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HELICOPTER SAFETY: A CONTRADICTION IN TERMS? – AN OVERVIEW OF THE STATUS AT THE BEGINNING OF THE 21ST CENTURY

B. van der Meer
Delft University of Technology
meneer.b.v.d.meer@gmail.com

D. Yilmaz
Delft University of Technology
d.yilmaz@tudelft.nl

J.A.A.M Stoop
Delft University of Technology
j.a.a.m.stoop@tudelft.nl

M.D. Pavel
Delft University of Technology
m.d.pavel@tudelft.nl

ABSTRACT

Helicopters' unique characteristics allow them to perform a large variety of missions under difficult conditions. As a result, their capabilities pose a unique challenge to the safety aspect. The goal of this paper is to present an overview of the status of helicopter safety at the beginning of the 21th century. The paper will define some common features characteristic to helicopter accidents which may lead to corrective actions in the future.

Two paths are followed for helicopter accident investigations: firstly by reviewing the published statistics on helicopter accidents, and secondly by reviewing publicly available accidents reports. Statistics show that only in 17,7% of the case field investigations are initiated after a helicopter accident.

There are technological arrears especially in the helicopter systems, cockpit and in flight training. The companies or private users that exploit helicopters usually select which safety system they can install in the helicopter. This 'voluntarily' process does not always ensure a proper safety level of the configuration currently flown and needs to be improved.

To improve the recent helicopter safety status, several remedies, which are frequently reported in various sources too, are summarized and listed: reconsidering top-down safety system structure, which has been used in fixed wing systems, implementing state-of-the-art technologic developments into helicopter cockpit/system with a more 'mandatory and flight scenario dependent' aspect, installing flight recording devices (both data and cockpit visual), extended simulator training sessions for emergency scenarios, and several more that were mentioned in the conclusion.

ABBREVIATIONS

AAIB	Aircraft Accident Investigation Branch
AI	Accident Investigation
ADM	Aeronautical Decision Making
AUS	Australia
AW	Agusta-Westland
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
CFIT	Controlled Flight Into Terrain
CIR	Cockpit Information Recorder
CS	Certification Specifications
CS-27	'Small'helicopters. MTOW: <3175kg/7000lbs, or 9 passengers or less
CS-29	'Large' helicopters. MTOW: >3175kg/7000lbs, or 10 passengers or more
CVR	Cockpit Voice Recorder
EASA	European Aviation Safety Agency
EC	EuroCopter
EGPWS	Enhanced Ground Proximity Warning System
EMS	Emergency Medical Services
FAR	Federal Aviation Regulations
FDR	Flight Data Recorder
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HOMP	Helicopter Operations Monitoring Program
HUMS	Health and Usage Monitoring System
ICA	Instructions for Continued Airworthiness
IHST	International Helicopter Safety Team
IMC	Instrument Meteorological Conditions
JHSAT	Joint Helicopter Safety Analysis Team
JHSIT	Joint Helicopter Safety Implementation Team
LOFT	Line Operated Flight Training
MEL	Minimum Equipment List
MMEL	Master Minimum Equipment List
MTOW	Maximum Take-Off Weight
NTSB	National Transportation Safety Board
OC	Operational Control
OPS	OPerationS
PIO	Pilot Induced Oscillation
QA	Quality Assurance
RPM	Rotations Per Minute
SMS	Safety Management System
SOP	Standard Operating Procedure
SPS	Standard Problem Statement
TCAS	Traffic-alert and Collision Avoidance System
UK	United Kingdom
USA	United States of America

1 INTRODUCTION

Helicopters are inherently unstable vehicles with rotary mechanisms within a vibratory environment with complicated system components. Moreover, their unique characteristics allow them to operate a variety of missions under difficult flight conditions. As a result, the capabilities of helicopters pose a unique challenge to the safety aspect.

When compared to fixed wing aviation[1], the helicopter aviation maintains a high accident rate. Statistics show that the accident rate is slowly stabilizing after a long time of steady reduction (Figure 1). The stabilization was predicted at a rate of 6 accidents per 1000 registered aircraft[3]. Thus, a call went out to the helicopter community, to assist in reducing the total amount of helicopter accidents by 80% by 2016[2]. The call was answered, and the International Helicopter Safety Team (IHST) was formed[2].

The goal of this paper is to present an overview of the status of helicopter safety at the beginning of this new decennium. The paper defines some common feature characteristic to helicopter accidents and safety. Two paths are followed for examining helicopter accident investigations: by reviewing the published statistics on helicopter accidents, and by reviewing publically available accident reports.

2 STATISTICS

2.1 'U.S. Civil Rotorcraft Accidents'

The 'U.S. Civil Rotorcraft Accidents, 1963 through 1997'[3] report gives an overview of the early days of helicopter safety. The report shows the progress of the helicopter fleet over the 34 year time span. In that time, the helicopter fleet increased from 2.196 in 1969 to 12.911 aircraft in 1997, while the amount of accidents per year decreased from 260 in 1969 to 175 in 1997[3].

During the 34 years covered in the report, the accident rate reduced almost a factor 10: from 118 accidents to 13,6 accidents per 1000 registered rotorcraft[3]. Figure 1 gives an overview of the change in accident rate. The report mentions the lessening of the decline near 1997. It suggest that the amount of accidents is reaching a steady number of 6 accidents per 1000 registered aircraft by 2010-2015[3]. When combining this with an expected growth of the helicopter fleet over the same time span, the report concludes that the number of perceived accidents might be rising.

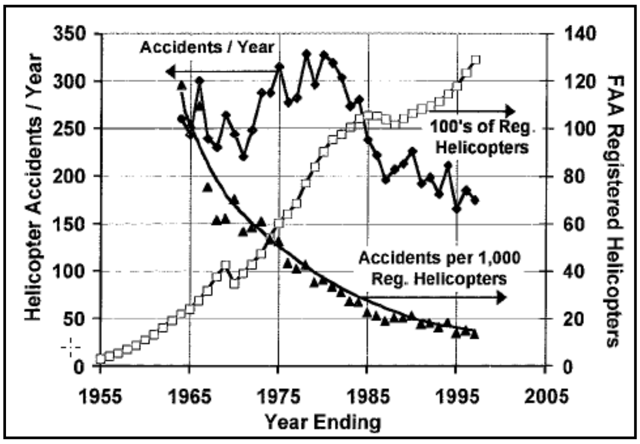

Figure 1: Total number of accidents, number of registered helicopter and accident rate per 1000 registered helicopters per year; from 1963 to 1997[6].

2.2 International Helicopter Safety Team (IHST)

The IHST was formed after the first International Helicopter Safety Symposium in 2005, with the goal of reducing the total helicopter accident count by 80% by 2016[2]. It comprises 2 parts: the first group is the Joint Helicopter Safety Analysis Team (JHSAT), and the second group is the Joint Helicopter Safety Implementation Team (JHSIT). The first group is responsible for investigating accidents, determine causes and form recommendations. The second team is tasked with the implementation of the recommendations offered by the JHSAT[2]. The JHSAT does not take the economic impact of the implementations into account; this is one of the tasks of the JHSIT.

The IHST studied the accidents in the year 2000, which is the basis for their statistical overview. An overview of the worldwide amount of accidents over a 14 year time span is presented in Figure 2.

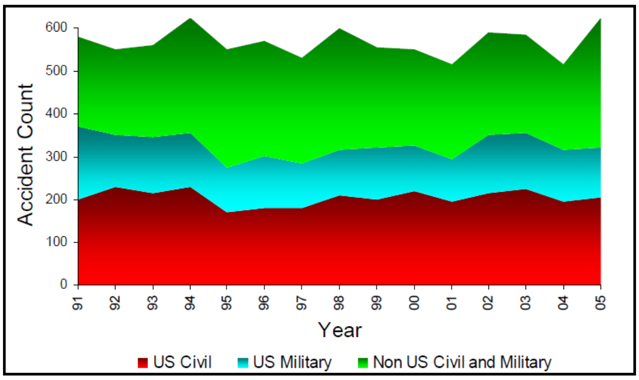

Figure 2: Worldwide helicopter accidents per year (accumulative); 1991 - 2005[2] (source: Bell Helicopter).

According to the statistics in Figure 2, the total amount of accidents was mostly steady between 1991 and 2005, leading up to the forming of the IHST.

Subdividing the number of accidents by flight phase shows the most dangerous phases of the flights, see Figure 3.

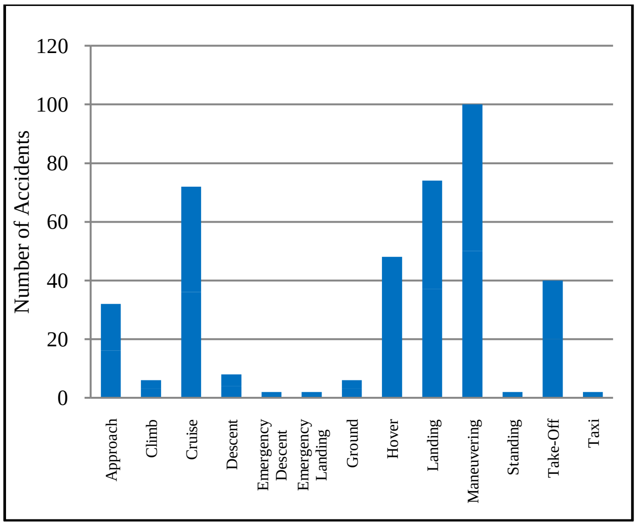

Figure 3: Number of helicopter accidents subdivided by flight phase[2].

Different mission types tend to have accidents at different flight phases. 'Aerial application', 'Firefighting' and 'Law Enforcement' tend to have more accidents during the maneuvering part of the flight; 'Air Tour', 'Offshore' and 'Personal/Private' have the most accidents during the cruise phase. More than 50% of the landing accidents occurred during instructional flights[2]. Unsuccessful autorotation landings are also included in the landing phase accidents.

The number of people involved in these flight phases is displayed in Figure 4. This subdivision is not equal to the number of accidents. From Figure 4 it is clear that the two most dangerous flight phases are 'Cruise' and 'Maneuvering', judging from the highest number of fatalities. An explanation for this is the higher speed of the 'Cruise' phase, and the limited time for corrections during the 'maneuvering' phase when a problem occurs. As stated above, the landing phase is more than 50% due to instructional flights.

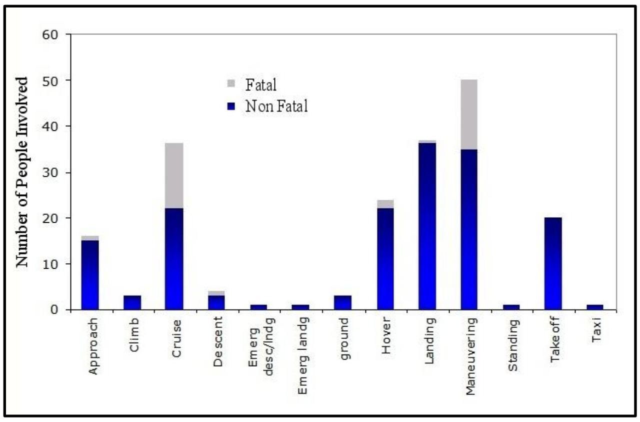

Figure 4: People involved in accidents, subdivided by phase of flight and severity[2].

A subdivision of the number of people involved by specific mission types shows another perspective (Figure 5). It can be observed that 'Training' and 'Personal/Private' involve the most people, followed by: 'Air Tour', 'Commercial Operations', and 'EMS'. However, even though some mission types have a higher number of people involved, there is not a single mission type that has an exceptionally high fatality rate.

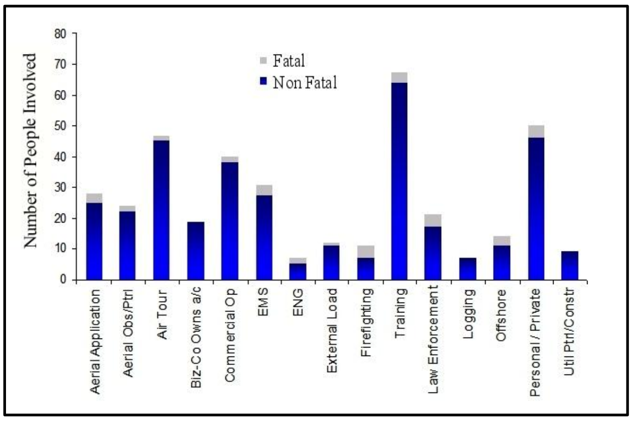

Figure 5: People involved in accidents, subdivided by primary mission and severity[2].

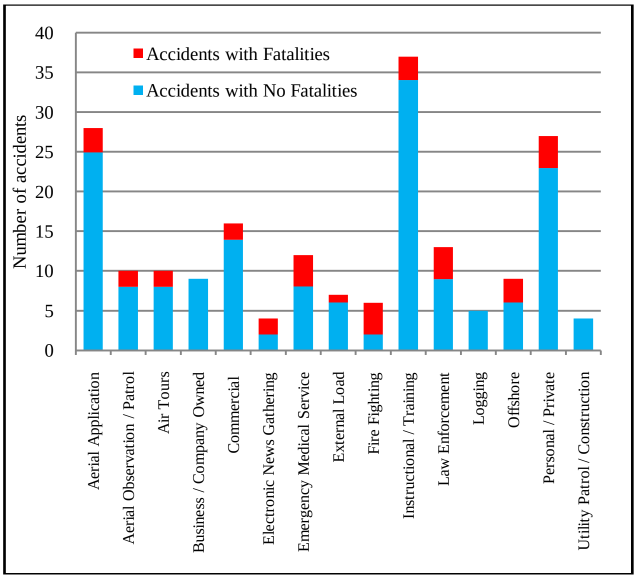

Figure 6: Number of helicopter accidents, subdivided by primary mission and severity[2].

The number of people involved is different from the actual number of accidents. Figure 6 shows the highest number of accidents in 'Training', 'Personal' and 'Aerial Application'. Comparing Figure 6 with Figure 5, 'Air Tour' is no longer among the most numerous.

One explanation for the high amount of accidents during the training and private flights can be the low experience of the pilot. Such helicopters are still completely manually flown, meaning that the experience of the pilot is vital. When the experience is displayed against the number of accidents (absolute), the pilots with less than 1000 flight hours have the most accidents (Figure 7).

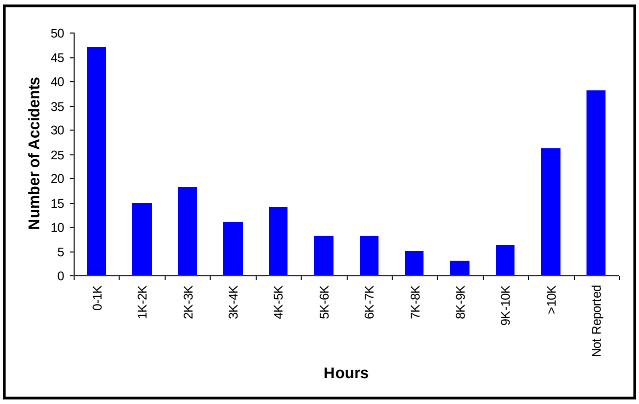

Figure 7: Distribution of Pilots' total reported helicopter flight hours[2].

When the number of accidents (Figure 6) and the number of people involved (Figure 5) are coupled with the amount of experience and the mission type, an interesting picture develops. The most accident prone helicopter activity remains 'Training/Instructional', with the highest amount of inexperienced pilots (Figure 8).

This does not appear to be the case for 'Air Tour'. The average experience for the other most accident prone mission types is in line with the general average. A clear explanation cannot be offered, as the cause can be in the entire helicopter operation: the received training, the helicopter equipment available, the mission type or environment, and/or the number of people on board of the helicopter during a single accident.

A similar argument can be made for 'Aerial Application' which showed a high amount of accidents (Figure 6), while not having a high amount of people involved (Figure 5). The experience of 'Aerial Application' pilots (Figure 8) is among the highest averages.

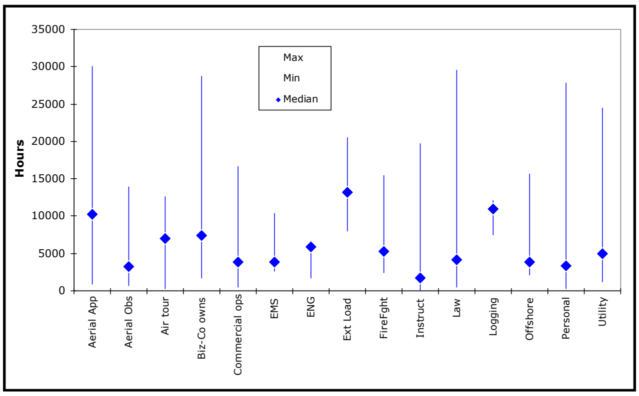

Figure 8: Pilot experience subdivided by mission type (Maximum, Minimum and Median total hours)[2].

The accident causes discovered in the more detailed examination of the accident are summed up in standardized definitions of causes and influential events, called 'Standard Problem Statements' (SPS). During an accident, several happenings can be part of the end result, of which each specific happening has an SPS. The distribution of the SPS identified is given in Figure 9. The most frequently used SPS is ‘Pilot Judgement and Actions’, followed by ‘Data Issues’.

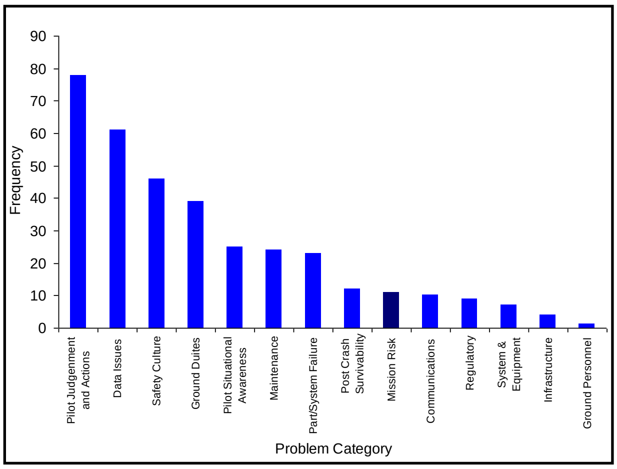

Figure 9: Percent of accidents in which problem categories were identified at least once[2].

The SPS ‘Pilot Judgement and Actions’ encompasses several subcomponents[2]:

- Procedure implementation
- Human factors – Pilot decisions
- Landing procedure
- Flight profile
- Human factors – Pilot / Aircraft interface
- Crew resource management

The SPS ‘Data issues’ encompasses two specific subcomponents[2]:

- Inadequate information available to the investigators
- Inadequate information in the investigation report

The IHST has subgroups over all continents. Europe, the USA and Canada together operate 69,8% of the worldwide helicopter fleet[2]. The subdivisions of SPS of these three regions show similarities, as is indicated in Figure 10. This means that helicopters face the same type of problems in the compared regions; and likely in the entire world.

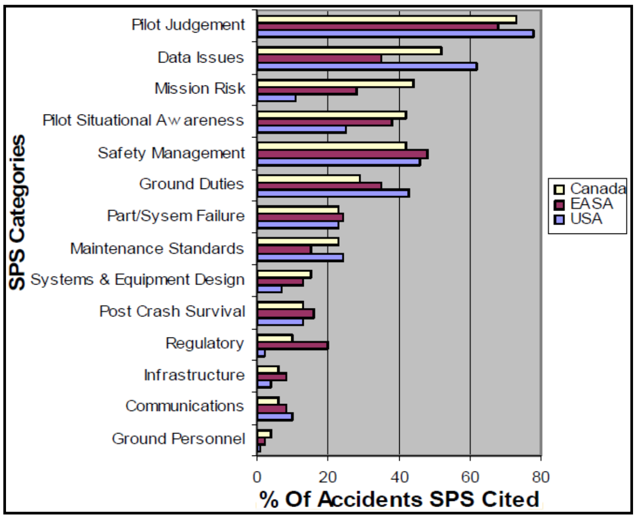

Figure 10: Comparison of the SPS’s of Europe, the USA and Canada[4].

2.3 Detailed accident investigations

Focusing at management, pilot skill and pilot training are significant areas for improving safety. One of the most important avenues for improving the safety of helicopters is finding the cause of an accident. Whenever an accident occurs, there should be an investigation to determine the cause. This process is fundamental, and is used successfully to this day[5].

Statistics were presented focused at detailed accident investigation after a crash. The data was representative of the USA. It showed that “*the NTSB did not go to the accident site on 82.3% of the 1,862 U.S. registered helicopter accidents that occurred during the 10-year period of 1995 through 2004”*[5] (Table 1). In total 26,5% of all cases that had a fatal ending were not field investigated by the NTSB. Due to the limited manpower of the NTSB, their efforts are focused on those cases believed to have the largest safety payback[5].

Accidents by injury severity	**Total helicopter accidents**	**NTSB field launched AI**	**Percentage of NTSB field launched AI**	**Percent *not* covered by NTSB field launched AI**
Fatal accidents	313	230	73,5%	26,5%
Serious injury accidents	229	36	15,7%	84,3%
Minor injury accidents	375	24	6,4%	93,6%
No injury accidents	945	39	4,1%	95,9%
Total accidents	1862	329	17,6%	82,3%

Table 1: NTSB field launched investigation statistics (AI: Accident Investigation)[5].

For CS-27 helicopters it is not required to carry a data retention device, or ‘Flight Data Recorder’ (FDR). Instead, when an accident occurs, the pilot’s statement is the primary source of information if no detailed investigation is launched. For an accident investigation it is important to know the facts, unshaped by human perception, memory and precision limitations; most of which are unintentional[5].

2.4 Safety ‘packages’

The oil company Shell uses helicopters to ferry workers to and from the oil platforms in the sea. In a Shell safety study[7] the payoff in safety vs. the investment needed was researched. To implement the advertised safety measures, ‘packages’ were introduced. These packages allow for the integration of systems such as ‘Health and Usage Monitoring System’ (HUMS), extra training such as ‘Line Operated Flight Training’ (LOFT), or management aiding systems such as the ‘Helicopter Operations Monitoring Program’ (HOMP). Four packages where suggested on top of the standard case (the ‘baseline’). The operating costs of a package equipped helicopter was calculated and compared with the calculated safety increase. To determine the increase in safety, the effect of each measure was estimated. When multiple measures would be introduced in one package, the other added measures would have only limited extra effect (due to an 'overlapping' safety increase). The 'baseline' meant no change to the helicopter. The 4 packages introduced were successively encompassing more solutions to safety problems. The effect of the packages is displayed in Figure 11:

- Package A: Baseline, no changes to helicopter
- Package B: Mix of performance class 2 and 3, partially implemented HUMS, Training including LOFT, SMS/OC/QA + helideck management
- Package C: HUMS, performance class 2, SMS/OC/QA + CAP437 helideck management, partially implemented design requirements, HOMP, simulator training, TCAS/EGPWS
- Package D: All mitigation measures; representative of future twin turbine helicopters such as the AW139, S92, EC225 and EC155B1
- Package E: Extension of Package D. Assuming the following in 10 to 15 years since writing of source [7]: FAR 29 closed the gap with FAR 25, operations have more stringent requirements, HUMS extended to rotor system and machine learning, operations conducted to performance class 1.

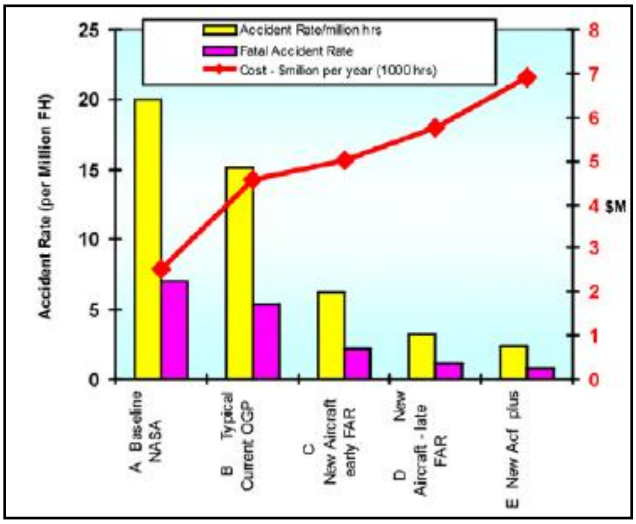

Figure 11: The solution packages assessment plot, showing the estimated effect of safety increasing solution packages, compared with the operating cost and the (fatal) accident rate[7].

Figure 11 shows the estimated effect of the 'packages', vs. the cost and the fatal accident rate. The baseline remains at 20 accidents per 1 million flight hours, and around 7 fatalities. The installment of safety packages will increase the costs per year. 'Package C' appears to be the best defendable cost vs. benefits. Installment of 'Package C' decreases the amount of accidents to around 6 per 1 million flight hours, while doubling the costs. Packages D and E have only limited extra safety benefit.

3 ACCIDENT REPORTS

3.1 Movements vs. accidents per year

The statistics available were compared to publically available accident statistics coming from the UK Civil Aviation Authority (CAA). These statistics show the number of helicopter taking off and landing at airports and oil rigs (called: 'movements') and the number of accidents per year[8, 9, 13]. Comparing these with the publically available data from Australia[10, 11], a clear picture emerges (Figure 12).

Comparing the number of movements of Australia and the UK, both are in the same order of magnitude. A clear trend upwards for the UK can be seen. Australian helicopter movements have a slight decline.

Comparing the (absolute) number of accidents of the same two countries, both are decreasing. This appears contradictory to the statistics of the IHST[2]. Figure 2 showed the number of accidents worldwide up to 2005, showing the number of accidents per year to be stable.

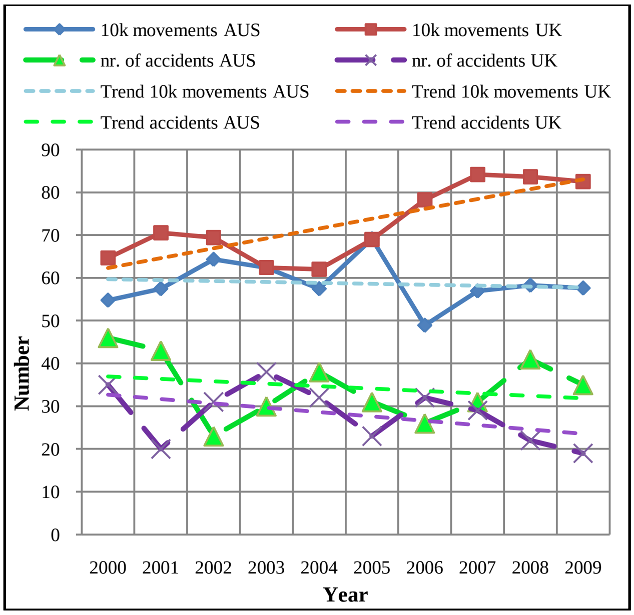

Figure 12: Number of 10k movements and accidents per year; comparing the United Kingdom (UK) and Australia (AUS). (UK helicopter movement statistics include only scheduled operations to/from full reporting airports and services to/from oil rigs)[8-11, 13].

The 'U.S. Civil Rotorcraft Accidents' report[3] predicted the number of helicopter accidents in the future. It was stated that an accident rate of about 6 accidents per 1000 registered helicopters could be the norm around 2015, based on their statistics and predictions, assuming no major safety improvement. If the helicopter fleet was to double in the same time, the number of perceived accidents would increase[3]. According to the UK Aircraft Registration Statistics[12], there is a slow but steady increase in the amount of helicopters used, however the absolute number of helicopter accidents is going down (Figure 12). In Australia the number of helicopters is also slowly on the rise[11], despite the number of movement remaining almost steady.

The IHST started its work around 2005. However, the statistics do not show a rapid decrease in the amount of accidents for both the UK and Australian helicopter fleet. The trend of a decreasing amount of helicopter accidents was set in before the IHST started. At present there is no causal relationship between the work of the IHST and the (absolute) number of helicopter accidents.

3.2 Accident report statistics

Accident reports give an interesting view on the statistics. The publically available accident reports from the UK provided the data, using 2 online databases: the Aircraft Accidents Investigation Branch (AAIB)[9] and the

Griffin Helicopters database[8]. All factors involved in a helicopter accident become part of the statistics. In total 139 accident reports where investigated.

Description	Accidents [%] (139 total)
General	
CS27	89,2
Conventional tail	89,2
<1000 flying hours	54,7
<250 flying hours on type	43,2
Co-pilot on board	34,5
Flown during the day	96,4
Accident on land	87,1
Flight phase	
Taxi	10,8
Take off	16,5
Cruise	43,9
Landing	30,2
Hover	23,7
Parked	7,2
Cause	
Loss of control	41,0
Mechanical problems	32,4
Mid air collision	0,7
Ground operations	15,1
Weather/environment	18,0
Mist/poor visibility	11,5
Fuel related	5,0
Animal strike	0,7
Navigation/planning	2,2
Wire strike	5,0
CFIT	10,8
Other	23,7
Consequences	
1 or more wounded	28,8
1 or more fatalities	8,6
Helicopter destroyed	30,2
(Emergency) landing	
With damage	71,9
Autorotation	20,9
Rollover	28,8
Rotor tail strike	9,4
Rotor ground strike	7,9
Tail ground strike	14,4
Tail boom separation	9,4
Crash	36,0
Accident reports	
(Partially) detailed	33,1

Table 2: Results from examining 139 accident reports.

- From the 139 accident reports investigated, only 15 were the larger CS29 helicopters (10,8%). Of these 15 accident reports, 12 were more detailed than only a short scenario description. The remaining 3 cases were minor incidents which did not do much damage and therefore did not require a large investigation. From the 124 CS27 helicopter accident cases, only 34 were more detailed. In total, 46 accident reports of a total of 139 accidents were more detailed than only a short scenario description.
- From the 16 cases (11,5%) that occurred (in part) due to mist or poor visibility, 11 cases ended in a helicopter being damaged beyond repair. In 7 cases there were 1 or more wounded during the accidents, and 5 cases ended in fatalities; only 1 case had both wounded and fatalities. In total there were 12 cases with fatalities, of which 5 were due to mist or poor visibilities.
- The most accident prone flight phase is the 'Cruise' with 43,9%. All the accidents which had fatalities happened during the 'Cruise' phase.
- In total 100 cases involved a landing which resulted in damage. These include crashes where no landing was initiated. An emergency landing is classified as a deliberate attempt to land the helicopter. Of the 139 cases, only 39 cases (28,1%) involved an emergency landing where the helicopter was undamaged. These include precautionary landings.
- Emergency landings can involve an autorotation landing. In total there were 29 cases (20,9%) where an autorotation landing was attempted. Only 5 cases resulted in an undamaged landing. The same 5 cases were part of the 39 cases of undamaged emergency landings stated above. None of the 29 autorotation landings resulted in a fatality, 11 attempts resulted in wounded and 8 cases resulted in the loss of the helicopter.
- The most frequent cause was 'loss of control' (41,0%, 57 cases), followed by 'mechanical problems' (32,4%, 45 cases). 'Loss of control' was responsible for 18 out of 40 cases with 1 or more wounded, and 4 cases with fatalities.

3.3 Analysis of the accident reports

'The Path to the Next Helicopter Safety Plateau'[5] showed that only a small percentage of the helicopter accidents where examined in detail on site. From the UK accident reports, the amount of detailed reports is only 33,1%.

There are some notable differences in investigation report detail between CS27 and CS29 helicopters. Two possibilities can be named. The first is the mandatory FDR installed in all CS29 helicopters, which aids in the investigation, allowing more convenient access to detailed information. The second possibility is the result of the selection process used by the investigation services, determining which accident results in the highest safety 'pay-off'.

Comparing the statistics from ref [3] and ref [2] with the helicopter movements and accidents from the UK and Australia (Figure 12), no clear picture emerges. Ref [3] states an perceived rise in helicopter accidents by 2015, with a stable helicopter accident rate of 6 accidents per 1000 registered helicopters; despite of Figure 1 showing a decreasing line. Nonetheless, Figure 2 shows an almost stable worldwide accident rate, and Figure 12 shows a decreasing (absolute) amount of accidents with an increasing amount of helicopter movements. The exact picture of helicopter accident statistics is not clear.

4 HELICOPTER SAFETY ANALYSIS

4.1 Safety establishment

The 'bottom-up' safety establishment is insufficient for guarding the helicopter safety.

The safety establishment in place consists of the investigation services, the regulatory services and the manufacturers. The safety of helicopter aviation is primarily guarded by this safety establishment designed to enforce it. This is more apparent when the safety establishment of the large fixed wing aviation is compared to the safety establishment of rotary wing aviation. The accident rate of large fixed wing aviation is 10 times lower compared to rotary wing aviation[1].

The fixed wing safety establishment is a strict 'top-down' system. Whenever an accident happens, and the investigation turns up a significant safety problem, a solution is to be found. This solution is then implemented on a mandatory base, meaning that every aircraft needs to have this solution present (usually within a time frame). Examples of this are 'Ground Proximity Warning Systems' (GPWS) or 'Traffic-alert and Collision Avoidance System' (TCAS). This top-down safety establishment assures a certain level of safety which results in fixed wing aviation being one of the safest forms of travel.

The helicopter safety establishment is different. Whenever a significant safety problem arises, a solution is to be found. However, the implementation of said solution is not mandatory. Helicopter users, being companies or privateers, can implement complementary safety equipment on a voluntary basis. This means that the helicopter users determine the level of helicopter safety, the equivalent of a 'bottom-up' safety establishment. The standard safety equipment installed in helicopters is stated in a 'Minimum Equipment List' (MEL). The helicopter equivalents of TCAS or GPWS are not mandatory, nor are many other systems that allow for an improvement in safety. Looking in the type specific Master-MEL (MMEL) for a Bell 212 and 412, none of these systems is mentioned in the MMEL[14].

Safety issues that have a (repeating) mechanical nature are corrected. These solutions are sometimes made mandatory. The helicopter fleet faces the same problems as fixed wing aviation: pilot fatigue, human error, Controlled Flight Into Terrain (CFIT), Inadvertent flight in Meteorological Conditions (IMC), mid-air collisions, hitting obstacles, etc. For many of these problems, systems are already available; however these are available on voluntary basis. A large amount of the systems and technology that made fixed wing aviation one of the safest forms of travel have therefore not been embraced by helicopter aviation. Proof for this lack of technology in the cockpit can be found in the selected documents that review helicopter safety. Suggested remedies include the implementation of more advance technology to the pilot[2, 3, 7].

It can be argued that the difference in safety establishment setup ('top-down' vs. 'bottom-up') can be held accountable for the large technological arrears in the helicopter fleet. Even though both systems are not perfect, the difference in accident rate between fixed wing and rotary wing aviation cannot be ignored[1].

4.2 Investigating accidents

There is limited information available to make a correct safety assessment.

A more 'top-down' structure related to safety equipment in helicopters would benefit all concerned. Nevertheless, the NTSB has given statistics about the number of cases that are actually investigated (Table 1)[5]. The publically available accident reports from the AAIB showed a similar amount of accident investigations. It can be argued that a high amount of accidents are not investigated in other countries as well. Therefore, with the presently low amount of thorough investigations by the NTSB and other investigation agencies like the AAIB, it can be argued that not all helicopter problems are properly understood.

4.3 Effects of solutions

Solutions to helicopter safety problems should be evaluated per mission type and made mandatory if beneficiary.

Helicopters are used for a variety of tasks. This means that not all safety recommendations may be beneficiary for every mission type. Therefore any improvement in safety should be verified against the usefulness of that solution in each mission type (training, private, law enforcement, transport, offshore, search and rescue, etc.). To maximize the effect of the solution offered, it should be made mandatory when beneficiary.

In the long list of recommendations published by the IHST this problem was foreseen. The recommendations are subdivided by mission types[2].

The technology used might not be needed during every flight phase. For instance, close-in object detection and ranging equipment (to be developed) to determine the available space the helicopter has during landing at an unprepared site, is not needed during the cruise. The same can be said for radar, which is not needed during the landing. Systems should be able to flexibly be switched on or off depending on the flight phase. The exact method and timing is to be determined. In the example offered, the close-in detection system could replace the radar on the screen.

4.4 Dangerous mission types

Training and other dangerous mission types should receive extra attention and use (new) technology.

During training, most pilots still step in real helicopters. The difficulty in controlling a helicopter is without question, and the emergency maneuvers that need to be trained are inherently more dangerous than normal flight. The high amount of training accidents is therefore not unexpected.

Training has the highest number of accidents (Figure 6), and the most people involved (Figure 5), however it is not the only dangerous mission type. Other dangerous mission types are 'Aerial application', 'Private', 'Air tour', 'Commercial Operations' and 'EMS' (Figure 5 and Figure 6). Each of these mission types is different. Further study should reveal which safety problems are specific for these categories of helicopter use.

4.5 Implementation of solutions

A plan of attack is needed to overcome the technological arrears in helicopters.

Due to the technical arrears, a large amount of solutions may present itself at once. This would require a significant investment from the helicopter companies in both helicopters and personnel. One solution to this problem was suggested by Shell[7], which suggested 'packages'. The study did a cost vs. benefit analysis (Figure 11), that allowed for a defendable tradeoff for safety vs. investment, as an intermediary step to upgrade the current fleet to higher safety standards.

5 FUTURE ACCIDENTS

The implementation of pilot aiding devices will improve the safety of helicopters. Nevertheless, the addition of technologies such as 'fly by wire' and 'flight envelope protection' can lead to new category of helicopter accidents. Although 'fly by wire' and 'flight envelope protection' have proven themselves in fixed wing aviation, if these systems are installed, the pilot is no longer directly in control of the helicopter. Hypothetically accidents can occur that are solely caused by a software error or a faulty sensor influencing the flight computers. This could even result in unpredictable behavior, such as Pilot Induced Oscillations (PIOs)[15]. A further issue arises over the skill of helicopter pilots should augmentation technology suddenly be disabled (in an emergency, by the pilot, or by a failure).

As being highly vibratory, agile and capable of performing a wide range of maneuvers, overall helicopter systems remain a challenge for implementing recent technologies into the cockpit and rotorcraft main/sub frames.

The predictable future accidents should be minimized with proper regulation and certification processes.

6 RECOMMENDATIONS

6.1 Published recommendations

The 'U.S. Civil Rotorcraft Accidents' focused with its recommendations on 4 specific categories[3]:

- Engines and fuel: Increase fuel management, improve fuel quantity measurement, re-examine auto rotation capabilities and improve, train auto rotation
- In flight collision: Fly above 750 feet, mark all manmade obstacles of 500 feet or higher on a GPS system, develop a low altitude spherical proximity sensor
- Loss of control: Automate piston-engine RPM management, install a low-price stability augmentation system, improve handling qualities, give refresher training focused on handling
- Airframe and components: Reevaluate certification criteria of power transmitting components, adopt more conservative fatigue criteria, incorporate helicopter design limit notification system, develop low-priced HUMS, incorporate more fail safe modes

The IHST came with a large amount of recommendations[2], which are subdivided per mission type. To name them in the order of most cited:

- Install cockpit recording devices
- Improve the quality and depth of NTSB investigation and reporting
- Training emphasis for maintaining awareness of cues critical to safe flight
- Autorotation training program
- Follow ICA procedures with confirmation of compliance
- In-flight power/energy management training
- Recommend enforcement action-certificate suspension/revocation
- Mission specific risk management program
- ADM training
- Establish mission specific SOP and flight OPS oversight program

There is difference between the recommendations from the 'U.S. Civil Rotorcraft Accidents' and the IHST. This is mainly because the former focuses more on the helicopter and pilot, and the latter more on a 'safety culture'. A 'safety culture' is instilling a sense of safety in every level of the helicopter user, from pilot to mechanic, from planner to manager, etc.

6.2 Possible solutions

Several suggestions for solutions can be named to resolve the problems at hand. Solutions are offered in the form of recommendations or suggestions in the selected documents.

To find the facts during an accident, a light weight FDR for smaller CS-27 rotorcraft is a must. Especially a camera in the cockpit, showing all the vital controls and instrument panels can be of tremendous aid in investigating an accident (Figure 13). Such a device is called a 'Cockpit Information Recorder' (CIR), and is essentially a 'Cockpit Voice Recorder' (CVR), a FDR and a camera with microphone in one package. According to ref [5] the CIR has the potential to reduce the accident rate by as much as 71,5%, purely by better understanding what goes wrong during an accident.

Figure 13: An example of a cockpit view of a CIR, showing all the important areas[5].

To aid the NTSB and other investigation services around the world, a data retention device (FDR, or CIR) needs to be mandatory. The development of a new form of 'quick investigation', where the CIR data is used to determine the basic facts during an accident, could aid in determining whether the accident has a simple cause or warrants more investigation. Another advantage of the CIR in helicopters is the more accurate data that will help in giving a better understanding of the causes helicopter accidents and required safety solutions.

More focus on the usage of simulators can alleviate the accident rate significantly. The simulator can be used to train emergency maneuvers like autorotation, and can help the trainee gain a better understanding of the helicopter before he/she actually takes to the sky. The simulator can also be used for refresher courses on emergency procedures.

The solutions offered to specific helicopter problems need to be evaluated per mission type for beneficiary use. When there is an understanding of the solutions needed, then 'packages' can be formed, with increasing amount of safety equipment. These packages can then be compared to the expected cost and safety increase, allowing for a defendable safety increase vs. costs. Using the 'packages' in this manner allows for a leap in safety and a new 'baseline'.

Summing up, the following recommendations can be made:

- Turn the 'bottom-up' safety establishment used into a 'top-down' system by removing the voluntary component.
- Introduce a mandatory CIR to minimize the existing information shortage.
- Utilize the method of 'packages' to establish an improved baseline for helicopter safety, as stated above, and introduce a workable transition period for implementation.
- Develop a 'quick assessment' method utilizing CIR to determine more accurately the cause and the need for more detailed investigations (on site).
- Improve the safety during helicopter training by using simulators to acquaint trainees with the helicopter controls and emergency procedures.

7 CONCLUSIONS

This study was intended to provide an insight into helicopter safety, considering the recent statistical accident studies and accident investigation reports.

The 'bottom-up' safety establishment is not able to provide the wanted safety level. This is mainly due to helicopter owners not embracing the solutions offered to increase helicopter safety. When compared to the 'top-down' safety establishment of large fixed wing aviation, the accident rates are a factor 10 lower[1] in the same allotted time.

The investigative services have limited manpower available to investigate accidents[5]. With the low amount of detailed accident investigations in helicopter aviation, there could be a lack of understanding about the causes. This lack of understanding and data allows for questionable statistics. This can be alleviated by mandatory installing a FDR or a CIR on all helicopters.

The study revealed a large bias for accident investigation towards larger CS29 helicopters, which may be due to the mandatory FDR installed[5].

The investigative services need to study possibilities for a quicker investigation method using FDR or CIR data, to determine more accurately the cause, and the requirement for a more detailed investigation on site. This 'quick assessment' will in addition aid in the better understanding of helicopter accidents.

The trend of helicopter accidents is hard to determine due to conflicting data, accident rates and conclusions.

The inherent dangerous flying characteristics coupled with the more dangerous missions will preclude the helicopter safety from reaching the same level of safety as the fixed wing aviation.

Embracing solutions involving new technology could result in similar type of accidents with helicopters as with fixed wing aviation fitted with pilot augmentation technology.

With the more frequent use of helicopters, extra focus needs to go to the safety of helicopters by all concerned. In the current 'bottom-up' system the safety establishment is not solely responsible for an increase in safety. The helicopter owners have the freedom to choose which solution gets installed, making them the single most important factor, unless the voluntary factor is withdrawn.

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1. CAA. *CAP 780: Aviation Safety Review 2008*. [PDF] 2008; 182]. Available from: http://www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=3325.
2. *US Joint Helicopter Safety Analysis Team: Year 2000 Report*. 2007, International Helicopter Safety Team.
3. Harris, F.D., E.F. Kasper, and L.E. Iseler, *U.S. civil rotorcraft accidents, 1963 through 1997*. NASA technical memorandum 2000-209597. 2000, Washington: NASA. 309 blz.
4. Seguin, S., *JHSAT Canada*, in *International Helicopter Safety Symposium*. 2009: Montreal.
5. Fox, R.G. *The Path to the Next Helicopter Safety Plateau*. in *AHS International 60th Annual Forum*. 2005. Baltimore, Maryland, USA: AHS International 60th Annual Forum: New Frontiers in Vertical Flight Proceedings. 2005.
6. Carlson, R.M., *Helicopter performance - Transportation's latest chromosome: The 21st Annual Alexander A. Nikolsky Lecture*. Journal of the American Helicopter Society, 2002. **47**(1): p. 3-17.
7. Clark, E., et al. *Helicopter safety in the oil and gas business*. in *32nd European Rotorcraft Forum*. 2006. Maastricht, The Netherlands.
8. *Griffin Helicopters* [cited 2010/2011 January - July]; Available from: http://www.griffin-helicopters.co.uk/.
9. *Air Accidents Investigation Branch, Accident report publications*. 2010 [cited 2010/2011 January - July]; Available from: http://www.aaib.gov.uk/publications/index.cfm.
10. ATSB, A.G.-. *Australian Aviation Occurrence statistics: 1 January 1999 to 31 December 2009*. [PDF] 2011 [cited 2011 May]; Available from: http://www.atsb.gov.au/publications/2009/ar2009016%283%29.aspx.

11. *Australian General Aviation Activity reports*. [PDF] 2011 [cited 2011 May]; Available from: http://www.btre.gov.au/info.aspx?ResourceId=226&NodeId=102.
12. CAA. *UK Register of Civil Aircraft Statistics - Aircraft Registration Statistics*. [PDF] 2011 2011 [cited 2011 May]; Available from: http://www.caa.co.uk/default.aspx?catid=56&pagetype=90&pageid=107.
13. CAA. *UK Airport Statistics*. [PDF or CSV] 2011 [cited 2011 May]; Statistical documents on linked subpages]. Available from: http://www.caa.co.uk/default.aspx?catid=80&pagetype=88&pageid=3&sglid=3.
14. Nielson, E., *Master Minimum Equipment List, 212, 412 series helicopter*, in *ECCN 9E991*, J.A. Authorities, Editor. 2008, European Aviation Safety Agency (EASA): Koln, Germany.
15. McRuer, D.T., *Aviation Safety and Pilot Control: Understand and Preventing Unfavorable Pilot-Vehicle Interactions*, ed. N.R. Council. 1997, Washington D.C.: National Academy Press.