ensuing autorotation.

11. Pilot judgment & actions – Landing procedures

Many accidents / incidents occur during the landing phase. Landing procedures are in place to improve flight safety. These procedures will include prescribed ways on how to carry out a safe landing, but also on how to select an appropriate landing location and what to do if something unexpected happens during the landing phase.

The pilot experienced loss of engine power due to failure of an exhaust valve. The pilot entered autorotation, but failed to maintain rotor rpm and the proper rate of descent resulting in an in-flight collision with terrain. The pilot's last known autorotation was 4 months before the accident.

12. Safety management – Management

The management part of the safety management system is an important task, which must not be underestimated. Various managers must be in place. They must be proficient in their assigned task and be aware of all aspects of safety management. More than once management tasks are being combined, making one person responsible for various aspects. This may lead to a lack of oversight, a disregard of a known safety risk, or even to conflicting interests.

Due to a black-out on an offshore platform it was decided to evacuate a number of persons by means of a SAR flight. The captain of the helicopter did make an assessment, concluded that there was no need to dispatch a SAR flight, but decided otherwise. The SAR helicopter used for the evacuation had only 4 passenger seats for 13 passengers and therefore was inadequately equipped for the mission. During the return flight the cockpit crew reported engine speed fluctuations and experienced controllability problems and decided to make an emergency landing in the North Sea.

13. Maintenance – Maintenance procedures / management

Maintenance procedures and tasks must be clear and strictly followed so as not to overlook anything. The management of the maintenance work must be well-organized and adequate. Responsibilities and authorizations must be well-defined.

After an inspection on a helicopter two spanners were missing. The work had been carried out by an engineer and a supervisor. According to the engineer it was not unusual to put spanners on the rotor head. When the engineer momentarily left his job, the supervisor thought the work was finished and signed off the inspection. The engineer thought the supervisor would finish the job.

14. Regulatory – Oversight and regulations

It is the mission of Aviation Authorities is to promote the highest common standards of safety and environmental protection in civil aviation. For that they develop common regulations, monitor and supervise the implementation, and provide the technical expertise and training. Inadequate oversight or a lack of regulations can lead to accidents, and so can regulations that are not in place or turn out to be inappropriate.

A fixed wing aircraft lined up for take-off at an airfield without ATC. After having radioed their intentions, they took off. Immediately after lift-off they saw a helicopter lining up in front of them on the same runway from an intersection and taking off in runway direction. The instructor on-board the fixed wing aircraft immediately took over control and made a sharp turn to the right. The two aircraft passed each other at a distance of about 20 meters. During the incident analysis it became clear that there are no dedicated rules in place for intersection take-offs.

15. Preconditions, condition of individuals – Cognitive factors

Cognitive factors are circumstances or influences that contribute to producing a certain result. Those conditions have an impact on the way people perform. One can be distracted from the normal course of action (by hearing a sudden alarm), can exhibit channelized attention (by completely focussing on a failed instrument), or even may be inattentive (by chatting to someone during an operation).

During an instruction flight the instructor wanted to demonstrate that the cockpit heater was off by switching it on. The action was apparently performed without consciously looking at the instrument panel. He most likely pulled the fuel shut-off valve control to its off position instead of pulling the heater control to its on position. The engine faltered and an autorotation was initiated, resulting in a hard landing and severely damaging the helicopter.

16. Pilot situation awareness – Visibility / weather

A pilot must constantly be aware of the external environment, like surrounding hazards and obstacles, and of the position and flight state of the helicopter within that environment. This situation awareness can be (severely) hampered during reduced visibility or bad weather conditions. Under those conditions more attention is required to correctly monitor the instruments and to trust them. The pilot may be distracted from the instruments while looking outside to find visual clues. Advanced systems, like enhanced vision systems or obstacle warning systems, may be useful under those conditions.

> The non-instrument rated private pilots did not obtain a weather briefing or file a flight plan for the night cross-country flight. During dark night conditions, a witness observed the helicopter descending from the clouds following a highway. The helicopter struck an electrical pole and impacted terrain. A weather study revealed that the accident site was in an area of low ceilings and restricted visibility. During examination of the helicopter, no anomalies were found with the engine or airframe that would have precluded normal flight operations.

17. Aircraft design – Aircraft design

Although an aircraft type can be certified, this is no guarantee that it is safe. Not everything can be tested beforehand under all imaginable conditions, or a certain usage has not been taken into consideration during the design phase. Components may give way under unforeseen high loads, after failure of a component the aircraft may not be recoverable, or required intervention times may turn out not to be in line with human performance.

> Two certificated helicopter instructors were in a turbine-powered helicopter practicing autorotations with a power recovery prior to touchdown. The flying pilot inadvertently activated the flight stop/emergency fuel augmentation switch during a power recovery, which resulted in engine and main rotor overspeeds. The engine subsequently lost power and an autorotation was accomplished. Investigation disclosed that the significant overspeed condition had resulted in a catastrophic failure of the turbine engine and the tail rotor drive shaft coupling. The flight stop switch on the collective has no protective guard and can be readily engaged, allowing the engine to enter the augmented fuel flow regime and, under certain conditions, causing the engine to overspeed. The switch has a history of inadvertent activation.

18. Maintenance – Performance of maintenance duties

Maintenance is an important part of safe operations. The maintainers should be given adequate time and tools to perform their assigned maintenance duties. And they themselves must perform their duties in a professional way and in accordance with the established procedures. It is all too easy to get distracted or to be called away for another task. This may lead to a maintenance task not being completed correctly or to not detect an impending failure.

During cruise the vibration level of the helicopter suddenly increased. Besides that, the helicopter behaved normal, there were no vibrations on the controls, no warning lights and all indicators showed normal values. The crew returned to the departure airport. After having stopped the rotors one of the main rotor blades turned out to be damaged at about the mid-span position. A day after the incident two spanners that had been used during an inspection, were missing. According to the engineer it was not unusual to put spanners on the rotor head. Supposedly the spanners were left behind on the rotor head. During start-up one or both spanners may have damaged the rotor blade. During flight a part of the blade's skin detached, causing the vibrations.

19. Preconditions, condition of individuals – Psycho-behavioural factors

The personal mental condition is of high importance for carrying out a safe operation. There are many psycho-behavioural factors that can 'ruin the day', like being tired, emotional, aggressive, demotivated, overconfident, and the like. A person must be 'fit for the task', and if not he/she should step back or being forced to step back.

A helicopter impacted terrain following visual flight rules flight into instrument meteorological conditions. The probable cause of this accident was the pilot's decision to take off from a remote, mountainous landing site in dark (moonless) night, windy, instrument meteorological conditions. Contributing to the accident were an organizational culture that prioritized mission execution over aviation safety and pilot's fatigue, the pilot's self-induced pressure to conduct the flight, and situational stress.

20. Regulatory – Accident prevention

The outcomes of accident analyses can be useful to prevent similar accidents from happening. To adequately facilitate those analyses sufficient flight data must be available. Therefore regulations must be in place, which mandate the installation of voice and data recorders, the parameters to be recorded, but also to carry out accident analyses on a regular basis.

The co-pilot on a commercial helicopter flight reported controlling difficulties and it was decided to initiate an emergency landing in the sea. During the analysis no technical cause of the difficulties could be found. A Flight Data Recorder was installed on the helicopter, but was lacking control forces as these are not required to be recorded.

Appendix B Technology Readiness Levels

Technology Readiness Levels (TRLs) are measures used to assess the maturity of evolving technologies (devices, materials, components, software, work processes, etc.) during their development and in some cases during early operations. Generally speaking, when a new technology is first invented or conceptualized, it is not suitable for immediate application. Instead, new technologies are usually subjected to experimentation, refinement, and increasingly realistic testing. Once the technology is sufficiently proven, it can be incorporated into a system/subsystem.

The National Aeronautics and Space Administration (NASA) uses the following definitions of the various levels.

Technology Readiness Level	Description
1. Basic principles observed and reported	This is the lowest "level" of technology maturation. At this level, scientific research begins to be translated into applied research and development.
2. Technology concept and/or application formulated	Once basic physical principles are observed, then at the next level of maturation, practical applications of those characteristics can be 'invented' or identified. At this level, the application is still speculative: there is not experimental proof or detailed analysis to support the conjecture.
3. Analytical and experimental critical function and/or characteristic proof of concept	At this step in the maturation process, active Research and Development (R&D) is initiated. This must include both analytical studies to set the technology into an appropriate context and laboratory-based studies to physically validate that the analytical predictions are correct. These studies and experiments should constitute "proof-of-concept" validation of the applications/concepts formulated at TRL 2.
4. Component and/or breadboard validation in laboratory environment	Following successful "proof-of-concept" work, basic technological elements must be integrated to establish that the "pieces" will work together to achieve concept-enabling levels of performance for a component and/or breadboard. This validation must be devised to support the concept that was formulated earlier, and should also be consistent with the requirements of potential system applications. The validation is "low-fidelity" compared to the eventual system: it could be

		composed of ad hoc discrete components in a laboratory.
5.	Component and/or breadboard validation in relevant environment	At this level, the fidelity of the component and/or breadboard being tested has to increase significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level, or system-level) can be tested in a 'simulated' or somewhat realistic environment.
6.	System/subsystem model or prototype demonstration in a relevant environment (ground or space)	A major step in the level of fidelity of the technology demonstration follows the completion of TRL 5. At TRL 6, a representative model or prototype system or system - which would go well beyond ad hoc, 'patch-cord' or discrete component level breadboarding - would be tested in a relevant environment. At this level, if the only 'relevant environment' is the environment of space, then the model/prototype must be demonstrated in space.
7.	System prototype demonstration in a space environment	TRL 7 is a significant step beyond TRL 6, requiring an actual system prototype demonstration in a space environment. The prototype should be near or at the scale of the planned operational system and the demonstration must take place in space.
8.	Actual system completed and 'flight qualified' through test and demonstration (ground or space)	In almost all cases, this level is the end of true 'system development' for most technology elements. This might include integration of new technology into an existing system.
9.	Actual system 'flight proven' through successful mission operations	In almost all cases, the end of last 'bug fixing' aspects of true 'system development'. This might include integration of new technology into an existing system. This TRL does not include planned product improvement of ongoing or reusable systems.

Appendix C Overview of listed technologies

This appendix shows all technologies that are listed in the technology matrix tool. For each technology a short name is given, followed by its designated category, a short description and the assigned Technology Readiness Level (TRL). Finally some information is given about the source and document title (when applicable).

Technology name	Category	Short technology description	TRL	Source	Title of reference documentation
Deployable Voice and Flight Data Recorder	Data Monitoring	Deployable VFDR according to ED-112 for flight data and voice data acquisition and storage. Crash Survival Memory Unit gets deployed in case of a crash or in case of sinking of the h/c after impact into water. Equipment is floatable and contains Emergency Locator Transmitter and Underwater Locator Beacon	9	Manufacturer’s data	
Digital Map	Avionics	Precise navigation system which also provides elevation and obstacle information to the pilot. Both integrated and standalone systems available	9	Manufacturer’s data	
Efficient Numerical Approaches for On-Board Rotorcraft Flight Performance Modelling	Situational Awareness	Efficient Numerical Approaches for On-Board Rotorcraft Flight Performance Modelling	9	ERF 2008	"Efficient Numerical Approaches for On-Board Rotorcraft Flight Performance Modelling"
Flight data evaluation and processing for accident and incident investigation	Data Monitoring	Download and analysis of voice and flight data for accident and incident investigation	9	Manufacturer’s data	

Full Authority Digital Engine Control	Data monitoring	The FADEC starts recording automatically when the engine exceeds some kind of limit (for a limited time) and can give vital information about the cause of failure and may result in future prevention.	9	ERF 2006; ERF 2002; AHS 2003	"Helicopter Safety in the Oil and Gas Business"; "The RTM 322 – Designed for Power Growth"; "Integration of the RTM322 FADEC into the WAH-64 Apache"
Immersive Visualisation	Other	Supporting Accident Investigation with an Immersive Visualisation	9	AHS 2011	"Supporting accident investigation with an immersive visualization of witness statements using the new method called IWI"
Laser radar obstacle and terrain avoidance system	Situational Awareness	An obstacle detection system which can sense objects as thin as wires, thus making it useful for wire strike prevention. The system uses an eye-safe laser which is mounted on the fuselage to provide the pilot with the information about the surrounding environment using both optical display and aural warning.	9	AHS 2005	"Assessment of Helicopter Wire Strike Accidents and Safety Warning and Protection Devices"
Light helicopter HOMP systems	Data monitoring	Flight data monitoring for light helicopters	9	EASA rotorcraft symposium 4	"A concrete operational evaluation of HFDM (Helicopter Flight Data Monitoring) system on light helicopters: lessons learned and Eurocopter recommendations"
Passive Tower-based Obstacle Collision Avoidance System (OCAS; AS of Norway)	Situational Awareness	OCAS is located on utility and power line towers and detects all air traffic entering a predefined warning zone and activates warning lights that illuminate the tower.	9	AHS 2005	"Assessment of Helicopter Wire Strike Accidents and Safety Warning and Protection Devices"

Radar Altimeter for altitude measurement	Situational Awareness	Precise height measurement providing pilot with real time and accurate information related to height above ground of his aircraft or helicopter. Equipment consists of one single unit containing both transmitter and receiver antennas as well as processing unit	9	Manufacturer's data	
Weather Safety through Online Weather Briefings	Situational Awareness	A web-based pre-flight weather briefing process, including an in-flight alerting system aim to ensure maximum awareness of the weather conditions that the pilot will encounter during the mission	9	ERF 2011	"Weather Safety through Online Weather Briefings"
Wire Strike Protection System	Aircraft Design	The WSPS consists basically out of cutters placed on the roof, bottom and around. These can cut through wires in case of collision and thus prevent an accident (the pitch angle is of great importance on chance of success for the WSPS)	9	FSD January 2003	"Most Fatal U.S. Commercial Helicopter Accidents Occur in Instrument Meteorological Conditions"
Active Inceptors in FHS for Pilot Assistance Systems	Situational Awareness	Active Inceptors in order to reduce the pilots workload and increase his/her situational awareness especially giving FLI Indications on a left hand sidestick to avoid overtorque	8	ERF 2010	"Active Inceptors in FHS for Pilot Assistance Systems"
Airworthiness Releases as a Result of Condition Based Maintenance	Data Monitoring	The US Army Aviation Engineering Directorate condition based maintenance program, including examples from field units and ongoing engineering support activities	8	ERF 2006	"Airworthiness Releases as a Result of Condition Based Maintenance"
Cockpit Information Recorder	Data monitoring	A cheap alternative for the FDR, for smaller helicopters. The CIR consists out of a colour camera, microphone and a GPS	8	ERF 2008	"Cockpit Image recording Systems"

Delivering Fleet Life Management to the Operator	Data Monitoring	This technology is intended to describe backgrounds and results of the RNLAF Chinook pilot program, and to introduce a few of the new and innovative structural integrity concepts that currently are being implemented on an operational level within the RNLAF	8	ERF 2007	"Delivering Fleet Life Management to the Operator"
Digital Range Image Algorithms for Flight Guidance Aids for Helicopter-Low-Level-Flight	Situational Awareness	Extensive simulation and flight tests were conducted to develop and test a complete set of algorithms for terrain following or contour flight, and more particularly to improve means of computing a reference OCL(obstacle contour line) for a terrain-following rotorcraft	8	AHS 2007	"Digital Range Image Algorithms for Flight Guidance Aids for Helicopter-Low-Level-Flight"
Enhanced Ground Proximity Warning System / Terrain Awareness and Warning System	Situational Awareness	Already used on airplanes. Used to prevent CFIT	8	ERF 2006	"Helicopter Safety in the Oil and Gas Business"
Improved Occupant Crash Safety in Helicopters	Crash-worthiness	A brief overview on the HeliSafe TA project with emphasis on DLR's contribution to the project	8	ERF 2008	"Improved Occupant Crash Safety in Helicopters"
System Architecture for new Avionics on Eurocopter Fleet	Avionics	The system presented in this article allows to EUROCOPTER helicopter fleet to adopt the latest generation digital integrated avionics system, with a "glass cockpit", a 4 axis autopilot and coupled with a Flight Management System that allows flying the helicopter automatically from the take-off to the landing.	8	ERF 2011	"System Architecture for new Avionics on Eurocopter Fleet based on IMA supporting civil and military missions"

TCAS II on Helicopters	Situational Awareness	The implementation of a Traffic Collision Avoidance System within a Helicopter with the aim to reduce the occurrence of mid-air collisions.	8	ERF 2008	"TCAS II on Helicopters - breaking the myth"
Active laser-based obstacle and terrain avoidance system combined with passive data base system (GPWS)	Situational Awareness	Combines all advantages of active TAWS/OWS (accuracy, real-time information, completeness) and passive databased systems	7	ERF 2011	"A new approach to a smart Helicopter Terrain Awareness and Warning System"
ALLFlight- Fusing sensor information to increase helicopter pilot's situation awareness	Situational Awareness	Main objective of this project is to demonstrate and evaluate the characteristics of different sensors for helicopter operations within degraded visual environments.	7	ERF 2010	"ALLFlight- Fusing sensor information to increase helicopter pilot's situation awareness"
Combined Usage of the LADAR (3D-LZ) and Brown-Out Symbology System (BOSS)	Situational Awareness	Evaluation of the usage of the Three Dimensional Landing Zone LADAR and the Brown Out Symbology System during a hover and landing scenario in severe brownout conditions.	7	AHS 2010	"Landing an H-60 Helicopter in Brownout Conditions Using 3D-LZ Displays"
Flight Testing of Rotorcraft IFR Steep Approaches using SBAS and GBAS guidance	Situational Awareness	This paper deals with the flight trials of rotorcraft steep IFR approaches under SBAS and GBAS guidance that have been achieved by Eurocopter in the frame of GIANT and OPTIMAL projects.	7	AHS 2008	"Flight Testing of Rotorcraft IFR Steep Approaches using SBAS and GBAS guidance"
Helicopter Slung Load Stabilization Using a Flight Director	Dynamic system	The flight director gives the pilot a convenient aid to effectively damp the load pendulum motion and to allow manoeuvring without exciting oscillatory load modes.	7	ERF 2009	"Helicopter Slung Load Pendulum Damping"

Miniature Voice and Flight Data Recorder	Data Monitoring	Miniature VFDR according to ED-155 for flight data and voice data acquisition and storage. Equipment can have all relevant sensors (Pressure, Gyros) integrated in case the h/c platform does not provide necessary data	7	Manufacturer’s data	
PAVE: A Prototype of a Helicopter Pilot Assistant System	Avionics	A pilot assistant system for helicopter operations that concentrates on safe take-off and landing phases even in very difficult visual conditions.	7	ERF 2007	"PAVE: A Prototype of a Helicopter Pilot Assistant System"
Predictive Ground Collision Avoidance Using Digital Terrain Referenced Navigation	Situational Awareness	Using a digital ground navigation database for predictive ground collision avoidance	7	EASA rotorcraft symposium 4	"Predictive Ground Collision Avoidance Using Digital Terrain Referenced (no GPS) Navigation"
Vibration passport technology for condition monitoring of helicopter engines	Data monitoring	Considers the problem of vibration monitoring of helicopter engines. Sensitivity of existing systems is limited because of limited frequency range usually used. High frequency vibration modelling could provide the development of vibration diagnostics of helicopter engines.	7	ERF 2010	"Application of vibration passport technology for condition monitoring of helicopter engines"
A Low Cost Approach To Helicopter Health and Usage Monitoring	Data Monitoring	This technology enables smaller size, lower cost, and older helicopters to have similar HUMS benefits as to the larger more expensive helicopters. Based on the development of more efficient algorithms, the system requires less computational power and is thus more accessible to a broad range of helicopters.	6	ERF 2006	"A Low Cost Approach To Helicopter Health and Usage Monitoring"
Active Sidesticks used for Vortex Ring State Avoidance	Avionics	Technology that helps the Pilot to avoid entering the VRS by calculating its closeness.	6	ERF 2009	"Active Sidesticks used for Vortex Ring State Avoidance"

Adaptive helicopter seat mount concept for aircrew vibration mitigation applications	Vibrations	Mitigation solution for vibration levels transmitted to aircrew	6	AHS journal 2010	"Investigation of Helicopter Seat Structural Dynamics for Aircrew Vibration Mitigation"
Autorotation training display on a flight training device	Other	A real-time trajectory optimization method for guiding a rotorcraft pilot through an autorotation following a total loss of power.	6	AHS 2005	"Evaluation of a rotorcraft autorotation training display on a commercial flight training device"
AWIATOR LIDAR Sensor	Situational Awareness	The LIDAR Sensor provides better situational awareness and increased safety by the clear detection of gusts, turbulences and wake vortices within the aircrafts flight path	6	CEAS 2007	"Forward looking clear air turbulence measurement with the AWIATOR LIDAR sensor"
Deployable System for Crash–Load Attenuation	Crash-worthiness	The new concept utilizes an expandable honeycomb-like structure to absorb impact energy by crushing. The new energy absorber offers most of the desirable features of an external airbag system without the limitations of geometric shape, poor shear stability, system complexity, and timing sensitivity.	6	AHS 2007	"Deployable System for Crash–Load Attenuation"
Engine Backup System	Aircraft Design	Engine hybridation during autorotation	6	Manufacturer's data	
Evaluation and optimization of the head-up guidance system model 2100 with regard to human-machine interaction	Situational Awareness	The Head-Up Guidance System (HGS) Model 2100 improves the human-machine interaction and in particular the stress, strain, situational awareness and the pilot's attention in different flight situations. It ultimately lowers the room for human errors	6	Deutscher Luft- und Raumfahrtkongress 2006	"Evaluation and optimization of the head-up guidance system model 2100 with regard to human-machine interaction"

HALAS - Helicopter Slung Load Stabilisation and Positioning System	Other	Automatic helicopter slung load stabilisation and positioning system for cargo handling and rescue hoist operations. With this pilot assistance system slung load oscillations can be automatically damped and the load can be precisely and automatically positioned. The system can handle rescue mission relevant challenges like variable cable lengths and side-mounted hoists.	6	Air Rescue magazine 1-2012	"HALAS - stabilisation and positioning system for rescue hoist operations"
Helmet Mounted ANVIS/HUD-24 System	Situational Awareness	The acquired Elbit Systems Ltd. helmet mounted ANVIS/HUD-24 system is intended to increase flight safety, in particular in operations where visual reference of the pilot is impeded, for instance during a brown-out or during shipboard operations – day and night.	6	ERF 2007	"Pilot-in-the-loop evaluation of a novel acceleration symbol for the RNLAF AS-532 U2 Cougar helicopter HUD"
Improved predictor-tunnel-configuration for a three dimensional flight guidance display	Situational Awareness	A three dimensional tunnel display including a predictor system that tells the pilot where his aircraft will be located in the near future. This technology facilitates the pilot's ability to anticipate a future position in his flight path.	6	Deutscher Luft- und Raumfahrtkongress 2006	"Verbesserte Prädiktor-Tunnel-Konfiguration für 3-Dimensionale Flugführungsdisplays"
Low-cost Obstacle Warning	Situational Awareness	A low-cost obstacle detection system is under study using automotive radar sensors which use the 76-GHz frequency	6	AINonline May 2012	"Eurocopter Researches Low-cost Obstacle Warning"
Obstacle and Terrain Avoidance	Situational Awareness	Obstacles (static objects like terrain or buildings and moving objects like traffic or people) are detected and a preventional haptic cue is provided (different levels of complexity: from simple warning to complex avoidance trajectories).	6	AHS 2005	"Intelligent Flight Path Guidance"

Stereo Based Obstacle Mapping	Situational Awareness	Creation of a three-dimensional obstacle map with a stereo based camera to avoid collisions and increase environmental awareness	6	CEAS 2007	"Stereo Based Obstacle Mapping from a Helicopter Platform"
Adaptive Nonlinear Flight Control and Control Allocation for Failure Resilience	Avionics	Reconfiguring control is implemented by making use of Adaptive Nonlinear Dynamic Inversion (ANDI) for autopilot control. The adaptivity of the control setup is achieved by making use of a real time identified physical model of the damaged aircraft	5	1st CEAS Specialist Conference on Guidance, Navigation and Control, 2011	"Adaptive Nonlinear Flight Control and Control Allocation for Failure Resilience"
ALLFlight - Helicopter Flight Trials under DVE conditions with an AI-130 mmW radar system	Avionics	Aims to provide an intuitive display in order to keep the workload low while providing all the necessary cues to perform the tasks safely and efficiently. Uses helmet mounted display which incorporates data from various types of sensors (TV, infrared, Ladar etc.). Paper concentrates on mm Wave radar.	5	ERF 2011	"ALLFlight - Helicopter Flight Trials under DVE conditions with an AI-130 mmW radar system"
Analysis of flight characteristics and prevention of PIO (Pilot Involved Oscillations)	Avionics	System to prevent Pilot Involved Oscillations	5	Deutscher Luft- und Raumfahrtkongress 2006	"Hohere Flugeigenschaftsanalyse und PIO-Pravention im Rahmen der Entwicklung moderner Hochleistungsflugzeuge"
Assessment of Anomaly Detection and Diagnosis	Maintenance	Application of Condition Based Maintenance to the AS332L1 helicopter. The presented results in this paper aim to demonstrate the ability of HUMS in operation for maintenance alleviation of dynamic components by the means of anomaly detection and diagnosis techniques using statistics and pattern classification.	5	ERF 2011	"Assessment of Anomaly Detection and Diagnosis applied to EUROHUMS data for maintenance alleviation"

Assisted Landing for Helicopters in Confined Areas	Situational Awareness	This technology is based on the implementation of a computer-based approach planning for manned helicopters in confined areas. The algorithms developed consider the procedures of pilots during the approach planning.	5	ERF 2010	"Assisted Landing for Helicopters in Confined Areas"
Autonomous Obstacle Avoidance for Rotorcraft including Vehicle Constraints and Mission Objectives	Situational Awareness	In order for unmanned rotorcraft to reach their potential, new methods for guidance, navigation, and control are created that include the effect of a complex array of obstacles that are dynamically changing	5	ERF 2010	"Autonomous Obstacle Avoidance for Rotorcraft including Vehicle Constraints and Mission Objectives"
Brown-Out Symbology Simulation (BOSS) on the NASA Ames Vertical Motion Simulator	Situational Awareness	The purpose of the Brown-Out Symbology Simulation (BOSS) study was to evaluate design issues for a new display symbology set designed to aid the pilot in performing approaches and landings in degraded visual conditions	5	AHS 2008	"Brown-Out Symbology Simulation (BOSS) on the NASA Ames Vertical Motion Simulator"
Depth image processing for obstacle avoidance	Situational Awareness	Usage of a stereo camera for automatic detection of obstacles and avoidance of collisions	5	Deutscher Luft- und Raumfahrtkongress 2006	"Depth image processing for obstacle avoidance of an autonomous VTOL UAV"
Fast Range Image Based Landing Field Detection	Situational Awareness	Usage of a specific algorithm to identify the largest, nearly planar, circular landing pad.	5	CEAS Conference 2007	"Fast Range Image Based Landing Field Detection"
Helicopter OPTIMAL Control in OEI Low Speed Flights	Avionics	The objective of the research on helicopter optimal control was to develop a control method that would allow for safe landing of multiengine helicopter in one engine failure at low velocity and low height flight.	5	ERF 2008	"Helicopter OPTIMAL Control in OEI Low Speed Flights"
Low level flight solutions for civilian missions	Operational support	State-of-the-art advances in the field of efficient algorithms enabling to compute Obstacle Contour Line (OCL) and flight path for a manually-flown or automatically-flown rotorcraft unit flying a low-level trajectory	5	ERF 2011	"Low level flight solutions for civilian missions"

Obstacle Avoidance Strategy	Situational Awareness	A simple ad-hoc strategy using a pair of miniature laser rangefinders (i.e. MLR100) and two PIDs cooperating with an obstacle avoidance controller	5	1st CEAS Specialist Conference on Guidance, Navigation and Control, 2011	"Obstacle Avoidance Strategy for Micor Aerial Vehicle"
Radar-Altimeter in the Function of Anticollision System	Situational Awareness	The possibility of turning a classical on-board aviation radar-altimeter into an anti-collision system by the application of a relatively simple complementary circuit.	5	ERF 2011	"Radar-Altimeter in the Function of Anticollision System"
Simulation of autorotation flights towards emergency landing fields	Other	Simulation of autorotational flights alongside generated trajectories towards emergency landing fields	5	Deutscher Luft- und Raumfahrtkongress 2010	"Simulation von Hubschrauber-Autorotationsflügen entlang generierter Trajektorien zu bekannten Notlandeplätzen"
Swashplateless helicopter controls	Aircraft Design	Increasing the degree of freedom in order to ensure redundancy during a partial failure of the actuator system	5	Deutscher Luft- und Raumfahrtkongress 2005	"Untersuchung der Auswirkungen von Aktuator-Fehlverhalten in Taumelscheibenlosen Hubschraubersteuerungssystemen".
Synthetic Vision System for Mobile Flight, Navigation and Information	Situational Awareness	A flight navigation and support system that increases the pilots situational awareness during difficult weather conditions due to a combined usage of an IMU-unit and a self-developed low grade/low cost sensory unit.	5	Deutscher Luft- und Raumfahrtkongress 2008	"Conception of Synthetic Vision System for Mobile Flight, Navigation and Information"
Testing of New Terrain Following Guidance Algorithms for Rotorcraft Displays	Situational Awareness	Guidance and cueing were accomplished through a Synthetic Vision System (SVS) and the Altitude and ground Track Predicting Flight Path Marker (ATP-FPM) from prior work	5	AHS 2007	"Testing of New Terrain Following Guidance Algorithms for Rotorcraft Displays"
Visual Landing Aid (VLA) Evaluation Using Simulated Dynamic Interface Methods in the Manned Flight Simulator (MFS)	Situational Awareness	The standard VLA package helped the pilot identify the ship position and direction of movement, provided glide slope alignment for the approach, and flight deck lighting to help the pilot determine the aircraft position over the flight deck.	5	AHS 2008	"Visual Landing Aid Evaluation Using Simulated Dynamic Interface Methods in the Manned Flight Simulator (MFS)"

Adaptive Control of a High Agility Model Airplane	Avionics	Adaptive control is a promising technology for future high-performance, safety-critical flight systems. By virtue of their ability to adjust control parameters as a function of online measurements, adaptive flight control systems offer improved performance and increased robustness	4	1st CEAS Specialist Conference on Guidance, Navigation and Control, 2011	"Adaptive Control of a High Agility Model Airplane in the Presence of Severe Structural Damage and Failures"
Automated Power Assessment for Helicopter Turboshaft Engines	Data monitoring	The overall approach consists of: 1) a steady-state data filter which identifies and extracts steady-state operating points within HUMS data sets; 2) engine performance curve trend monitoring and updating; and 3) automated ETF (engine torque factor) calculation	4	AHS 2008	"Automated Power Assessment for Helicopter Turboshaft Engines"
Bio-Inspired Non-Emissive Powerline Detection System	Situational Awareness	Inspired by the compound eye of the fly, the proposed system detects powerline cords with a high accuracy without the need of emitting radiation.	4	ERF 2006	"Toward a Bio-Inspired Non-Emissive Powerline Detection System"
Cognitive System Architecture (COSA)	Situational Awareness	Supporting system that monitors the pilots decisions while giving suggestions and advice	4	Deutscher Luft- und Raumfahrtkongress 2006	"Missionsauftragsanalyse in COSA als Funktionsmodul eines Pilotenassistenzsystems"
Detection of incipient bearing faults in a gas turbine engine using integrated signal processing techniques	Vibrations	Presented is a gas turbine engine bearing diagnostic system that integrates information from various advanced vibration analysis techniques to achieve robust bearing health state awareness.	4	AHS 2007	"Detection of incipient bearing faults in a gas turbine engine using integrated signal processing techniques"
Detection of velocity obstacles in real time	Situational Awareness	Early detection of static and dynamic obstacles to raise external environmental awareness	4	Deutscher Luft- und Raumfahrtkongress 2006	"Depth image processing for obstacle avoidance of an autonomous VTOL UAV"; "Missionsplanung für kleine UAV-Systeme in hindernisreichen Umgebungen"

Error Detection of Flight Control Actuators	Maintenance	Model based error detection system that seeks to prevent possible defects of the flight control actuators	4	Deutscher Luft- und Raumfahrtkongress 2006	"Modellbasierte Fehlererkennung für Flugsteuerungsaktuatoren"
Helicopter Crashworthiness on Soft Soil	Crash-worthiness	The paper finally concludes on the suitability of standard specifications for soft soil crashes as well as the applicability of structural concepts developed mainly for crash on concrete. Besides, it addresses the feasibility of each simulation methodology, in terms of industrial application, and their capability to simulate correctly the physical phenomenon involved in soft soil impacts	4	ERF 2010	"Helicopter crashworthiness on soft soil: crash cases study, structure elements tests and numerical simulations"
Helicopter Integrated Pictorial Symbology for 4-D Re-Routable Approach-to-Landing	Situational Awareness	A novel display concept for Helicopter Integrated Pictorial Symbology (HIPS) has been developed for carrying out a curved and descending helicopter approach-to-landing and touch-down, subject to a commanded velocity profile along the trajectory.	4	AHS 2008	"Helicopter Integrated Pictorial Symbology for 4-D Re-Routable Approach-to-Landing"
Helicopter Windshield Spherical	Aircraft Design	Large Spherical Windshields with high resistance against Bird strikes acc. CS 29.631	4	Manufacturer's data	
Overview of Path Planning for Helicopters with Respect to Pilot Assistance Systems	Workload	This technologies main focus is on a dedicated trajectory generation helping the pilot in pre-flight planning and therefore reducing the navigational workload	4	Deutscher Luft- und Raumfahrtkongress 2010	"Overview of Path Planning for Helicopters with Respect to Pilot Assistance Systems"
A Practical Regime Prediction Approach for HUMS Applications	Data monitoring	As an extension to regime recognition to improve safety and/or reduce maintenance by predicting if the aircraft will be flown in a damaging way, a regime prediction approach is presented in this paper.	4	AHS 2007	"A Practical Regime Prediction Approach for HUMS Applications"

Rapid Helicopter Drive Train Fault Detection Using Adaptive-Network-Based Fuzzy Method	Data Monitoring	A new application of the adaptive-network-based fuzzy logic method to detect the failures of the mechanical systems through their vibration signals	4	ERF 2006	"Rapid Helicopter Drive Train Fault Detection Using Adaptive-Network-Based Fuzzy Method"
Toward a Real-Time Measurement-Based System for Estimation of Helicopter Engine Degradation Due to Compressor Erosion	Data monitoring	The tool allows operators to discern how rapidly individual turboshaft engines are degrading. The approach uses optimal estimator called a Kalman filter designed to estimate the compressor efficiency using only data from the engine's sensors as input	4	AHS 2007	"Toward a Real-Time Measurement-Based System for Estimation of Helicopter Engine Degradation Due to Compressor Erosion"
Ship Motion Prediction for Recovery of Helicopters	Dynamic system	This paper presents an investigation into the application of artificial neural networks trained using singular value decomposition and conjugate gradient algorithms for the prediction of ship motion. It presents the results of the application of Artificial Neural Network (ANN) methods for the prediction of ship motion.	4	ERF 2006	"Ship Motion Prediction for Recovery of Helicopters"
TRIADE project	Data Monitoring	The TRIADE project will provide a compact SHM system the size of a credit card, embedded in or attached on the part or structure under control It could analyse the humidity, temperature, pressure, vibration, strain and acoustic emissions during the flight of an aircraft or a helicopter	4	Aerodays 2011	"Development of technology building blocks for structural health monitoring sensing devices in aeronautics", TRIADE Project, funded under EU's Seventh Framework Programme (FP7)
A Hybrid Modelling Technique for Energy Absorption Capabilities of a Crashworthy Helicopter Structure	Crash-worthiness	Approach to optimize Rotorcraft structures in order to maximize the Energy Absorption Capabilities during a crash and therefore increase survivability of the passengers	3	ERF 2011	"A Hybrid Modelling Technique for Energy Absorption Capabilities of a Crashworthy Helicopter Structure"

Advanced modelling and flight control design for gust alleviation on ship-based helicopters	Workload	Development of an air wake compensator for the control laws which has the ability of reducing the pilot workload in the lateral, longitudinal and yaw axes	3	AHS 2008	"Advanced modelling and flight control design for gust alleviation on ship-based helicopters"
Air jets for dynamic stall control on the OA209 airfoil	Aircraft Design	The design and numerical investigation of constant blowing air jets as Fluidic Control Devices (FCDs) for helicopter dynamic stall control is described.	3	ERF 2010	"Numerical investigation of air jets for dynamic stall control on the OA209 airfoil"
An effective crashworthiness design optimization methodology to improve helicopter landing gear energy absorption	Crash-worthiness	This paper presents an effective simulation-based optimization algorithm for optimal design of large-scale, computationally expensive crashworthiness problems.	3	AHS 2007	"An effective crashworthiness design optimization methodology to improve helicopter landing gear energy absorption"
Helicopter Seat Absorber Optimisation	Crash-worthiness	Evaluation and Optimisation of the Seat Absorber performance in different impact scenarios.	3	ERF 2008	"Helicopter Seat Absorber Optimisation with Regard to Different Body-sizes passengers"
Manoeuvre Envelope Determination through Reachability Analysis	Situational Awareness	Knowledge of the safe manoeuvring envelope is of vital importance to prevent loss of control aircraft accidents. Determination of the safe manoeuvring envelope is addressed in a reachability framework	3	1st CEAS Specialist Conference on Guidance, Navigation and Control, 2011	"Manoeuvre Envelope Determination through Reachability Analysis"
The Effect of Rotor Design on the Fluid Dynamics of Helicopter Brownout	Situational Awareness	Optimising two key geometric properties on the rotor in order to minimize the Brownout effect when flying in ground proximity	3	ERF 2009	"The Effect of Rotor Design on the Fluid Dynamics of Helicopter Brownout"
A Method of Reducing Blade Sailing through the use of Trailing Edge Flaps	Aircraft Design	This paper considers the use of a trailing edge flap for the reduction of the blade sailing phenomenon. Results are presented using two helicopter blade dynamics methods to which aerodynamic models for the trailing edge flap have been applied	3	AHS 2007	"A Method of Reducing Blade Sailing through the use of Trailing Edge Flaps"

A System To Optimize The Human-Machine Interface	Other	System to lower the human-operator work load in order to avoid quick fatigue as well as to minimize human errors	2	CEAS Conference 2007	"A System of Optimizing The Human-Machine Interface at Aircraft"
Adaptive Flight Control System	Situational Awareness	Evaluation of the necessity for an adaptive flight control system that independently corrects itself and adapts to the current flight situation	2	CEAS Conference 2007	"Notwendigkeit adaptiver Flugsteuerungssysteme am Beispiel der Reglerentwicklung für den Technologiedemonstrator ARTIS"
Advanced alerting system - capabilities for part time display of vehicle parameters	Workload	Eurocopter proposes an innovative approach, which reduces the workload of the crew to analyse and interpret the situation of the aircraft thanks to a new design of a crew alerting system associated with a sophisticated monitoring of vehicle parameters.	2	ERF 2010	"Advanced alerting system - capabilities for part time display of vehicle parameters"
Damage and usage monitoring for vertical flight vehicles	Data monitoring	Three different technological innovations that introduce new capabilities: (1) mapping and tracking of damage using high-resolution, eddy-current imaging in a scanning mode, (2) monitoring with on-board networks of sensors for direct detection and characterization of fatigue and corrosion damage, using portable data acquisition units to plug-in and record inspection data in difficult-to-access locations and (3) on-board, real-time dynamic stress monitoring with networks of magnetic stress gages.	2	AHS 2007	"Damage and usage monitoring for vertical flight vehicles"

Integration of RFID Technologies in Helicopter Maintenance Processes	Maintenance	Eurocopter is developing a project for integrating RFID (Radio Frequency IDentification) tags on helicopter parts for maintenance. These technologies will support configuration management and provide maintenance information.	2	ERF 2010	"Integration of RFID Technologies in Helicopter Maintenance Processes"
Runway Incursion Prevention	Situational Awareness	The Surface Movement Awareness & Alerting System (SMAAS) provides increased Situational Awareness and supplies the crew with intelligent alerting for conflicts with surrounding traffic	2	Deutscher Luft- und Raumfahrtkongress 2006	"Runway incursion prevention: concept for an onboard surface movement awareness & alerting system"
Smart Helicopter Terrain Awareness and Warning System	Situational Awareness	A smart helicopter TAWS system – as described in this paper - requires a combined solution of database plus a real time laser based obstacle warning sensor system	2	ERF 2011	"A new Approach to a Smart Helicopter Terrain Awareness and Warning System"
Structuring and Communication of HUMS Data	Data Monitoring	Technology to fuse the data from different HUMS systems and versions into a common knowledge base, so that the data can be accessed through a single interface.	2	ERF 2006	"Structuring and Communication of HUMS Data"
3D audio for enhanced cockpit communication	Workload	By providing audio spatially to the pilot it is possible to reduce workload for the pilot		ERF 2002	"3-Dimensional Audio For Enhanced Cockpit Communications"
ACE-3D	Operational support	ACE 3-D Mapping of In-Service Airframe Defects		AHS 2005	"ACE 3-D Mapping of In-Service Airframe Defects"
Active Flap Rotor System	Dynamic system	The active flap control system uses smart materials (piezo) to actively improve vibration, noise and aerodynamics performance		AHS 2005	"Design, Development, Fabrication and Testing of an Active Flap Rotor System"

Advanced technologies for rotor system Condition-Based Maintenance (CBM)	For information only	Requirements for implementing Condition Based Maintenance (CBM) in the challenging rotor system environment, and will review recent research advances in the area of sensor and electronic technologies that enable CBM benefits.		AHS 2008	"Advanced technologies for rotor system Condition-Based Maintenance (CBM)"
Air Data Inertial Reference Unit	Avionics	ADIRU is a key component of the integrated Air Data Inertial Reference System (ADIRS), which supplies air data (airspeed, angle of attack and altitude) and inertial reference (position and attitude) information to the pilots Electronic Flight Instrument System displays as well as other systems. Used on aircrafts		International Conference on Robots and Systems 1999	"State Estimation of an Autonomous Helicopter Using Kalman Filtering"
Air-Data System	Avionics	ADS - provides anemometric information to the AFCS		ERF 2002	"A New AFCS for Eurocopter's Helicopters"; "A New Avionics System for the EC225/725 Cougar - an advanced helicopter cockpit & avionics system"
All-Electric Rotorcraft	Aircraft Design	By reducing the mechanical and hydraulic components/system, reducing complexity and possible improved performance and handling (due to Advanced Control Technologies), helicopters could become more safe.		ERF 2002	"The All-Electric Rotorcraft – Challenges and Opportunities"
APM's	Avionics	Acquires helicopter angles and rates, calculate the AFCS laws and transfers it to actuators		ERF 2002	"A New AFCS for Eurocopter's Helicopters"; "A New Avionics System for the EC225/725 Cougar - an advanced helicopter cockpit & avionics system"

ATR (Advanced Technology Rotor)	Dynamic system	A bearingless rotor which reduces vibrational loads by increasing the number of rotor blades and keeping the hinge offset as low as possible by smart flexbeam design. By increasing the number of rotors the enlarged rotor blade speed range dynamic blade tuning is much easier.		AHS 2008	"Recent advances in Eurocopter's passive and active vibration control"
Attitude-Heading Reference System	Avionics	AHRS - receives signals needed for stabilisation		ERF 2002	"A New AFCS for Eurocopter's Helicopters"; "A New Avionics System for the EC225/725 Cougar - an advanced helicopter cockpit & avionics system"
Automated Power Assessment	Maintenance	By processing the data available in a HUMS system, an estimation of the engine power can be made.		AHS 2008	"Automated Power Assessment for Helicopter Turboshaft Engines"
Automatic Dependent Surveillance Broadcast	Avionics	A next generation surveillance broadcasting system to track other traffic and also provide weather information		Internet	
Automatic velocity control system	Avionics	A feedback control system which control the helicopter to maintain a set airspeed or inertial velocity		Manufacturer's Patent, granted 2012	"Automatic velocity control system for aircraft"
Auto-Pilot Mode Selector	Avionics	APMS - unit to select the correct AFCS mode		ERF 2002	"A New AFCS for Eurocopter's Helicopters"; "A New Avionics System for the EC225/725 Cougar - an advanced helicopter cockpit & avionics system"
A Worldwide Terrain Database suitable for Aviation use	For information only	SRTM data is being used to create a resolute, accurate and consistent terrain model for use in a broad range of aviation applications		Deutscher Luft- und Raumfahrtkongress 2006	"A Worldwide SRTM Terrain Database suitable for aviation use"

Combing Real-Time, with 3-D vision	Situational Awareness	Combining video feeds with 3D imaging of the surrounding (by LAser raDAR (LADAR)) can give an enhanced image of the surrounding (with the possibility to detect collision)		IEEE Conference on Decision and Control, 2004	"Real-Time and 3D vision for Autonomous Small and Micro Air Vehicles"
Composite Helicopter Blades	Vibrations	Also an option to reduce vibrations and thus reduce the wear on components and the vibrations transmitted to the crew		AIAA, Journal of Aircraft, 2010	"Effect of Uncertainty on Hub Vibration Response of Composite Helicopter Rotor Blades"
Development of an Integrated Three-Function Valve	Aircraft Design	The ITFVs uses two hydraulic spools to combine the function of bypass valve, pressure relief valve and delta pressure transducer into a simple and compact assembly		ERF 2002	"Design and development of a two-fail-operate fly-by-wire flight control rotor actuation system utilising integrated three-function valves"
Electromagnetic AVCS	Dynamic system	An active system consisting of accelerometers, a control system and piezo actuators which decrease the vibrational loads experienced in the cabin.		AHS 2008	"Recent advances in Eurocopter's passive and active vibration control"
Energy absorbing seat and cabin environment	Crash-worthiness			ICAS 2006	"Development of helicopter safety devices"
Fibre-Optic Gyros	Avionics	FOGs - a replacement of mechanical gyroscopes		ERF 2002	"A New AFCS for Eurocopter's Helicopters"; "A New Avionics System for the EC225/725 Cougar - an advanced helicopter cockpit & avionics system"
Fire Detection System for Engine and Main Gear Box Compartment	Other	A new system used to detect fire, by a UV-IR optical flame detector		ERF 2002	"NH90 Helicopter – New Fire Detection System for Engine and Main Gear Box Compartment"

Flight Data Acquisition and Flight Data Monitoring	Data Monitoring	Gives extra information in case of an accident investigation, can prevent accidents due to operational oversight, provide tools for training and flight purposes, prevent unnecessary inspection and gathering fleet data		(information missing)	(information missing)
Flight envelope protection system	Avionics	Flight envelope protection by means of limit prediction and avoidance		Pennsylvania State University, thesis, 2005	"Envelope protection systems for piloted and unmanned rotorcraft"
Flight Management System with autopilot	Avionics	Provides improved helicopter stability		ERF 2006	"Helicopter Safety in the Oil and Gas Business"
FLYSAFE project	Situational Awareness	FLYSAFE is a weather uplink and flight safety program. It links all sorts of weather observation and prediction techniques and unifies them in objects which can be requested by aircraft and ATCs.		Aerodays 2011	"Airborne Integrated Systems for Safety Improvement, Flight Hazard Protection and All Weather Operations; Weather Uplink and Flight Safety, the FLYSAFE project", funded under EU's Seventh Framework Programme (FP7)
Ground Collision Avoidance System (on the ground)	Avionics	GCAS is used in aircrafts to prevent on ground collisions		ERF 2002	"Eurocopter's Research Activities on All-Weather Helicopters"
HEDGE project	Avionics	The aim of the HEDGE project is to develop and demonstrate new helicopter approach procedures as well as other EGNOS (European Geostationary Navigation Overlay Service) applications for general aviation.		Aerodays 2011	"HElicopters Deploy GNSS in Europe (HEDGE) project", commissioned by the GSA (European Global Navigation Satellite Systems Agency) and part-funded under the EU's Seventh Framework Programme (FP7).

Helicopter Rotor Blade Lag Fluid Elastic Embedded Chordwise Inertial Dampers	Dynamic system	An embedded fluid elastic inertial damper is a small, single degree of freedom system that consists of a mass, rigidly connected to a fluid vessel, on an elastomeric spring located in the rotor blade cavity. The damper is tuned to a specific problem frequency and oscillates out-of-phase with the rotor blade resulting in an inertial moment about the lag hinge.		AHS 2005	"Design and Model Testing of Helicopter Rotor Blade Lag Fluid Elastic Embedded Chordwise Inertial Dampers"
Helicopter Rotor Lag Damping Augmentation Based on a Radial Absorber and Coriolis Coupling	Dynamic system			AHS 2005	"Helicopter Rotor Lag Damping Augmentation Based on a Radial Absorber and Coriolis Coupling"
Helicopter Usage Spectrum Development	Maintenance	The recording the way a helicopter has been used gives extensive insight in the predicted lifetime, the chance on failure and repair requirements. This technology can individually monitor the helicopters.		AHS 2005	"The Art of Helicopter Usage Spectrum Development"
Hontek coating	Maintenance	Rotor corrosion protection by means of a coating		AHS 2009	"Enhanced erosion protection for rotor blades"
Hydraulic Lag Damper Models	Vibrations	Reduces the vibrations and thus will reduce the wear on components and the vibrations transmitted to the crew		AIAA, Journal of Guidance, Control, and Dynamics, 2010	"Integration of Hydraulic Lag-Damper Models with Helicopter Rotor Simulations"
IMD-HUMS	Maintenance	Health and Usage Monitoring System		AHS 2005	"Integrated Mechanical Diagnostic System (IMDS) fleet introduction for US Navy/Marine Corps helicopters"

Intelligent Flight Path Guidance (IFPG)	Situational Awareness	This technology enhances the Day, Night and All Weather (D/NAW) capabilities of helicopters. IFPG are mainly passive guidance systems, that calculates a trajectory, depending on the helicopter capabilities, and provides Flight Path Guidance. A combination of internally stored terrain information, from a DTED database, in combination of real-time state and performance is used. This is also called the Helicopter Terrain Following (HTF) system.		AHS 2005	"Intelligent Flight Path Guidance"
Magnetorheological Fluid-Elastomeric Lag Damper	Dynamic system	The magnetorheological fluid–elastomeric lag damper consists of a flow valve, a flexible snubber body, and a flexible center wall separating the body into two fluid chambers. Magnetorheological fluid enclosed in the snubber body can flow through two magnetorheological valves and be activated by a magnetic field in the valves.		AIAA Journal, 2010	"Adaptive Snubber-Type Magnetorheological Fluid–Elastomeric Helicopter Lag Damper"
Mobile Aircrew Restraint System (MARS)	Other	Mobile Aircrew Restraint System: A webbing retractor mounts to the aircraft cabin ceiling, extending or retracting webbing as the aircrew moves about the cabin. Should the aircraft crash or the aircrew fall, the retractor locks, preventing further webbing extraction.		AHS 2005	"Development of a Mobile Aircrew Restraint System"

New Diagnostic Techniques for Advanced Rotorcraft Monitoring System	For information only	The advanced rotorcraft monitoring system considers to successfully complete the conversion to the condition based maintenance and capabilities of existing HUMS.		ERF 2011	"New Diagnostic Techniques for Advanced Rotorcraft Monitoring System"
Novel Display to minimize the risk of Spatial Disorientation	Situational Awareness	Spatial Disorientation remains a major source of accidents. This Novel Display should provide additional information about the position and attitude of the helicopter, such that pilots can recover from disorientation.		AIAA World Aviation Congress, 1997	"Simulation Test of a Novel Display to Minimize the Risk of Spatial Disorientation"
OASYS Radar (Amphitech Systems)	Situational Awareness	The OASYS Radar uses a radar mounted on the nose of the helicopter to transmit a 35 GHz radio frequency to detect obstacles in the flight path. The radar constantly searches for obstacles in its field of view. At a given instant of time, the system uses data from the aircraft's GPS receiver to calculate the aircraft's flight path for the succeeding 19 seconds.		AHS 2005	"Assessment of Helicopter Wire Strike Accidents and Safety Warning and Protection Devices"
On-board health assessment of an electro-mechanical actuator	For information only	In flight monitoring of motor input current to detect possible actuator failures. The technology targets at ensuring safety while increasing maintenance intervals		CEAS Conference 2007	"On-board health assessment of an electro-mechanical actuator using wavelet features"

Passive Millimeter-Wave Imaging	Situational Awareness	mmW imaging makes it possible to view the surrounding, due to receiving the black body radiation of objects. mmW is especially effective in bad weather conditions as it can 'see' through clouds and mist		Partners in Techno-logy Forum 2005; SPIE Proceedings Vol. 6211: Passive Millimeter-Wave Imaging Technology, 2006; SPIE Proceedings Vol. 5077: Passive Millimeter-Wave Imaging Technology VI and Radar Sensor Technology VII, 2003; Digital Avionics Systems Conference, 2000	"Passive Millimeter-Wave Imaging and Potential Applications in Homeland Security and Aeronautics"; "Passive Milimeter-Wave Imagery of Helicopter Obstacles in a Sand Environment"; "Millimeter-wave radiometric measurements of a treeline and building for aircraft obstacle avoidance"; "Real Time Passive Millimeter-Wave Imaging from a Helicopter Platform"
Piezo-LIVE	Dynamic system	The Piezo-LIVE (P-LIVE™) is a weight-efficient, power-efficient, active device that uses smart piezoactuators to control harmonic vibration in helicopters, tiltrotors, and other applications. The P-LIVE™ provides a stiff mounting with vibration attenuation over a reasonably large variable rpm range.		AHS 2005	"Active vibration treatment for rotorcraft with piezo-LIVE technology"
Pilot Assistance for Rotorcraft	Avionics	Main target of this research project was the development of a pilot assistance system, which helps pilots in critical situations and supports them in the handling of the helicopter and the fulfilment of the mission		ERF 2009	"Pilot Assistance for Rotorcraft"

Powerline Detector	Situational Awareness	The Powerline Detector is a system that senses the electromagnetic fields surrounding power lines and uses this information to alert the pilot to the proximity of wires.		AHS 2005	"Assessment of helicopter wire strike accidents and safety warning and protection devices"
Real Time Adaptive Fusion	Situational Awareness	Fusion combines multiple visual sources, like Infra-Red, Image Intensified feeds and normal feeds to an optimized image		ERF 2002	"Future Battlefield Rotorcraft - a System of Systems"; "Real-Time Image Fusion: A Vision Aid for Helicopter Pilotage"
Restraint and Seat Systems	Crash-worthiness	Cockpit Airbags and Harness Restraint Systems for the future		Manufacturer's data	
Seat attenuator and slide	Crash-worthiness	A vertical moving attenuator and slide along the helicopters axis to damp impact loads and vibrations		ICAS 2006	"Development of helicopter safety devices"
Self-Monitoring Smart Electro-Mechanical Actuator (SEMA)	Avionics	SEMA's		ERF 2002	"A New AFCS for Eurocopter's Helicopters"; "A New Avionics System for the EC225/725 Cougar - an advanced helicopter cockpit & avionics system"
Several techniques to improve crashworthiness	Crash-worthiness	Using Energy-absorbing materials, kneeling landing gear, crashworthy seat, self-healing crashworthy fuel tank, fuel lines and tank foam to suppress fire, fixed tail dragger landing gear and applying a higher impact withstanding		Asia Simulation Conference 2008	"Several Key Techniques for Civil Helicopter Crashworthiness Safety Design and Simulation"
Symbology Injection in Night Vision	Situational Awareness	Increasing effectiveness of panoramic and normal NVD, by implementing symbologies which provide additional information		ERF 2002	"Flight Evaluation of Helicopter Pilot Night Vision Aids Using a Novel Racetrack Methodology"

Synthetic Vision System	Situational Awareness	SVS is a computer-mediated reality system for aerial vehicles that uses 3D to provide pilots with clear and intuitive means of understanding their flying environment. It can also use data from X-band radar, visual, and IR cameras.		Digital Avionics Systems Conference, 2002; NASA Ames Research Center, 1992	"The NASA Approach to Realize a Sensor Enhanced-Synthetic Vision System (SE-SVS)"; "Enhanced/Synthetic Vision Systems: Human Factors Research and Implications for Future Systems"
Traffic Collision Awareness Equipment	Avionics	TCAD (Traffic Collision Awareness Device) is used in aircrafts to prevent mid-air collisions		ERF 2002; Digital Avionics Systems Conference 2002	"Eurocopter's Research Activities on All-Weather Helicopters"; "Some VDL Applications for Helicopter Safety and Efficient Operation"
Ultrasonic Ice Protection System	Aircraft Design	A non-thermal system to remove ice layers <3mm from rotor blades by using ultrasonic transverse shear stresses		AHS 2008	"Investigation of an Ultrasonic Ice Protection System for Helicopter Rotor Blades"
WAAS, EGNOS	Avionics	Wide Area Augmentation System (USA) and European Geostationary Navigation Overlay Service (EU) uses ground stations, GPS, GLONASS and Galileo satellites to improve its accuracy by reporting the error, accuracy and availability of the satellite signals. This enables highly accurate navigation which can be used for instrument landing systems to land with low visibility		Internet	

Appendix D Technology categories

This appendix provides brief qualitative descriptions of the technology categories, including some examples of relevant technologies and of their (potential) safety benefits. It is to be noted that these safety benefits are examples only and are not meant to constitute the results of the study.

1. Aircraft Design

This category includes items pertaining to aircraft design. Some examples are:

- All-electric rotorcraft (e.g. avoiding hydraulic systems)
- Integrated three-function valve, simplifying hydraulic system lay-out
- Ultrasonic ice protection system
- Engine backup system to aid auto-rotational flight

This category typically addresses aircraft design-related SPS's. On a more technology specific level these items could also be beneficial for other SPS's like mission risk, part/system failure, skill based errors and judgment & decision making errors.

2. Avionics

More and more avionics are being developed to aid the pilot and operator in their day-to-day job. A few interesting examples, some of which are already in use on fixed-wing aircraft, are:

- Improved Flight Management Systems, Attitude-Heading Reference Systems and Air Data Systems
- Self-monitoring smart electro-mechanical actuators
- Traffic collision awareness equipment
- Ground collision avoidance system
- Automatic Dependent Surveillance Broadcast
- Flight envelope protection system
- Analysis of flight characteristics and prevention of PIO (Pilot Involved Oscillations)

This category mainly addresses the SPS's related to pilot situation awareness, flight profile and safety management, thereby aiding the pilot to grasp and manage the situation and reducing the workload.

3. Crashworthiness

Crashworthiness in the design cannot prevent accident / incidents from happening, but it will protect the occupants (or other sensitive loads) against the impact. A few examples:

- Energy absorbing materials in construction and seats
- Self-healing, crashworthy fuel tanks
- Seat attenuator and slide system
- Airbags and harness restraint systems

This category is beneficial for e SPS's related to aircraft design, as it can reduce the consequences of an accident / incident and increase survivability.

4. Data Monitoring

Accident analysis is strongly dependent on the availability of adequate and accurate data. But those data can also be used to directly inform the pilot during the flight. Many developments are in place to facilitate data acquisition, like:

- Light helicopter HOMP systems
- Full Authority Digital Engine Control with vibration and condition monitoring
- Flight data acquisition and monitoring system (can also be used for training and fleet management)
- Cockpit information recorder (audio, video and GPS)
- Miniature or deployable voice and flight data recorder
- Flight data evaluation and processing tool for accident and incident investigation

Data monitoring technologies bring benefits regarding operation and maintenance-related SPS's. Systems like these will also support the accident analysis effort, thus providing means to avoid future (similar) accidents.

5. Dynamic System

The dynamic system is an important part of the helicopter, being the primary source for transmitting power and providing thrust and control. The system is prone to high vibration and loading levels. New technologies are actively trying to reduce those levels:

- Various new-technology types of blade lag dampers, such as fluid-elastic inertial or magneto-rheological fluid–elastomeric dampers
- Active vibration, noise or load reduction through piezo-electric actuators that correct unwanted blade behaviour by making small tab deflections

- Helicopter sling load stabilisation using a flight director to guide the pilot, thereby reducing the load instability
- New rotor concepts with increased blade number to ease vibration and noise reduction

This category addresses SPS's related to part/system failure and aircraft design, by providing means to alleviate loads and vibrations.

6. Maintenance

Maintenance plays an important role in continued airworthiness and safety. Some interesting new technologies are being developed that can alleviate the maintenance burden or prevent accidents / incidents:

- Use of RFID (Radio Frequency Identification) tags on helicopter parts
- Helicopter usage spectrum development (monitoring individual helicopter usage)
- Health and Usage Monitoring System (HUMS)
- Rotor blade corrosion coating
- New diagnostic techniques

This category typically addresses maintenance-relates SPS's, in particular maintenance procedures and the performance of maintenance duties.

7. Operational Support

Many aircraft defects can be timely detected or even prevented when a good life monitoring system is in place. Improvements in operational support processes can be beneficial. One example is the US Army ACE-3D (Airframe Condition Evaluation) program, linking a defect database to a 3D visualisation tool.

This category addresses the SPS's related to maintenance procedures.

8. Situational Awareness

Many accidents / incidents are related to (lack of) situational awareness, especially during aerial work or inadvertent flight into degraded visual environment. Technologies can be used to drastically improve safety:

- Digital ground navigation database for predictive ground collision avoidance; this may be coupled to an intelligent flight path guidance system
- Ways of combining information from various visual sources (sensors)
- Novel display techniques to minimise the risk of spatial disorientation

- Advanced symbology injection in night vision systems
- Combining real-time imagery (video) with 3D vision
- Weather uplink and flight safety program, linking and unifying all sorts of weather observation and prediction techniques
- Various types of obstacle detection and terrain avoidance systems (using laser, radar, laser radar or millimetre-wave imaging)

This category generally addresses the SPS's related to pilot situational awareness. But also the ones related to mission risk, in particular to terrain/obstacles and (partially) to pilot judgment and actions, with an emphasis on landing procedures.

9. Vibrations

Vibrations can lead to additional fatigue and therefore to accidents / incidents. Systems that reduce the vibration level will have a positive safety effect:

- Adaptive helicopter seat mount concept for aircrew vibration mitigation applications
- Hydraulic lag dampers that reduce vibration levels
- Composite helicopter blades, also to reduce vibration levels

This category indirectly aims at reducing the pilot's workload and improving his performance. Thus it mainly addresses the SPS's related to cognitive factors and psycho-behavioural factors.

10. Workload

Workload reduction is also an important step to increase safety:

- Advanced alerting system - capabilities for part time display of vehicle parameters
- 3D-audio for enhanced cockpit communication to reduce workload

This category directly aims at reducing the pilot's workload and improving his performance. Therefore it mainly addresses the SPS's related to cognitive and psycho-behavioural factors.

11. Other

This category comprises miscellaneous other technologies that do not fit in any other category. Some examples are:

- New fire detection system for engine and main gear box compartment using UV-IR optical flame detector
- Autorotation training display on a flight training device, showing optimized autorotation trajectory for the actual flight condition

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