THE HISTORY OF HELICOPTER SAFETY

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ABSTRACT

Helicopters had their beginning in the early 1940s. This fledgling aviation segment had its growing pains and helicopter accidents occurred fairly often. Engineers and pilots learned from these early problems and the safety of helicopters started to improve. Both the military and civil fleets developed somewhat along similar lines, but cross-pollination related to safety features and analyses have improved both fleets. Significant improvements in crash survival in some military fleets occurred and flowed over to the civil fleets. Hazard identification techniques during initial helicopter design has improved the initial helicopter airworthiness. The "lessons learned" from previous helicopter experiences need not be repeated in new designs. Risk management processes are developing to ensure that initial aircraft airworthiness is maintained or improved throughout the operational life of a fleet. Prevention of accidents from material failure causes is a fairly mature process, whereas the ability to identify and correct specific human error in helicopters is still in its infancy. Measurement of occupant risk is a key issue to be able to determine if safety is actually improving or degrading. This paper will cover this journey from the 1940s through 2004. The past, the present, the pitfalls, the roadblocks, and the potential of future safety are discussed.

SAFETY THREAD

Bell Helicopter has produced 12,035 civil helicopters and 17,881 military models through mid-year 2005, for a total of 29,916 helicopters. As would be expected with such a large fleet of fielded helicopters, there has been a variety of "lessons learned" and safety related activities over the years. Helicopter safety has improved over the years. We are poised to go to the next safety plateau. This paper describes the major safety areas and activities in the last 59 years, since the first Bell helicopter crash in 1946, and directions toward the future.

EARLY DAYS SAFETY

Experimental helicopters flew in the early 1900s in various European countries, with many concepts being tried and tested. No real helicopter production run occurred until Sikorsky started building R-4 helicopters for the US Army Air Corp with first delivery in 1944. The first civil helicopter in the world to be certified was a Bell 47B, serial number 1, registry number NC-1H, on May 8, 1946. In that first year of 1946, there were seven civil Model 47 and one Army YR13 accidents. Three of the Model 47s involved in accidents were experimental helicopters, one of which was a fatal accident on August 10, 1946. The next year, 1947, there were 33 accidents. Although this sounds rather bad by today's standards, the helicopter was a fledging industry then, and accidents were not uncommon for any civil or military model helicopter built by any manufacturer for their first years. Helicopter pilot training, like designing and building helicopters, was in its infancy. The known flight experience of the helicopter pilot ("known pilot helicopter times") in three of the eight accidents in 1946, were 7 hours 15 minutes, 9 hours 30 minutes, and 61 hours 50 minutes. The high time pilot was in the fatal accident (experimental NX92843, serial number 7), which also had the highest airframe time of the accident group, at 275 hours. The first couple of years were difficult safety years. But things improved on many fronts: more and better pilot training, better maintenance/training, and aircraft improvements to both the engine and the rest of the aircraft. Thus the accident rate settled down to a constant level (Fig. 1). The fluctuations since 1976 in the annual accident rates of Fig. 1 were related to changes in the FAA flight hours estimate process. Basically, the Model 47 accident rate has been holding fairly constant since the early 1950s, even though that helicopter has been out of production for over 30 years.

EARLY ACCIDENT CAUSES

The accident causes for the worldwide fleet of 47 series helicopters for the period of 1947 through 1996 is shown in Fig. 2. This includes all civil models and military versions. Although most accidents have several cause factors, in this chart the initiating cause factor is used. It is interesting that engine failures were less frequent than the Non-Engine Airworthiness failures (e.g., failures occurring in the rest of the aircraft) and even maintenance-related failures. Perhaps that was due to the engine being well developed, with experience in airplane use, whereas the aircraft itself was a new concept

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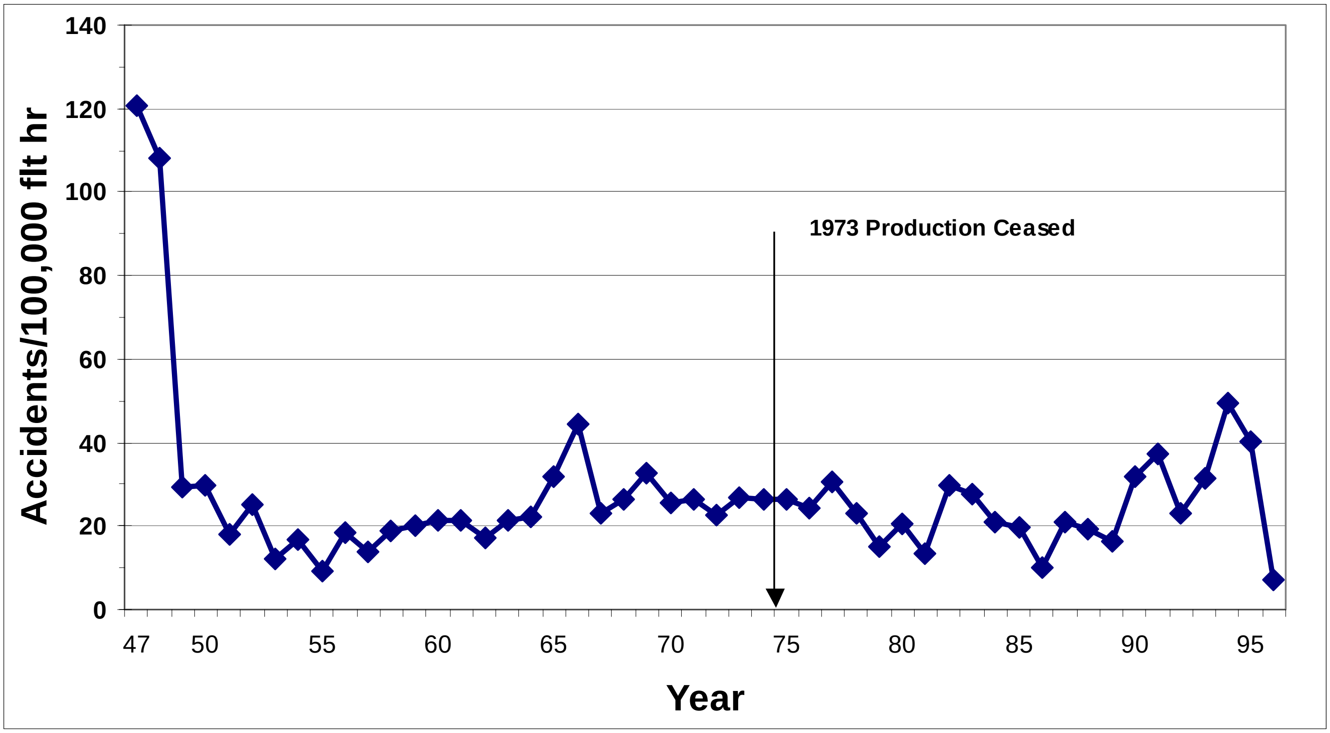


Fig. 1. U.S. Registered Model 47 Accident Rates

with a lot of dynamic components that also required considerable new types of maintenance. The majority of accidents were due to human or unknown causes. There were a lot of "lessons learned" that occurred in those early years.

Although the helicopter was more expensive, was slower, and had much lower payload than an airplane, the helicopter could do missions that were impossible for an airplane. The ability to hover was truly unique. These different missions put helicopters into more hazardous situations. To expand the civil helicopter market, the helicopter manufacturers had to develop new missions and new helicopter applications, and demonstrate their aircraft to operators. For example, crop dusting equipment was developed and demonstrated. Eleven Model 47s went to Argentina to spray the locust swarms in 1947 and 1948.

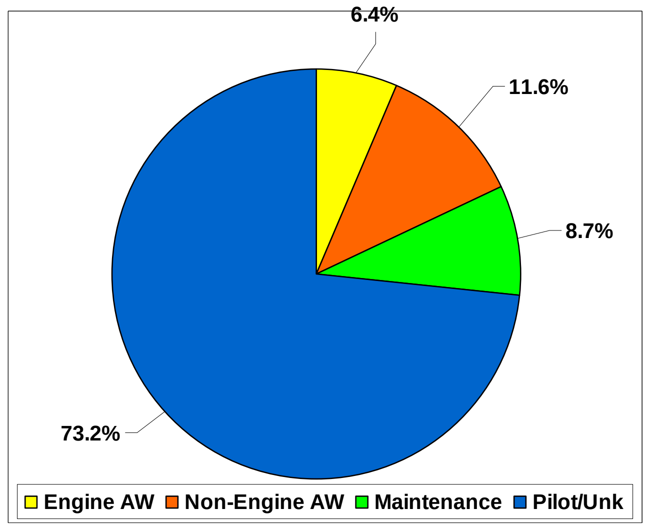


Fig. 2. Model 47 worldwide accident causes.

MATURING INDUSTRY START SAFETY IMPROVEMENTS

Helicopters started to make significant improvements in the 1960s. Turbine (turboshaft) engines were introduced, which provided more power per pound of weight than reciprocating engines, so payloads improved. Both the reciprocating engines and turbine engines continued to improve and initiated accidents less frequently. The most recent improvement has been the use of electronic controls. Engines continue to improve, becoming less of a safety issue.

The aircraft itself has improved. Early helicopters like the R-4 and 47 used tubular frame construction. Helicopter fuselage constructions progressed to aluminum bulkheads and skins. Some, like the 206, went to monocoque construction, using honeycomb sandwich construction. Fiberglass and other composite materials, including carbon fibers, continue to replace metallic materials. The construction materials of main rotor blades have progressed from wood to metal, and most recently to composite materials (e.g., fiberglass or similar non-metallic materials), primarily due to a slower crack growth rate than occurs in metals. Composite materials are increasingly used in rotor hubs for several reasons, but primarily due to weight savings.

Part failures that cause accidents have become relatively rare events, but each manufacturer corrects these unique failures as soon as possible and continues to make further improvements. Bell's worldwide history of accident causes for our fleet of civil turbine models, including military surplus turbine aircraft flying on civil registries, for 1994 through 2003, is shown in Fig. 3. Engine airworthiness failures and non-engine airworthiness failures (e.g., rest of the aircraft) each accounted for 7% of the known initiations of all accidents. Although most accidents have several accident cause factors, the initiating cause is used to allow percentages to be determined. Note that 12% of the accidents were due to totally unknown or undetermined causes, which is approaching the combined percentage (14%) for all types of airworthiness failures. One cannot fix or improve anything that is not understood. Those accident causes will continue to occur in the future. This unknown cause area is a major roadblock to making further significant safety improvements.

Fatigue analyses and fatigue part testing during certification have certainly reduced the number of part failures in the fielded aircraft. When it was determined that operators were dramatically changing the mission flight profile (change the load spectrum in different flight phases) for which the part was designed/certified, the manufacturer had to refine analyses and reduce retirement lives as warranted. One approach used was the Retirement Index Number (RIN) system that Bell developed to account for different loading frequencies

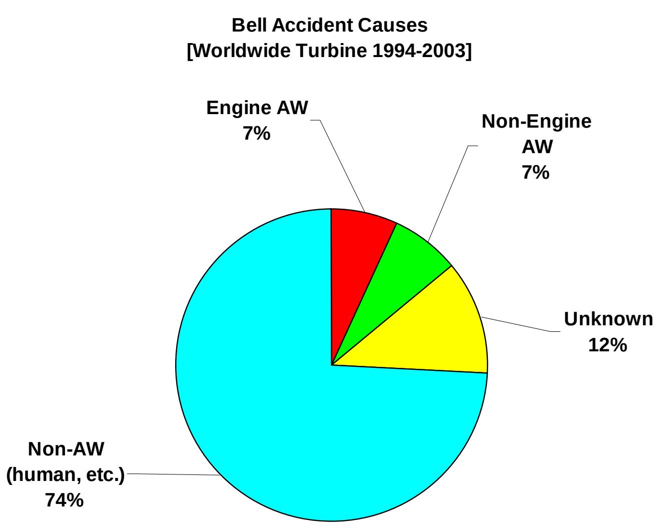


Fig. 3. Accident causes of Bell Helicopters worldwide.

to determine retirement life for different load spectrums. Fatigue analyses are based on a design mission profile (e.g., specific number of hours spent in different flight phase loadings). Since the loads on some components vary with the different flight phases, their retirement lives vary accordingly. When helicopters are operated beyond the certified design criteria, the laws of physics continue to apply and parts fail prematurely. Bell uses a Retirement Index Number (RIN) to allow tracking for early retirement of the part before failure based on the flight profiles and usage. This had a significant effect to reduce the retirement life (e.g., replacement time before fatigue failure can occur) of some dynamic parts where the helicopter was operated in severe operations such as logging. Another recent approach is to design certain critical items to be more damage tolerant to a flaw in the material.

For the existing aircraft fleet, a major safety improvement starting to enter the helicopter fleet is the Health and Usage Monitoring System (HUMS). These HUMS range from a simple event monitoring systems to elaborate systems with accelerometers that uses vibration signatures to identify impending component failure (e.g., cracked gear tooth, crack rotor blade, internal engine problem, or bearing going bad). HUMS are appearing on some military and civil helicopters. Some oil companies have seen the benefits of HUMS and have started requiring HUMS on helicopters they use. As operators see the cost/benefit of HUMS, they will be used on more of the helicopter fleet. A fully refined HUMS is definitely a needed safety feature of the future.

THREE SAFETY PROTECTION LEVELS

There are three levels of protection in helicopter safety. First, initial aircraft certification's primary aim is to ensure that a basic design will not fail within certain constraints. Pilot certifications likewise are aimed to similar outcome of not having a pilot-initiated accident. The second level of safety is the backup if the first level of protection fails for any reason. In some instances, redundancy of aircraft systems can be used. HUMS can be a major second level protection contributor where redundancy is not possible. Autorotational capability is also a second level protection. The third safety protection level is to protect the occupant from a fatal injury, regardless of what initiated the sequence. This last protection level includes crash survival features discussed later.

AIRWORTHINESS RESPONSIBILITY

In the USA, engines are certificated under 14CFR33 regulation with the Federal Aviation Administration (FAA). The rest of the helicopter is certificated under Normal Category Rotorcraft 14CFR27 (maximum gross weight under 6,000 lb, recently moved to 7,000 lb) or under Transport Category Rotorcraft 14CFR29 for maximum gross weights above 14CFR27. Military helicopters are qualified to U.S. military requirements by the military services; thus those helicopters were not certified to civil Part 33/27/29 requirements. These military aircraft can be released out of military services into the civil use and are allowed to fly in civil world with some restrictions. These aircraft are typically called military surplus helicopters. Over 1,000 military surplus helicopters are presently on the U.S. registry, and their numbers grow every year. RIN counting to change retirement lives was a Bell response primarily due to military surplus helicopters operating beyond their design, resulting in accidents.

The company that certifies a particular product to a particular FAA Part (e.g., 33, 27, or 29) receives a Type Certificate (TC) from the FAA. This TC holder is then permitted to produce that aircraft or engine design. That TC holder also has the responsibility for continuing airworthiness for that particular model. The TC holder identifies part failures in the field and the means to return the fielded fleet to the previous certificated airworthiness condition. TC holders have systems in place such that the airworthiness issues are handled quite well.

SYSTEM SAFETY

System Safety Engineering had it origin in the 1950s and early 1960 in the U.S. Air Force Ballistic Missile Division, where safety is especially critical. This new pro-active systematic concept of System Safety was to identify the safety problems ahead of experiencing catastrophic events and thus able to minimize and manage those risks in the design process. One of the key points was that everything operates as a "system" and that all failures (parts, humans, management, and the environment) affect the final outcome of the "system." The System Safety approach is a pro-active and systematic approach to identify potential initiating failure conditions and their worst likely effects on the "system." In the helicopter world, we consider the system to be the entire aircraft. The severity of potential failure (hazard) effects is ranked as Catastrophic, Critical, Serious, and Minimal consequences. The more serious events then can be corrected or minimized.

MIL–S–38130 was first published in 1963. Bell's System Safety effort was initiated on a USAF military helicopter contract in 1969 to MIL-S-38130A of 1966. In July of 1969, MIL-STD-882 became the System Safety Engineering standard, with revisions up to present Revision D (Ref. 1). U.S. military services require System Safety efforts on military aircraft and engines.

A Risk Matrix is a hazard severity versus frequency of occurrence matrix used for an individual hazard to understand its relative risk. Once that risk is determined, then appropriate actions can be taken to reduce that risk to a lower risk level that is an acceptable level. A typical Risk Matrix from MIL-STD-882D is shown in Fig. 4. Different countries and organizations will have variations of this matrix, but the key is to allow ranking of most serious and frequent hazards relative to those of minimal severity and extremely rare. Along with the higher risk comes the requirement for higher authorities to make decisions on acceptability and on whether or not correction/mitigation is warranted.

In the last decade or so, many of the System Safety concepts have been or are being integrated into the civil aviation world, under terms like Safety Management System (SMS). Transport Canada Agency and the FAA are deeply involved in risk management systems, as are civil aircraft manufacturers. New aircraft certifications are now requiring Function Hazard Assessments and System Safety Assessments, which are part of SMS for initial certification. The reader is encouraged to go to the Transport Canada web site (www.tc.gc.ca/civilaviation/sms/menu.htm) and the FAA web site (www.asy.faa.gov/) for more details.

		HAZARD SEVERITY			
		I Catastrophic	II Critical	III Marginal	IV Negligible
HAZARD PROBABILITY	A Frequent	1 High	3 High	7 Serious	13 Medium
	B Probable	2 High	5 High	9 Serious	16 Medium
	C Occasional	4 High	6 Serious	11 Medium	18 Low
	D Remote	8 Serious	10 Medium	14 Medium	19 Low
	E Improbable	12 Medium	15 Medium	17 Medium	20 Low

Fig. 4. Hazard Risk Matrix example.

SMS also has a place in Continuing Airworthiness of existing aircraft to stay within the certificated configuration. The closed loop process used by most TC Holders includes problem identification, problem analysis, and notification to proper authorities, problem correction, and fielding the correction. This is a continuous process that TC Holders use to improve their fleets and meet several FARs.

CRASH SURVIVAL

The last safety protection level is to provide means of occupant survival if a crash occurs for any initiating cause. There are four requirements to survive a crash in any type of vehicle (Ref. 2). They are as follows:

1. Maintain a livable volume for the occupant throughout the crash sequence.

2. Restrain the occupant.

3. Keep the crash loads experienced by each occupant within human tolerance.

4. Provide time to escape. Primarily, this is time to escape a post crash fire fireball.

There was considerable research by various Government-sponsored agencies into various aspects of airplane crashworthiness, but the U.S. Army was the primary force behind crash survival actually being introduced into helicopters. In the mid 1960s, the post crash fire threat was the primary threat to the survival of U.S. Army helicopter occupants. The Army decided that a Crashworthy Fuel System (CWFS) should be developed and installed in all Army helicopters. Severe drop tests and material puncture/tear tests were developed, with the result being MIL-T-42722B (Ref. 3). The US Army introduced the CWFS into production helicopters and retrofitted them into existing helicopter fleets (Ref. 4). The first CWFS delivered was installed in a new production UH-1H in May 1970. This was to become the most significant single improvement for crash survival in helicopters. Table 1 from Ref. 5 shows the effectiveness of CWFS in preventing thermal fatalities in CWFS-equipped Army helicopters compared to non-CWFS-equipped Army helicopters for about the same number of accidents.

Table 1. CWFS Effectiveness (1970 – 1976)

	No. of Accidents	Post Crash Fires	Thermal Related Fatalities
Survivable – No CWFS	1,160	43	159
Survivable – With CWFS	1,258	16	0

The U.S. Army pulled information and ideas from different crash survival research areas together into the Crash Survival Design Guide. This became the initial handbook on how to include crash safety features into a helicopter design. There were several updates of the Crash Survival Design Guide, with the latest being TR89-22 in five volumes (Ref. 6). The Army then required these crash survival requirements in their new generation of helicopters (e.g., UH-60 and AH-64) from the beginning of the design. MIL-STD-1290A (Ref. 7) was basically the key Crash Survival Design Guide criteria, but placed into a requirement type of document that could be mandatory on military helicopter contracts.

Introduction of crash safety features into civil helicopters lagged the military by a few years. There were no certification requirements specifically to improve crash safety (other than “everyone needs a lap belt”). This is important, as there are significant weight penalties to include crash survivable features. This places the operator at a payload disadvantage with his competitors who use helicopters without the safety features. In 1980, Bell introduced the Model 222 with shoulder harnesses for pilots and passengers, energy-attenuating crew and passenger seats, and a Crash Resistant Fuel System (CRFS) as standard equipment. Reference 2 discusses these safety features and Bell introduction into different models and their respective weight penalties. The CRFS was a lighter-weight version of the military CWFS, but provided protection to 56 ft/sec impacts as compared to 65 ft/sec with a CWFS. Since impact survival (disregarding any post crash fire) was not likely at speeds above 50 ft/sec, the need to go to higher impacts speeds of 65 ft/sec of a military CWFS only adds aircraft weight with no additional survivors. The weight penalty on a helicopter with 13 passengers to include a CRFS and passenger energy attenuating seats with shoulder harnesses as standard equipment was 157 lb over the FAA certification requirements at that time. This in essence, was lost payload equivalent to one passenger compared to a comparable size helicopter by other manufacturers that only met the FAA requirements. That is quite significant in the competitive world of commercial helicopter operators. Bell introduced these crash safety features 10–14 years before the FAA changed the regulations to require these same safety features.

It became apparent that the industry needed the appropriate crash protection level for civil helicopters to be in realistic FAA regulations. If all manufacturers are required to provide the same crash safety features to the same level, the resulting weight penalty is common to all, thus eliminating the competitive disadvantage of having crash safety features. Further, if the designer knows in the beginning that he needs to plan on an additional 200 pounds or so of weight for these features, he can plan on more rotor and power to compensate. The Aerospace Industries Association (AIA) had a Rotorcraft Airworthiness Group consisting of the Vice President of Engineering from the four primary helicopter manufacturers (Bell Helicopter, McDonnell Douglass Helicopters, Sikorsky Aircraft, and Boeing Helicopters). This AIA group assigned a crash survival engineer from each company to determine what crash safety features were needed and the appropriate criteria for civil helicopters. As a result, criteria were developed and briefed to the FAA as a potential level that industry could support. That effort was discussed in Refs. 8 and 9. At the same time period, the FAA had a research contract to determine the crash safety criteria based on analysis of civil helicopter accident data, which resulted in DOT/FAA/CT-80/11 (Ref. 10.). The crash safety criteria from these two efforts was comparable and was to later become regulations, specifically amendments:

- 27-30 and 29-35, Crash Resistant Fuel Systems.

- 27-28 and 29-32 added a passenger shoulder harness on helicopters produced after 1994.

- 27-25 and 29-29 Energy Attenuating crew and passenger seats (e.g., dynamically tested) for new Type Certificate applicants.

Reference 8 discusses helicopter safety and all of these changes and their relationship to comparable new crash safety related regulatory changes of Part 23 and Part 25 airplanes.

The military is still leading in some new areas of crash survival, such as Cockpit Air Bags systems (similar to automotive air bags). On the civil side there is promising research work on external air bags mounted to the fuselage belly. Inflatable belts are also being developed.

WHERE TO CONCENTRATE EFFORTS

Airworthiness causes are separated by certification responsibility (e.g., the Type Certificate Holder). Thus the engine manufacturer certify their engines under Part 33 and are responsible to the FAA to keep the fielded engines to the same certification level. Similarly, the helicopter manufacturer certifies his helicopter to either Part 27 or Part 29 and is responsible for those parts. Basically, the helicopter manufacturer is responsible for the entire helicopter except for the engines. Other companies may get Supplement Type Certificates (STC) and are responsible to the FAA for their parts/systems, which modify an aircraft. STCs vary and are not on all models. Since part failures are very rare events and there are difficulties in dealing with STC variability, all airworthiness (AW) failures are considered as either Engine AW or Non-Engine AW to simplify accident analyses.

For the Bell civil turbine helicopter fleet worldwide, the annual accident rates for the last 20 years (1985–2004) are shown in Fig. 5. This accounts for 50 million flight hours and includes all of Bell's civil certificated models with a turbine engine. It does not include U.S. military models, military surplus on civil registries, Model 47s, or any helicopter produced by a licensee (e.g., Agusta). The annual accident rate for all causes is coming down. Note the accident rate of the lowest line, due to non-engine airworthiness (Bell's responsibility for the aircraft certificated to Part 27/29 requirements), is quite low, with sporadic increases due to a helicopter part (other than engine) failure. Accident investigation would identify the component failure. Field inspections or restrictions would be used while engineering analysis/tests were determining the root causes, and correction. Replacement parts are introduced to the field as quickly as possible. Thus the non-engine airworthiness rate drops back quickly.

The distance to the next line up on the figure is the accident rate due to engine failure/malfunctions, which are the engine manufacturers' (Part 33) responsibility. The engine manufacturers continue their effort to decrease their engine-caused accident rates. Some of these accidents attributed to the engine are "claimed power loss," but the engine runs fine during the accident investigation. They are counted as an engine airworthiness failure, since it cannot be proved what actually happened. These "claimed power loss" accidents will continue to occur until recorders can be used to document what really happened. Thus the accident rate for all airworthiness failures (Engine and Non-Engine) is the red line on the Fig. 5, which is quite low—0.53/100,000 hours for 2004. Airworthiness failures are minor contributors to the overall accident rate.

The distance between the center red line (all airworthiness) and the top blue line is the human and unknown causes. Primarily, the human cause is the pilot. Thus the total accident rate is the blue line or about 3.9/100,000 hours in 2004. This chart also shows that the total elimination of all airworthiness failures could not reduce the overall accident rate by more than about 15.7% for the last 5 years). Said differently, 84.3% of the accidents would still occur if an aircraft or engine never failed. We must address the human and unknown side to significantly reduce accidents. Bell, and others, have made major efforts to address the human error accident causes with success in some areas. The reason for the overall Bell accident rate reduction of Fig. 5 is due to many efforts by different people, including the Bell training

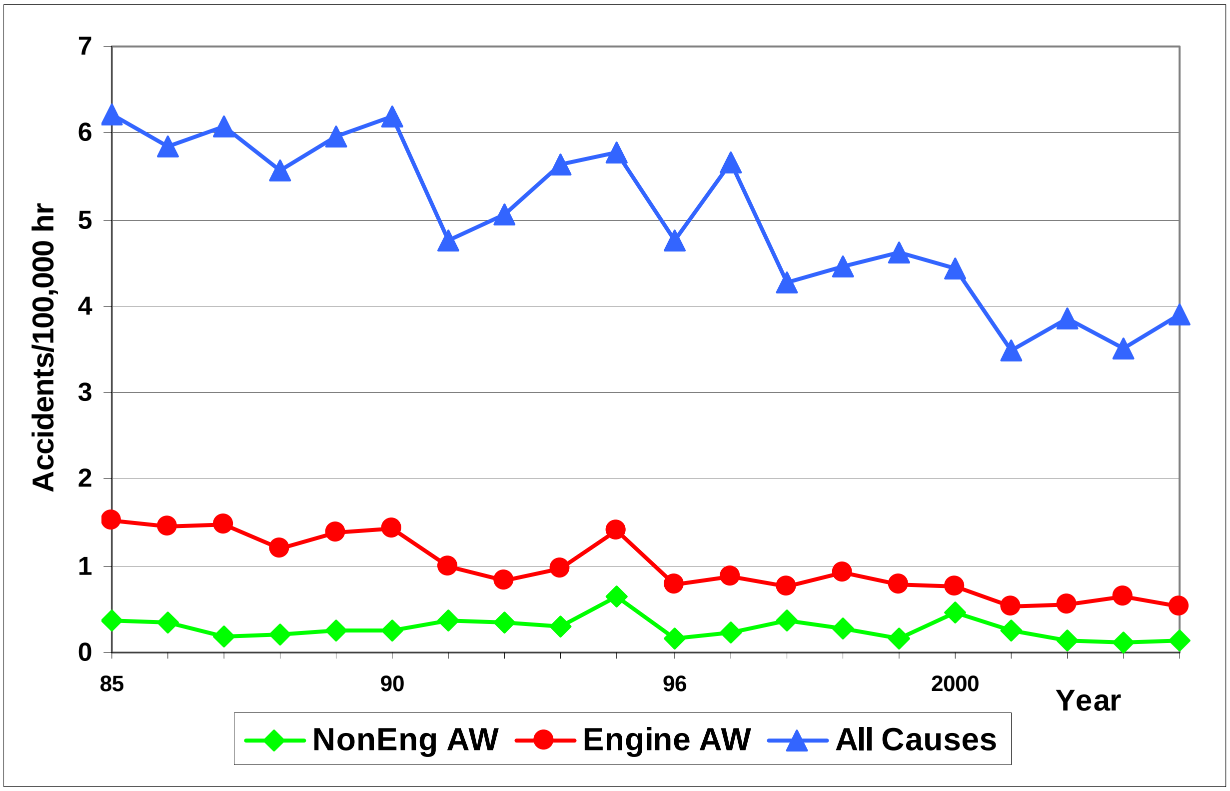


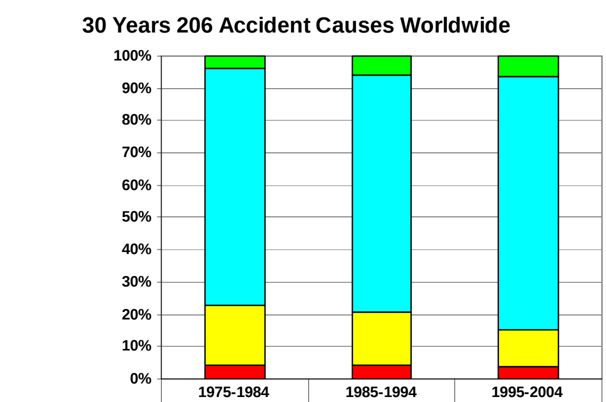
Fig. 5. Bell Civil Turbines 20-year history worldwide (1985–2004).

pilots at Bell's Customer Training Academy. Documenting and then understanding all of the various human errors and what really happened in the cockpit is the challenge to make significant improvements in safety.

Bell helicopters (civil models and military surplus on civil registries) accounts for 8,310 helicopters or 36.7% of the 22,865 helicopters worldwide per Rotor Roster 2005 (Ref. 11). Thus it is highly likely that helicopters of other air-frame and engine manufacturers have similar accident cause distributions to those of Bell models and less than one third of their accidents caused by airworthiness failures. We all need to find a way to document and understand human error accidents and those unknown causes. Serious accidents to any model helicopter affect adversely the manufacturers of other models.

ACCIDENT CAUSES

Airworthiness failure causes contribute little to all causes. Civil helicopter models and military surplus helicopters on civil registries are tracked by Rotor Roster (Ref. 11). This 206 fleet has flown 51,633,000 hours worldwide in the 30-year period of 1975 through 2004. The civil 206 series accounted for 19.5% of all 22,647 civil models registered worldwide at the end of 2004. Likewise, the 206 accounts for 20.1% of the 11,973 helicopters registered in the USA. Overall, Bell has produced 6,151 civil Model 206s since the 1966 introduction to the civil fleet. The percentages of 206 accident causes are shown in Fig. 6 for three 10-year periods worldwide. The lower two values are airworthiness (AW) failure initiated accidents. Accidents caused by aircraft failures, other than engine, are labeled as Non-Engine AW,



	1975-1984	1985-1994	1995-2004
Unknown	3.7%	6.0%	6.5%
Human (Non-AW)	73.7%	73.1%	78.4%
Engine AW	18.2%	16.8%	11.2%
Non-Engine AW	4.4%	4.1%	4.0%

Fig. 6. 206 accident cause trends of 30 years.

accounting for about 4% of accident causes. The Engine AW (including confirmed failures and suspected/claimed power losses) has been reducing and presently accounts for 11.2% of accident causes. Thus about 85% of all accidents causes are not airworthiness related. What can we do about those 85% causes?

HUMAN JUDGMENT

Bell studies of accident causes always end up with roughly three fourths of the accidents being somehow pilot related (e.g., human error). In 1985 and 1986, a special safety study was done on human error related accidents of all civil Bell models around the world. The purpose of the study was to identify the root causes of these human errors, which could hopefully lead to improved helicopter design. The result of this study (Refs. 12 and 13) was not what was anticipated and set Bell on a different course. Although there were many root causes found, there was one that was present in every accident sequence: that was poor pilot judgment. Thus in early 1987, Bell investigated several means of improve pilot judgment and ended up with two basic paths. One approach was the individual pilot teaching approach. This included the development of an individual pilot training aid with software that a pilot could use on a PC. This became Cockpit Emergency Procedures Expert Trainer (CEPET), which included pilot interaction (judgment) in the sequence based on actual accidents. It basically was a fault tree approach, which incorporates Bell pilot staff/engineering staff knowledge, where the pilot could make a good or bad decision. A bad decision got the pilot into a worse situation and would be faced with another decision point. CEPET was developed for the 206B, the 206L, and eventually the 212/412. Bell developed a Human AD document to discuss different pilot issues and decision-making. This booklet is distributed free several times a year and is available on Bell's website (www.bellhelicopter.com/).

The other direction was to provide face-to-face judgment training briefing in groups. A three-hour safety course was developed with judgment training embedded among other safety subjects. This course was part of the Bell 206 pilot ground school starting in March 1987 and was presented by the Chief Safety Engineer. This safety briefing was also given offsite to customers, agencies, organizations, and FAA seminars. The Chief Training Pilot also developed and gave safety briefings with different safety-related subjects, which included embedded judgment training. The whole safety effort was funded and considered the Helicopter Professional Pilots Safety (HELIPROPS) program. A full-time HELIPROPS Manager was hired to coordinate the safety efforts as well as do customer safety briefings. After seeing significant positive feedback in that first year, Bell spread the HELIPROPS approach to three other manufacturers who developed their own approach. Helicopter Association International (HAI) also supported the HELIPROPS approach. Did the HELIPROPS effort started in 1987 have any significant effect on accidents?

Bell believes it did. The number of fatalities per year that occurred in U.S. registered helicopters (from NTSB data) is shown in Fig. 7. Also included in that figure is the number of fatalities in 206s. Although it is impossible to do special

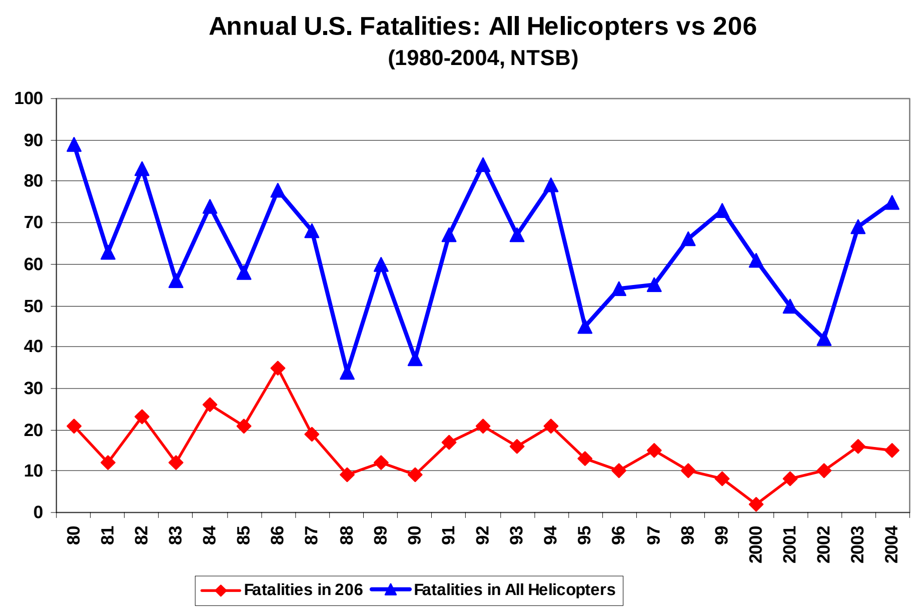


Fig. 7. Fatalities in U.S. registered helicopters.

training for all pilots quickly, it is possible to start with briefing attendees who further spread ideas of a new safety culture, which applies to pilots of all types of helicopters. Note the sudden drop in fatalities in 1988 and 1990 for all helicopters and a corresponding drop in fatalities in the 206.

The 206 fatalities curve is shown in Fig. 8 and the number of HELIPROPS safety briefings (in the 206 pilot ground class and to external meetings that included pilots of all types of helicopters) are included as bars. Note the concentrated training effort of 1987 through 1993 and the number of fatalities. The average number of fatalities/year for the 7-year period (1980 to 1986) was compared to the fatalities for the 7-year HELIPROPS period (1987-1993), which shows a significant drop in the later period. Is this drop statistically significant or just due to randomness?

A Student T test, with one-tailed test, was applied to several metrics for these two time periods to see if the HELIPROPS period change from the prior period was statistically significant at the 0.05 level. If it is statistically significant at the 0.05 level, that means that 95 times out of 100, the value in the two periods are different and not just due to randomness of rare events. Table 2 shows the results of the statistical significance tests for three different metrics. Metrics shown as the average over the time period but the actual annual values are used in the calculations to account for scatter. In 1987, there were 2,362 Model 206s on the registry and in 2004 there were 2,404 Model 206s on the registry, so the fleet continued to grow. Bottom line: there was a statistically significant difference for the 7-year period of concentrated HELIPROPS activities as compared to the prior 7-year period.

MEASURING SAFETY

Safety is the management of risk. To make significant safety improvements, you must be able to measure safety. There is no absolute safety (black/white) – there are only different levels of gray (e.g., low to high levels of risk). Fig. 9 shows that variability. The key to safety is to first measure risk, then make a change, and then measure the new risk. If the later risk is lower than the original risk, safety has improved. The typical safety metric (since early days of the first airplanes) is the accident rate expressed as accidents per 100,000 flight hours. Obviously, a serious or fatal injury

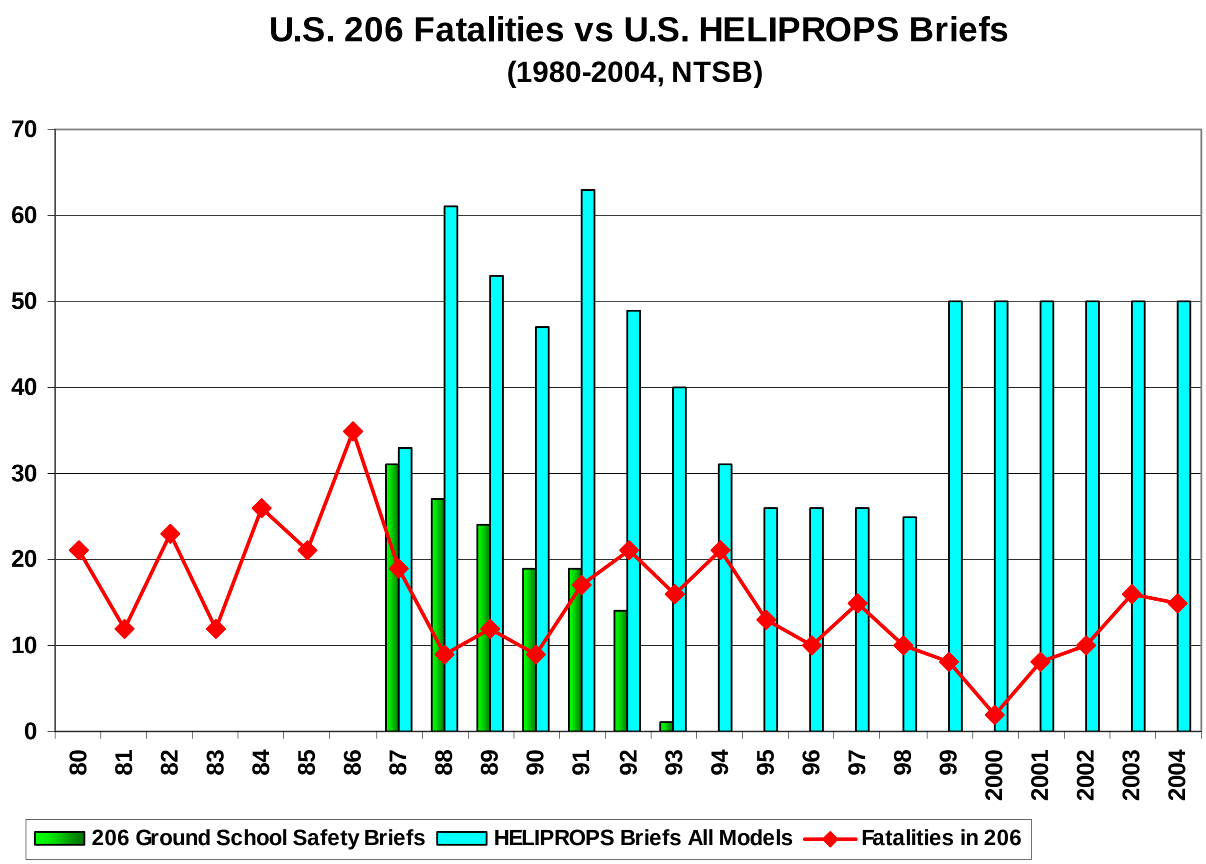


Fig. 8. HELIPROPS safety training effects on number of 206 fatalities.

Table 2. Statistical Significance of HELIPROPS changes

Metric	Average for 1980 to 1986	Average for 1987 to 1993	Difference is Statistical Significance to 0.05 level (95%)
Number of Accidents/year	53.29	33.43	Yes*
Fatalities/100,000 hr	2.33	1.60	Yes
Accidents/100,000 hr	5.20	3.76	Yes*

* Actually still different to 99.5%

will be categorized as an accident. But basically, an accident rate is really measuring the risk of the helicopter being damaged within the definition of an accident. Less than 10% of occupants in helicopter accidents receive a fatal injury. There are two elements of safety, which are (1) being involved in a sudden deceleration event (e.g., an accident), and (2) the possibility of being injured.

Webster's Dictionary defines "safety" as "the condition of freedom from harm, loss or injury." The ultimate risk results in death. The proper way to measure risk is number of events of concern for a certain amount of exposure. The risk to the aircraft is the number of accidents per flight hour. This is NOT the risk to the occupant. The key is to remember that safety is primarily an outcome related to the occupant, whereas an accident is an event primarily related to reporting aircraft damage.

The human occupant is the reason for safety. We try to reduce the injury potential for that occupant. If we can prevent the bad event (e.g., an accident) in the first place, we do. But we cannot stop all accidents despite all of the aviation community efforts, so we must protect the occupants. Thus the most important measure of safety is the occupant's Risk of Fatal Injury (RFI). RFI is defined as:

$$\text{RFI}=\frac{\text{No. of accidents}}{\text{Flight hours flown}}\times\frac{\text{No. of people with fatal injuries}}{\text{No. of people onboard all accidents}}$$

The first fraction is the likelihood of being in an accident (e.g., the accident rate). The second fraction is the likelihood of being killed, given that an accident occurs. The product of these two factors is the individual's risk of a fatal injury per 100,000 occupant hours of exposure. The risk of injury varies on the gray scale just like the risk of damage to an aircraft. We must measure that initial risk of fatal injury and then find ways to further reduce that risk. A periodic measurement of risk determines if safety is improving or not. Using NTSB data and FAA flight hour estimates, Fig. 10 shows the U.S. helicopter industry accident rate and occupant's RFI. Moreover, the accident rate history of U.S.

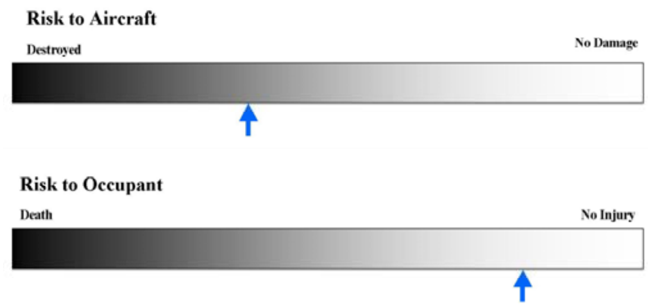


Fig. 9. Safety is not absolute, only shades of gray.

helicopter industry as a whole is not improving and appears to be increasing. Data are from Helicopter Association International (who collects NTSB accident information and FAA flight hour estimates) and from the NTSB website data bank. The trend for RFI for a U.S. registered helicopter occupant is holding constant and not improving. We must try some other approaches to make that leap to the next safety plateau (Ref. 14).

SAFETY GOAL POTENTIAL: 80% REDUCTION IN 10 YEARS

Once it is possible to measure safety, analyses can be performed to identify accident causes within Safety Investment Areas (SIA) and their respective frequency. Since there are always limits to the amount of money available to fix safety problems or make improvements, the most severe and most frequent safety problems should be corrected first, before correcting those problems that are extremely rare or that do not cause serious injuries.

There was a National Safety Goal established by the White House Commission on Aviation Safety study (Ref. 15). Specifically, Recommendation 1.1 stated "Government and industry should establish a national goal to reduce the aviation fatal accident rate by a factor of five within ten years and conduct safety research to support that goal."

A study (Ref. 16) was conducted to determine (1) if an 80% reduction (e.g., a factor of five) was possible for the U.S. civil helicopter fleet and (2) if so, to identify Safety

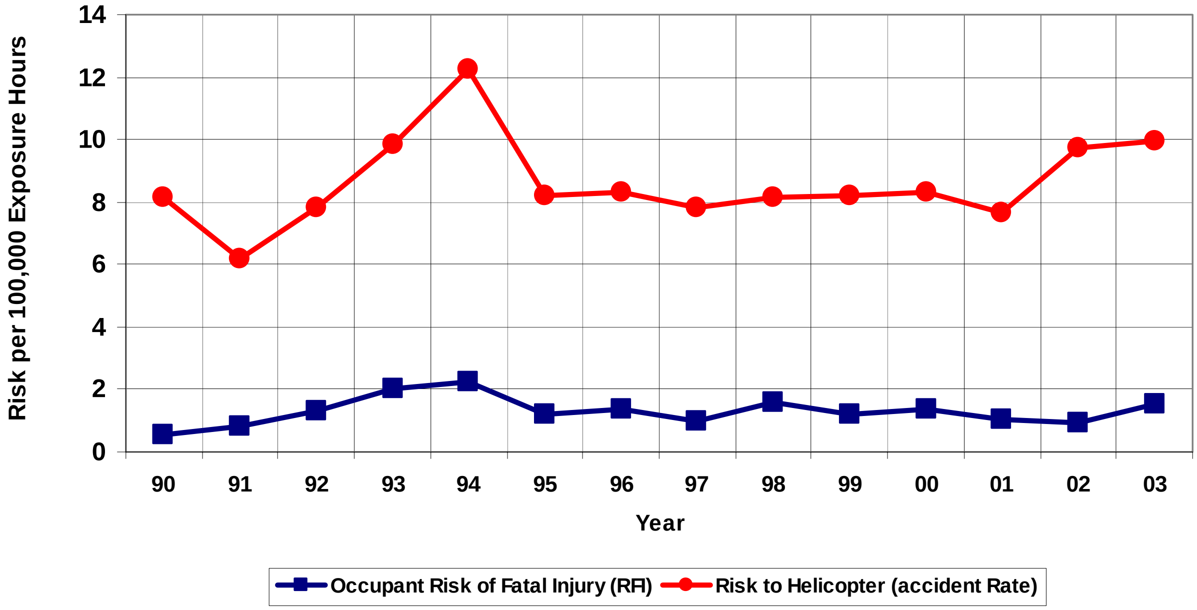


Fig. 10. U.S. registered helicopter accident rates and occupant risks.

Investment Areas (SIA) needed to achieve such a reduction. The basic ground rules used were as follows:

- SIA had to be applicable/retrofitable to the existing fleet, as 90+% of the future fleet in 10 years are aircraft flying today. Introduction of new technology aircraft will have little effect of the fleet-wide rates due to the small numbers introduced each year.
- SIA must be cost effective and affordable. Cost of a helicopter in the helicopter fleet ranges from $50,000 to more than $10 million each.
- Priority for SIA selection was most effective (e.g., cover large number of accident causes), most cost efficient (must be affordable), and available soon: Basically, the “biggest bang for the buck with a short time to fleet introduction.”

The civil U.S. helicopter fleet was analyzed for the latest 5-year period of 1990–1994, using NTSB accident data and FAA flight hours estimates for three groups as shown in Table 3.

The accident causes were determined with their respective accident rate frequencies. These accidents were then grouped into SIA areas that could have prevented or mitigated that type of accident cause. For example, all of the wire strikes, post strikes, fence strikes, and tree strikes could have been prevented if there was an active obstacle strike detection system onboard that could detect nearby threats and alert the pilot. There are several SIAs that could have prevented the same accidents so each SIA was initially

Table 3. Helicopter accidents and exposure.

Group	Flight Hours	Accidents	Fatal Accidents
Piston	2,361,526	486	66
Turbine	7,990,747	294	77
Military Surplus UH-1	171,049	24	4
Combined Fleet	10,523,322	804	147

listed. The SIA areas and their frequency of occurrences were determined as accident rate, fatal accident rate, and RFI in Table 4 for the combined fleet. More detailed group breakdown information is in Ref. 16. There are multiple SIAs for the same accident, so the total of the frequencies does not equate to the total accident rate.

By applying the ground rules on priority of assigning a SIA, the accidents assigned to the most effective SIA were removed from the helicopter fleet accidents. The next best SIA then could only affect the remaining accidents, and those affected accidents were then removed from the fleet. This priority sequencing was used until nearly all of the accidents were mitigated by an SIA. This provided a priority list of SIAs, and how much accident reduction was possible for each. SIAs were added until achievement of the 80% reduction goal was reached. The resulting SIAs in order of priority and their respective rate reduction potential are shown in Table 5.

Table 4. Combined Fleet Risk Related to SIAs.

SIA problems	Accidents/100,000 hr	Fatal accidents/100,000 hr	Risk of fatal injury/100,000 occupant hr
1. Obstacle strike	0.89	0.31	0.28
2. Loss of aircraft situational awareness	2.49	0.59	0.57
3. Real time aircraft performance exceeded	1.56	0.13	0.08
4. Loss of situational awareness internal to aircraft	1.43	0.15	0.11
5. Loss of visibility	0.47	0.24	0.24
6. Inability to respond in short duration emergency	0.38	0.04	0.02
7. Aircraft component failure	1.95	0.30	0.25
8. Maintenance error	0.76	0.10	0.07
9. Cockpit actions unknown	5.85	1.11	1.04

As a result, it is possible to reduce the accident rates and RFI rates by 80% using the SIAs and priorities shown. These are not the only SIAs that could help, but they are the simplest and easiest from which to measure effectiveness and progress toward the goal. The potential exists to drive the helicopter fleet accident rate down to 0.36/100,000 hr. For a perspective, the accident rate in 2003 for all U.S. registered Part 121 Scheduled Air Carriers was 0.30/100,000 hr. For the last five years (2000–2004), the Part 121 Scheduled Air Carriers had a rate of 0.23/100,000 hr. The helicopter industry has the potential to have comparable accident rates.

A key SIA is the CAVR (Cockpit Audio Visual Recorder), also described in more detail in Ref. 14 as a Cockpit Information Recorder (CIR). We must document what happened in the cockpit, and ONLY THEN can we correct procedures and know what type of training is needed to correct specific accident causes. Further, we can then evaluate the effectiveness of different trainings.

ROADBLOCKS

There are several myths in helicopter safety that need to be understood and corrected. We must work with facts, and not perceptions that are not necessarily true. These perceptions prevent the industry from moving forward based on facts. Some continuing myths are "Twin-engine helicopters are always safer than single engine helicopters. The rest of the aircraft other than the engines are the same on single or twin engine helicopters, so it can be disregarded, etc." These myths are not *always* true and draw attention away from the rest of the aircraft and the largest and far more complex problem of the human pilots. Concentration on the myths further ignores the different hazard levels of different types of missions, which can have significant effects. Over the last 20 years, these myths and ramifications have been discussed in Refs. 2, 12, 13, and 17. There are situations where an occupant in a twin-engine helicopter is safer than in a single engine helicopter, but the reverse is also true.

Table 5. SIA Solutions to Achieve 80% Reduction

SIA number	SIA solutions	Accidents / 100,000 hr	Fatal accidents / 100,000 hr	Risk of fatal injury / 100,000 occupant hr
	Present risk rates. *Implemented SIAs below will yield residual rates shown (100% acceptance & implementation)*	7.64	1.40	1.23
1, 2	Add Proximity detection Systems	5.07	0.76	0.65
1,2, 3, 4, 7	Add HUMS, aircraft health, real time performance, and pilot aids	2.14	0.39	0.37
1,2, 3, 4, 7, 9	Add cockpit image & audio monitoring	0.36	0.06	0.10
	Residual risk after combined potential of all SIAs.	0.36	0.06	0.10
	10-Year future goal/target (80% of present)	1.53	0.28	0.25

Another myth is that all helicopters are created equal and their safety is equivalent. That is not true either. Every helicopter model is different and has good and less-desirable features and characteristics. The author considers all helicopters to be safe, but some are safer than others. To illustrate this fallacy of these myths, see Fig. 11 from Ref. 17, which shows the occupant's flight life span, which is the average number of hours, an occupant can fly before receiving a fatal injury. This is the reciprocal of the RFI or 1/RFI. The time period is 1987 to 1996 for U.S. registered helicopters. The red bars are the flight life span, if you could only die from all airworthiness failures (including engine). Of course, "All Causes" data are the real measure of concern, and even 85,000 hours is a long, long time for an individual to be in the air.

A roadblock to the helicopter industry is the lack of accurate flight hour exposure data. If we cannot measure risk, we cannot tell whether our "improvement" is an actual "improvement in safety," or whether it made the problem "worse" or just moved the problem into another area. We must be able to accurately measure the "bad outcomes" per "units of exposure."

Exposure data is critical, but difficult to obtain. Availability of flight hours has been a constant problem. FAA General Aviation and Avionics Survey used a sampling technique to estimate flight hours on annual basis. Although this technique produced errors from year to year on an individual model, hours over 5+ year period has improved accuracy, as the annual high/low errors start to cancel each other out. The FAA stopped providing helicopter model flight hours in 1997, so there are no Government flight hour data available at the model level for the years since 1996.

Bell in the 1970s became aware of lack of exposure data, which precluded measuring safety degradation or improvements. Bell started tracking every Bell helicopter individually by serial number. The concept is to determine airframe total flight hours at different dates. Once that data is entered, the computer can interpolate between data points for any given date to determine the flight hours. Setting the interpolation point at January 1 of each year develops the annual airframe hours for that serial number aircraft. Limiting this to only US. registered aircraft makes the data comparable with FAA data, which is strictly U.S. registered aircraft. Then the annual hours of each serial number helicopter for that given year are totaled. Flight hours for a specific serial number aircraft are pulled from various sources such as (1) accident or incident reports, (2) discrepancy reports, (3) warrantee claims, (4) Bell Customer Service Representative visits to operators, and (5) "for sale" sites on Internet.

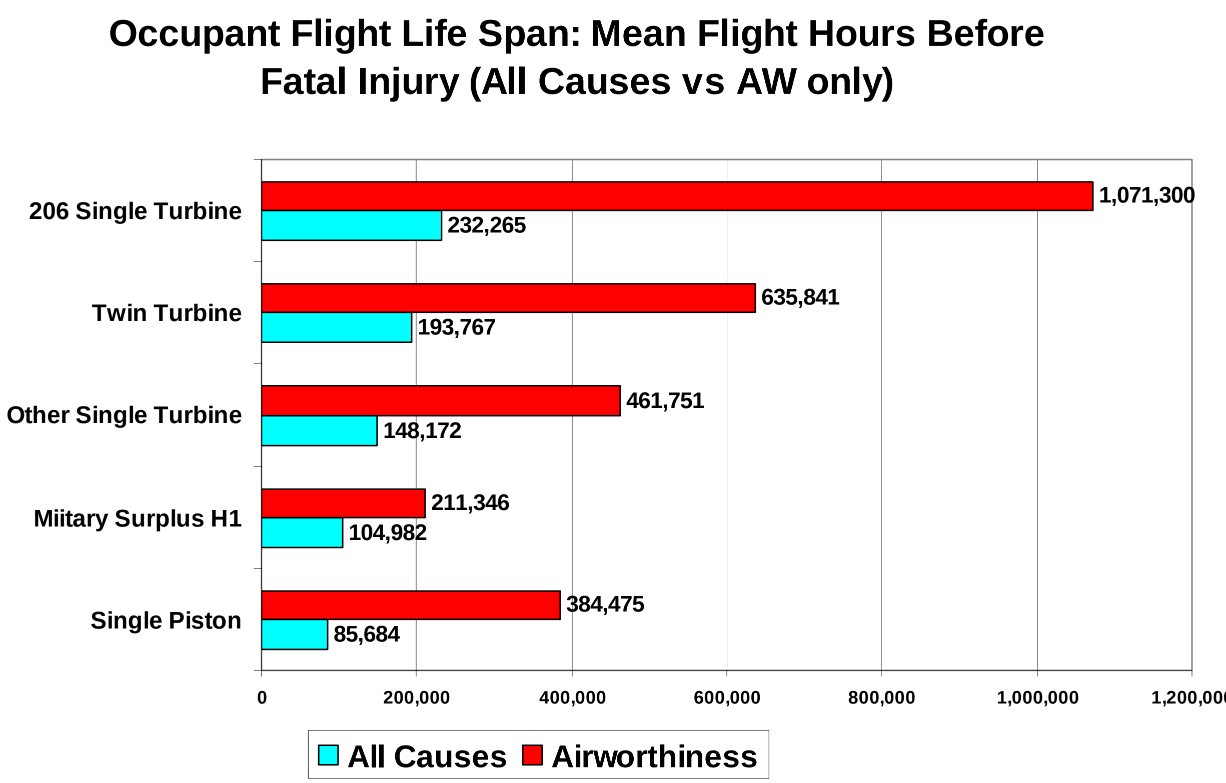


Fig. 11. Occupant flight life span.

An example of one serial number helicopter flight hour history is Fig. 12. This aircraft had left the US, was on the UK registry, and returned to the US registry. There is hope in the future to have good Government flight hour data. Bell has worked with HAI and the FAA to use this same technique for all helicopters. There is an FAA funded research program underway where HAI is combining their electronic formatted Maintenance Malfunction Incident Report (MMIR) for flight hours generation by using this same Bell process to develop annual flight hours at meaningful model levels. At the end of each year, HAI would total the flight hours flown under U.S. registry to the helicopter model level and provide that to the FAA. If we can prove the effectiveness of this process on the helicopter fleet, a similar computerized system could be used on General Aviation airplanes in the future.

A common misconception is that the exposure to risk should be related to number of takeoffs, such as accidents per departure. Helicopters appear safer that way, since helicopters make many takeoffs per hour, compared to an airliner that will fly for hours before landing. That is a false measure that should not be used, since there is a risk of injury throughout the entire flight, not just during a takeoff

throughout the entire flight, not just during a takeoff or landing. Departure data is required to be reported to the FAA for all scheduled Part 121 air carriers, but nothing is required for the helicopter and General Aviation world. The NTSB in a recent recommendation is pushing for reporting of flight hours and departures for non-scheduled Part 135 operators, which will include some helicopters. This would not affect the majority of helicopters, which do not operate under Part 135.

The single most-important improvement in helicopter safety could be driven by documented information of what happened (or not) in the cockpit during an accident sequence. We accident investigators and regulators don't know details. Pilot error is largely based on circumstantial evidence, and ends up with accident causes such as "failed to maintain RPM," "failed to maintain clearance," "fuel exhaustion,"—the list goes on.

FUTURE CHALLENGES AND DIRECTIONS

The helicopter industry, including the regulatory side, needs to work on these major roadblocks. For example, HUMS—

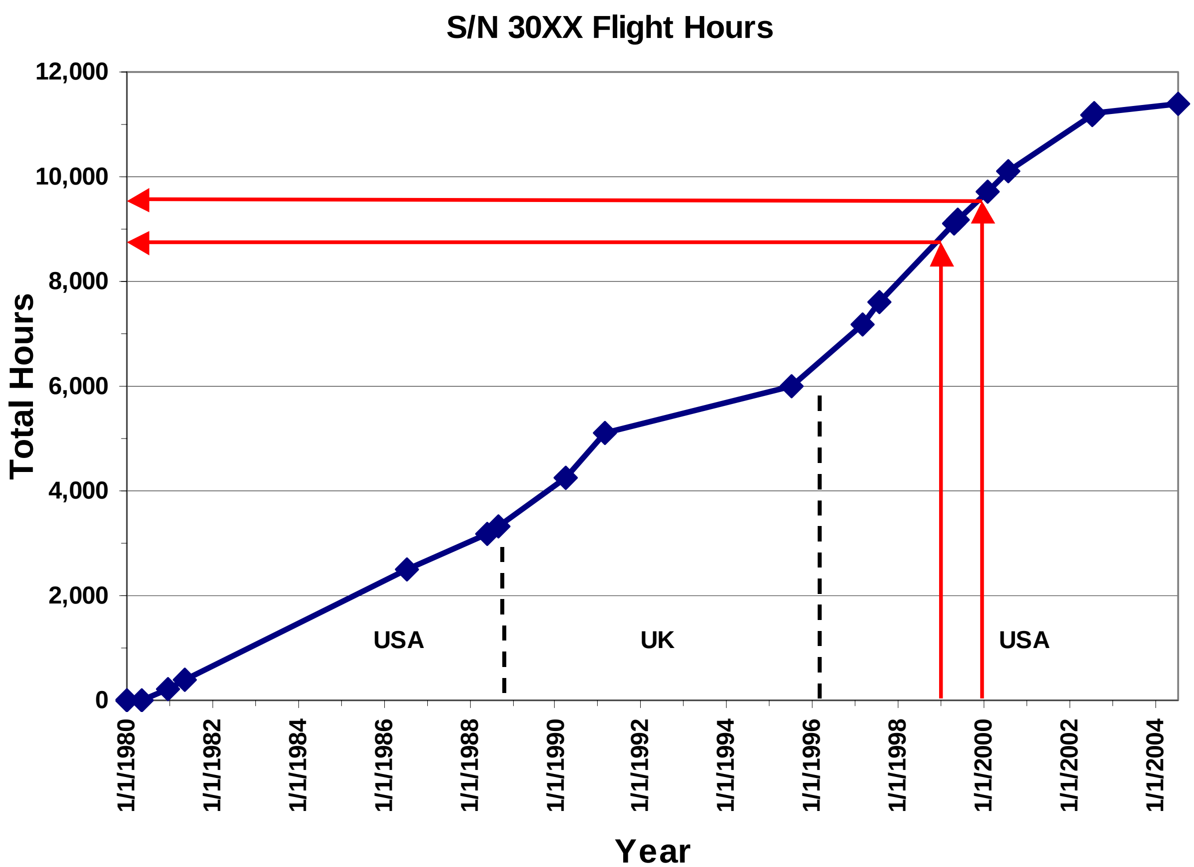


Fig. 12. Individual helicopter flight hours tracking.

possible maintenance credits and alerting a pilot of an impending problem—is always a good subject for a lively discussion. We need research and trial programs to build a more robust and useful HUMS, to be able to validate that the HUMS indication occurs XX hours before a catastrophic component failure. With such confidence, the pilot should be alerted that the helicopter requires an inspection before another flight. We in the industry and the regulatory agencies must work together to find ways to make improvements and also make use of technologies developed from outside of aviation. Figure13 provides a roadmap of basic safety investment approaches that could allow an 80% reduction of accident rates in the future.

The largest single problem that prevents helicopters from rising to the safety level of the airlines is that we do not know what is happening in the cockpit. If you don't understand what happened in a crash, you cannot fix anything and these human error accidents continue year after year. We must find a way to document what is happening in the cockpit, and that information must be retained in crash-survivable media or transmitted outside of the aircraft. Many contend that we already have Flight Data Recorders (FDRs) and Cockpit Voice Recorders (CVRs) to provide this information. This comment is misleading. Reference 14 discussed the fallacy of this, as very few helicopters have FDRs. Since the FDR requirement of 14CFR135 is for multi-turbine powered helicopters with 10 or more passengers, the maximum number of helicopters meeting those requirements (including those not operating under 14CFR135) would be only 6.5% of the U.S. civil helicopter fleet.

The helicopter industry needs a Cockpit Information Recorder (CIR) to provide information inside the cockpit before and during a crash. This information will allow the accident investigators to understand what actually happened (or not) in those human and unknown caused accidents. Once we can document and understand the actions and sequences, we can make the appropriate corrections. This

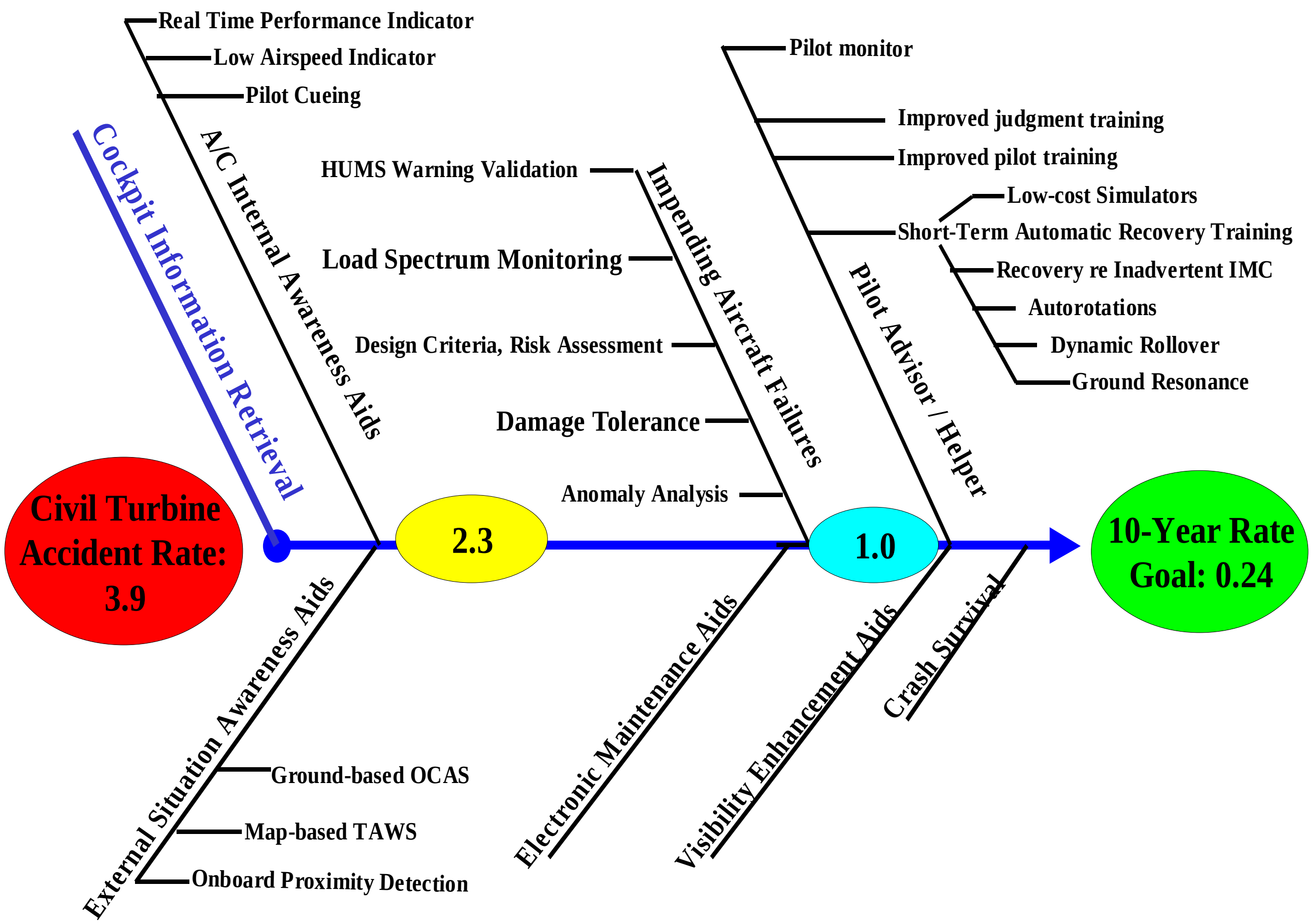


Fig. 13. Safety investments for the future.

knowledge on every helicopter accident can save costs/time of accident investigations, reduce regulatory concerns, and speed up corrections to the field. Most importantly, it would allow us to correct and mitigate the human error accidents and raise helicopter safety to a new level. Reference 14 describes these benefits and issues regarding a CIR. A CIR should contain:

- A still color camera (day/night)
- An area microphone
- A GPS
- Data processing/memory capability
- Crash survivable recorder.

A CIR unit would likely contain the first four items and provide output to existing crash-survivable recorders. A typical still shot photo is shown in Fig. 14, which would include the instrument panel and the pilot's controls (cyclic, collective, and pedals). A CIR could be a "poor man's FDR/CVR."

Fig. 14. CIR view of cockpit.

Further in the future, we should make the CIR wireless. An onboard transmitter would be added to transmit analyzed critical data to a satellite, to a land line via Internet to the Operator's PC and the Manufacture's PC (Fig. 15). The PC would be programmed to determine if a crash occurred (e.g., analysis of GPS data for anomalies). If analysis indicates a crash and no human action occurred from the operator in a few minutes, the PC would automatically notify the Search and Rescue function. The PC alert message would provide aircraft identification, time of last contact, and longitude/latitude of the wreckage. This would shorten rescue response time, which increases the probability of survival. This satellite transmission approach is already being used now for helicopter flight following with a small GPS unit. The automotive industry has this GPS tracking and crash alerting capability (when airbag deploys) in GM's OnStar® system in many of their automobiles.

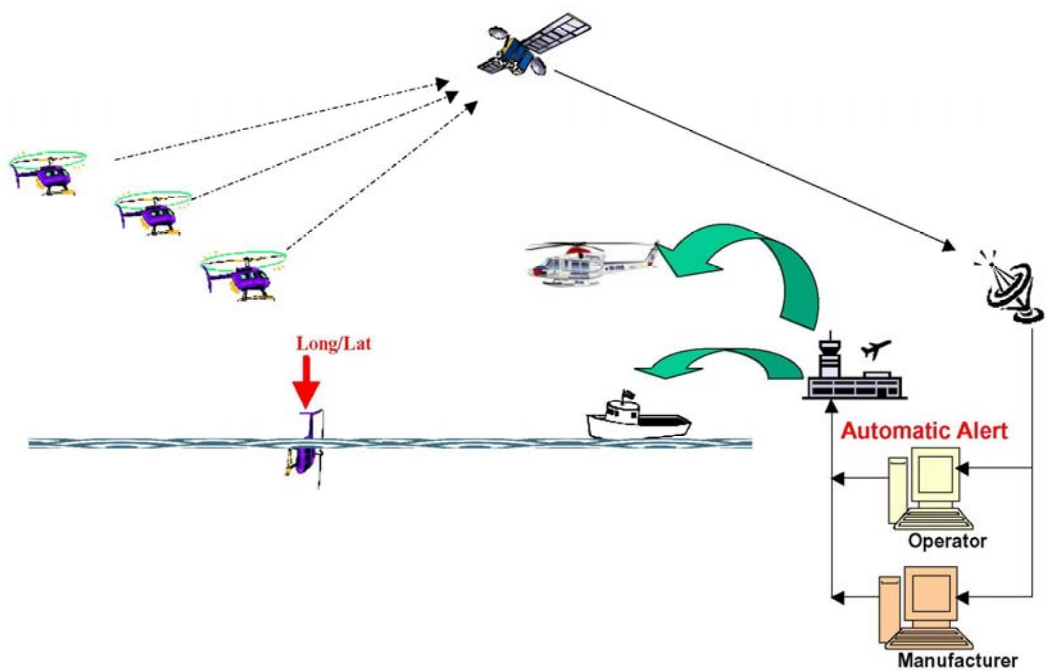


Fig. 15. CIR wireless automatic crash alert via satellite.

SUMMARY/CONCLUSIONS

Helicopter safety has been improving over the years. The accident frequency appears to be flat or even increasing. The accident rates due to airworthiness issues remain very low and consistent year-to-year. Industry will continue to keep airworthiness issues corrected. The largest single potential area to make significant improvement in safety is in understanding what went on in the cockpit of each accident helicopter. Once we can document the cockpit information and sequence, we can finally understand and aggressively attack those accident causes. A Cockpit Information Recorder (CIR) tied to a crash-survivable recorder can allow quicker, more complete, less costly accident investigations. This would allow safety problems to be corrected in weeks, not years. The CIR provides the potential to reduce our helicopter accident rate by at least half if not two-thirds. The CIR can provide facts and understanding, which is required to go to the next plateau level of safety.

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