HELICOPTER FLIGHT SAFETY ENHANCEMENT: A EUROCOPTER CONTINUING ACTION

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Abstract

Helicopters are highly complex systems, often used for demanding missions in hostile environments. But despite these handicaps, the safety records of turbine helicopters are close to that of commuters. This result can only be achieved by using multiple complementary techniques. Eurocopter has always been at the leading edge, quietly leading the way to enhance flight safety. For example it was the first helicopter manufacturer to power an helicopter with a turbine engine and to produce major mechanical components, like the rotor blades and hubs, in composite, allowing them to benefit from the high damage tolerance performance of these materials.

Although flight safety is the result of many concurring factors, including but not limited to product design, engineering practices, manufacturing procedures, maintenance and operational procedures, regulations, and manufacturer's and operator's quality assurance procedures, this paper mainly focuses on search for safer designs.

Since the introduction of composite rotors, many other technological advances have allowed and will allow further safety enhancements: advances in the material characteristics, in the computing/modelling science and tools, in the electronic field, ...

This paper illustrates through multiple examples how Eurocopter takes benefits from the in-service experience and from the technological advances to continuously enhance the safety records of its products. This encompasses use of different complementary solutions: fail safe or damage tolerant design, piloting aids, all weather capability, health and usage monitoring systems,... Examples of improvements already in service or still at the research stage are given.

1. Introduction

Helicopters are highly complex systems, tricky to pilot, and often used for demanding missions in hostile environments. The helicopter industry's striving to continuously improve the safety of its products is thus no wonder. Dramatic improvements were achieved over the last 30 years as illustrated by the evolution of the US civil helicopter accident rate which now compares with that of General Aviation (figure 1). It is even better when only turbine helicopters are considered. Turbine helicopter accident rate is indeed close to that of commuters. It remains however much higher than that of large air carriers and has been leveling off for some years.

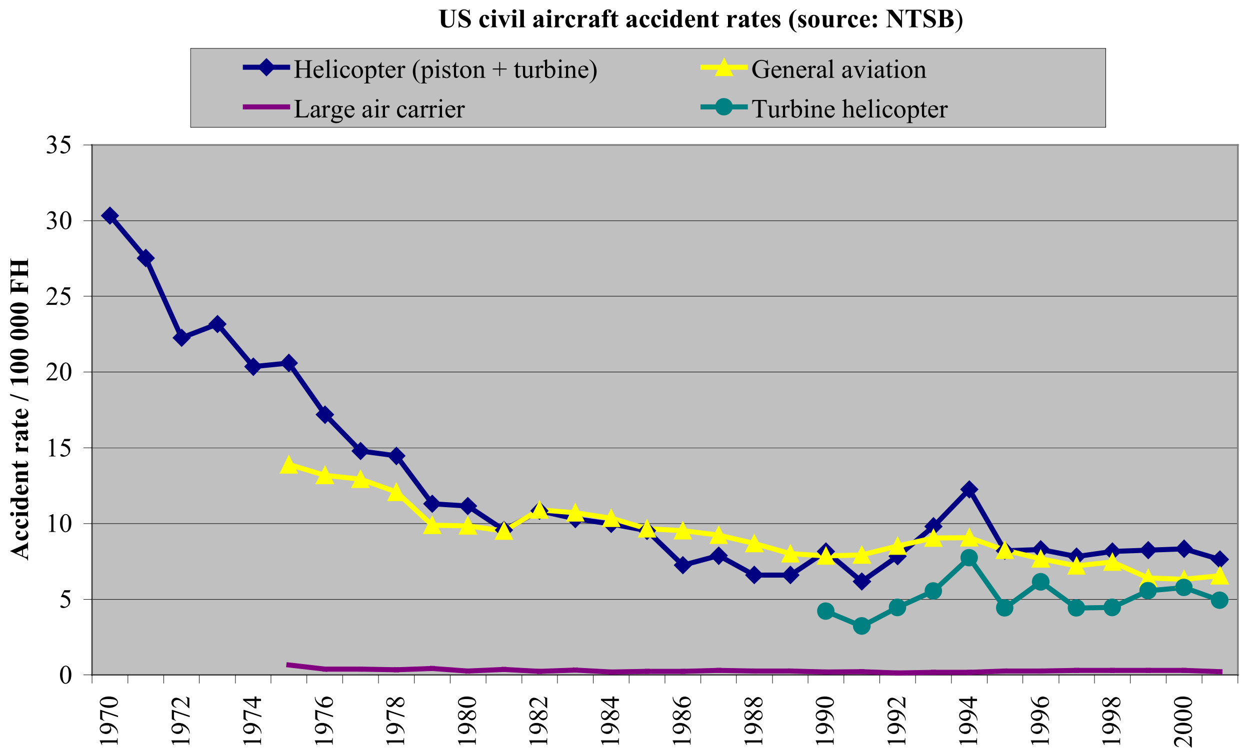

Figure 1

Quietly leading the way Eurocopter has always been at the leading edge toward an enhanced flight safety. It was, for example, the first helicopter manufacturer to develop a turbine helicopter: the Alouette II which made its maiden flight in 1955. Ever since then, Eurocopter quest for safety has never weakened and as a result of this policy Eurocopter figures are much lower. Furthermore, there is no plateau in the Eurocopter fleet total accident rate which, on the contrary, has been halved in the last 15 years.

But whatever the past improvements and the present status, in term of safety records low is never low enough.
In order to identify how to go on improving the helicopter safety records we will first briefly look at how the past decrease was achieved and continue by looking at the accident causes and at the future threats. Ways forward will then be presented.

2. The Eurocopter Safety Policy

"An accident is never accidental." This sentence has been the basis of Eurocopter flight safety policy for years and even decades. In accordance with the Heinrich principle (the same dangerous action will lead to an injury once in thirty and to a serious injury once in three hundreds), return on experience (REX) is the keystone of the Eurocopter flight safety policy. It is constantly used to enhance the fleet safety and design products

– less and less damage-/error-prone,
– more and more damage/error tolerant, and
– with a higher and higher crash survivability,

which can be safely operated in as adverse conditions as possible.

Any major incident is analysed in order to determine the necessary conservatory and/or corrective measures on the existing material. Lessons learned from past incidents are also used to identify strategies for preventing their reappearance on new designs and/or rendering them more tolerant, and steer the related Research and Development activities.

One of the key efficiency factor for this policy is the wide range of events looked at as a "Major Incident" by Eurocopter. For Eurocopter, a Major Incident is any event caused by or likely to cause:

– Mission abort, notably through application of a Flight Manual procedure.
– In-flight loss or rupture of, or damage to parts that is liable to jeopardise airworthiness for continuation of the mission.
– Undesirable operation or condition entailing the application of an emergency procedure.
– Abnormal heating liable to cause a fire.
– etc.

This addresses any incident wherever it occurred or was discovered (in flight, during first line maintenance, overhaul or repair, production, …).

Thanks to this field service feedback and to its high Research and Development activity Eurocopter developed innovative concepts with improved damage/error prevention and damage tolerance characteristics compared to former designs. Here are some examples:

– 1955: the Alouette II is the first turbine helicopter.
– 1971: the Gazelle main rotor blade is the first serial composite blade. This achievement was made possible thanks to a co-operation between EC and ECD (Sud Aviation and MBB at that time).
– 1971: the Gazelle features a Fenestron (fan in fin) tail rotor. The shroud around the rotor prevents rotor/personnel damage due to collision with the surrounding/rotor and the large fin provides the required yaw stability in case of tail rotor failure in cruise. As a result, the observed rate of accidents involving the Fenestron is about one tenth that of a classical tail rotor.
– 1977: the AS350 is the first helicopter with a composite main rotor hub. The glass fibre rotor head and the replacement of all the ball or needle bearings by elastomeric bearings provide a high damage tolerance. The same principle of elastomeric bearings is applied on the Spheriflex™ hub, which is now used by Eurocopter for the main and tail rotor hubs of all its new products but the Tiger main rotor (the Tiger has a rigid hub, which provides it with the high manoeuvrability suitable for an attack helicopter).
– 1983: certification of the Super Puma L1 de-icing/anti-icing system. The Super Puma L1 remains today the only helicopter certified for flight into known icing conditions.
– 1992: the Super Puma MK2 features amongst other things super-emergency engine ratings providing increased safety margins in case of engine failure and an EFIS flight deck improving the information available in the cockpit, and thus reducing the pilot workload and increasing its situational awareness. It has been estimated that three accidents which occurred on a Super Puma MK1 would have been avoided would the MK2 flight deck have been available at that time.
– 1991: first flight of the Tiger helicopter, first operational helicopter with a fully composite airframe.

Ever since then these concepts have been continuously improved (e.g. [1] and [2]).

Similar progresses were achieved by Turbomeca on its engines, which significantly contribute to the decrease in the accident rate.

The same in service feedback approach is applied to the maintenance documentation. All comment, question, remark received, whether dealing with the content or with the wording, is analyzed and the documentation improved as far as needed.

Eurocopter maintenance documentation also benefits from the technological advances. Since 1995 Eurocopter has been developing electronic documentation for all its production aircraft. This helps reduce out-of-sequence, missed, and/or incorrectly performed maintenance actions.

3. Accident causes

The validity of this safety enhancement procedure is clearly demonstrated by the continuous decrease in the total accident rate mentioned in the introduction. In order to identify how to further decrease the accident rate, let us look first at the accident root causes. All the helicopter accident studies (e.g. [3] to [8]) concur on identifying the operational causes as the by far major contributor. They account for as much as 80 to 85% of the total accident rate. Maintenance causes are coming after, with some 10 to 15%. Finally, technical causes represent a "mere" 5%.
In addition, it should be noticed that the operational share is continuously increasing. Figure 2 shows the evolution of the 3 year moving average shares of technical, maintenance and operational causes of accidents on the Eurocopter fleet.

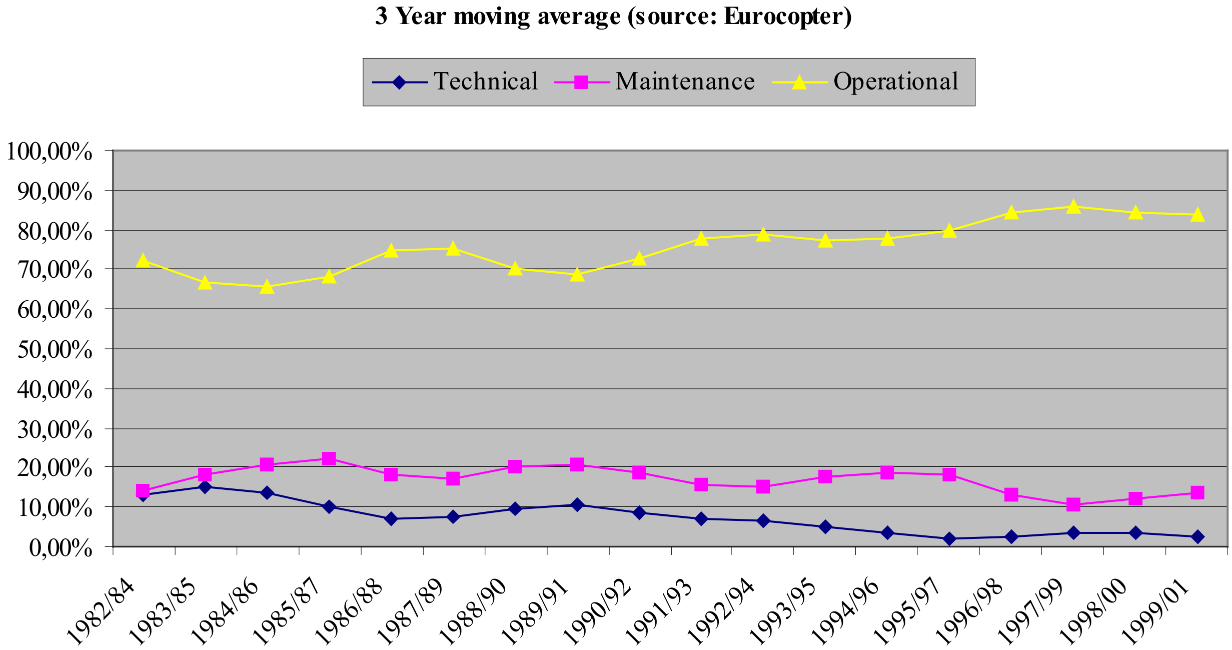

figure 2

Contributions of technical and maintenance causes are clearly decreasing, at the expense of operational causes. As far as the Eurocopter fleet is concerned, this does not mean that the operational accident rate is increasing: the three rates are steadily decreasing, but the operational rate is decreasing more slowly than the two others.
This can however be put together with the observation of the increase in operational accident rate for Non Public Transport helicopter weighting less than 5 700 kg reported by the UK CAA in [5].

Reduction in operational accident rates is clearly the key to an improved helicopter flight safety.

4. Foreseeable Threats

In order to identify the necessary safety improvement actions the present picture has to be completed with the foreseeable threats. They are described below.

4.1. Lack of experienced crews

One of the major, if not the major foreseeable threat is the lack of experienced crews. This will result from "a change in the age composition of the pilots, due to forthcoming retirements and a shortage of fully qualified maintenance technicians" [9]. This concern is echoed by other reports:

> "HAI Officials also are studying how to respond the growing concerns within the industry about a potential shortage of pilots and mechanics during the next five years. Vietnam-era personnel are nearing retirement, and the number of airframe and powerplant mechanics graduating from technical schools remains low compared with 10 years ago." [10].

> "The number 1 problem in the industry is the inability to find enough adequately trained pilots. There are much fewer pilots exiting the military, and those that tend to be much more specialized. Also the higher salaries and better cockpit environments of the business and regional airlines are significant draw on the rotorcraft pilot base." [11].

This is a rather bad omen for the already high operational accident rate.

4.2. Cost reductions

A second threat is "a gradual reduction of safety margin due to a need for further cost reductions". [9]. "Contracts, which reward high regularity or even, impose penalties for low regularity could constitute a potential safety problem." [9].
"As air traffic grows and the stringent requirements of commercial schedules impose increased demands upon aircraft utilization, the pressure on maintenance operations for on-time performance will also continue to escalate. This will open further windows of opportunity for human error and subsequent breakdowns in the system's safety net" [12].
Another bad omen, unfortunately not limited to maintenance and operational causes as the same pressure exists throughout the industry.

4.3. Environment

As a price of success, helicopters are used in heavier and heavier weather conditions like extreme temperatures, low altitude flight in bad visibility conditions (for example for Emergency Medical Services and military operations), and severe icing conditions.

5. Way forward

Further safety enhancement will obviously be possible only through efforts from- and co-operation between- all the interested parties, mainly the aircraft and engine manufacturers, the Airworthiness Authorities, the aircraft operators, and the Air Traffic Control agencies. In the following we will however focus on the aspects for which the aircraft manufacturer is the prime responsible.

The continuous decrease in Eurocopter accident rate and the low level now reached proves the Eurocopter safety policy is a good one and has to be continued, and even reinforced in all aspects: damage/error prevention, damage tolerance, all weather capability, survivability, and REX. Examples of recent or under development improvements are given below, with some emphasis on aspects with high helicopter specificity compared to fixed-wing.

5.1. Damage/error prevention

Damage/error prevention encompasses:
– a design preventing the occurrence of damages/errors during manufacturing, maintenance, and/or operation,
– a design allowing an easy maintenance,
– a maintenance program adapted to the actual need (neither over- nor under- maintenance),
– a clear, unambiguous maintenance documentation, and
– Quality Assurance procedures.

Quality Assurance applies to the design, the manufacturing, the maintenance, and the operation as well. It is one of the most effective answer to the cost pressure. But because of the importance of maintenance and operational causes we will focus here on the prevention of maintenance and operational errors, starting with the reduction of the crew workload.

5.1.1. Crew workload

Like any other industry, the helicopter industry benefits from the fast advances in the computer and display fields. They are used to minimize the crew workload for example through:

- MMI improvement: display of piloting and navigation information on larger , more easily readable displays,
- Auto-pilot upper modes (e.g. SAR),
- Accurate navigation system, coupled with the auto-pilot,
- Mission Planning: Eurocopter has recently developed a PC based Mission Planning System called SIRINAM™ which helps the crew to prepare his mission in a reliable way. Its functions are data preparation, mission planning, helicopter performance computing, and onboard avionics computers up/down loading. For example, it allows the pilot to review the location of potential obstacles along the route and at planned and alternate landing sites.

5.1.2. Comfort

Even if research on crew comfort are not primarily motivated by safety concerns, comfort contributes to flight safety by reducing at the same time the crew fatigue and the appeal of fixed-wings on experienced pilots. It is therefore worth being mentioned here. Eurocopter is designing smoother and smoother rotors and is continuously improving the efficiency of its anti-vibration systems. For example, the EC225 will benefit from an active control of the cabin vibration. In the same spirit, Eurocopter has an on-going research program on cockpit noise minimization means like low noise gears, noise filtering suspension struts, and noise active control systems.

5.1.3. Training

Training is obviously not forgotten as a crew error prevention means. That is why Eurocopter allied with Thales Training & Simulation to build and operate a helicopter training simulation center: HELISIM. This option will be efficient for new type transformation but also for recurring training which should become mandatory.

5.1.4. FOQA

The Eurocopter "Major Incident" procedure is a key contributor to the helicopter flight safety improvement. But mainly technical incidents and maintenance difficulties are reported. Extending REX to operational incidents looks thus promising. The main difficulty is there that of collecting the data. Solutions could be derived from the Flight Operation Quality Assurance (FOQA) and Operational Flight Data Monitoring (OFDM) programs presently implemented by large aircraft operators. Eurocopter is reflecting on the role the helicopter manufacturer should play in such a program and on how the fixed-wing experience could be transposed to helicopters. The CVFDR equipped helicopters represent indeed a very small percentage of the fleet and the helicopter small fleets are common. For example, in 1996 75% of the operators affiliated to the Helicopter Association International operated less than 5 helicopters and 39% only one. This is an area where helicopter specificity have to be carefully considered.

5.1.5. Optimized maintenance program

Maintenance is a major contributor to flight safety and to operating costs as well. In view of improving the maintenance quality while releasing the cost pressure Eurocopter continuously uses REX to optimize the maintenance program of its products. In addition, Eurocopter customizes on request the maintenance program of its helicopters to best fit the operator's type of operation and maintenance organization.

5.2. Damage tolerance

Damages tolerance encompasses:

- a damage tolerant design,
- a design allowing easy detection of the possible damages,
- the delivery of clear, unambiguous inspection instructions and rejection criteria,

- and possibly specific inspection/monitoring means like Health and Usage Monitoring Systems (HUMS).

5.2.1. Damage tolerant design

As on fixed-wings, damage tolerance is as widely used as possible. As far as avionics is concerned, there is no major helicopter specificity and helicopter manufacturers use the same concepts and standards as their colleagues from the fixed-wings. Helicopter specificity stem mainly from the high number of critical mechanical components, from the mechanical and structural component sizes, and from the high frequency of the fatigue loads they are subjected to.
Not surprisingly, rotors and transmissions account for a high percentage of the airworthiness and maintenance accidents. Eurocopter has thus been devoted a lot of efforts at improving their damage tolerance. For example, the EC225 MGB will benefit from an advance brought by research on tolerance to loss of lubrication of the gearboxes: the spray cooling [13]. In case of loss of lubrication, the rotating components are cooled by a spray directed onto the hot areas. This limits the heat dilatations which are the prime reason for bearing seizing. Similarly, the structure of the EC225 blade includes several features that improve the damage tolerance behaviour. This includes multidirectional fabrics, new resins with improved aging behaviour, improved lightning protection, and a 3 boxes structure. In case of damage, the loss in torsional stiffness is limited by this structure, which enhances the blade damage tolerance.

But the application of damage tolerance to helicopters may be hampered by … regulation! Most of the work on damage tolerance has first been dealing with fixed-wings. As a result, the method favoured by the regulation and the Airworthiness Authorities is the crack tolerance concept (a crack is assumed to exist and its propagation is monitored). While well adapted to the fixed-wing component sizes and crack propagation rates, this concept is ill adapted to helicopters. Components are much smaller and the propagation rates much higher because of the high load frequency (up to 1.5 10^6 cycles per hour, to be compared with a few hundreds per hour on a fixed-wing). Application of the crack tolerance concept to helicopters would result either in an unacceptable weight increase resulting from a design for low/no propagation or in asking the operators to dismantle, inspect, and reinstall components with a periodicity generally not exceeding a few tens of hours with the aim of detecting a a few mm long crack which should never appear on the fleet. The hazard to the helicopter flight safety resulting from this heavy maintenance is incommensurate with the expected safety improvement. That is why the helicopter manufacturers developed the flaw tolerance concept: components are substantiated to sustain detectable flaws representative of those likely to be encountered in service and periodically checked to verify they are flaw-free [14]. The inspection intervals are then higher, typically a few hundreds or thousands of hours, and flaws are easier to detect than small cracks. If no damage is found, the part is returned to service for another inspection interval period, up to replacement time if any. Would a damage be found, the part would be scrapped or repaired. This approach is not allowed by present regulation.
Nevertheless a working group including Airworthiness Authorities and Industry representatives proposed in early 2002 a rule for fatigue evaluation of metallic structure which allows either crack growth or flaw tolerance approaches.

More generally, regulation is often driven by fixed-wings and may be not optimum for helicopters. Helicopter manufacturers have to be more pro-active during the early stages of rule making, including the research stage, to ensure that helicopter specificity are taken into account from the beginning.

5.2.2. HUMS

The development of HUMS started in the late eighties as one of the initiatives taken in answer to the growing awareness of helicopter flight safety issues. Convinced of the potential benefits of HUMS, Eurocopter has been the first aircraft manufacturer to develop, commission, and support such systems for its helicopters. It now supports more than 80 systems world-wide, operated by both civilian and military operators. The experience gained on HUMS in more than 150 000 flight hours confirms the monitoring capability of HUMS with its associated benefits on safety [15]. Eurocopter is thus developing HUMS as an option for all its helicopter range. But health monitoring of mechanical components is still a maturing technique and appropriate organisations and procedures are a prerequisite to a HUMS efficient handling. That is why the Eurocopter approach has evolved from a product-oriented to a service-oriented approach. This starts with an assistance to the operator to help him choose the functions/modules the most suited to him and includes support contract to help him analyze the data and determine the most appropriate maintenance actions [16]. More research is required to get the full safety potential of HUMS. This research is presently in progress.

5.3. All weather capability

Helicopter operations are presently limited by bad visibility and by icing conditions. Not to mention the IFR rules, which are well adapted to the fixed-wing aircraft but do not take into account the helicopter specific capabilities like the steep approach and hover ones. That is why Eurocopter launched the All Weather Helicopter program whose objectives are:

- to use new technologies to
  - increase the helicopter ability to fly in adverse meteorological conditions, including icing,
  - allow helicopter operation at night, and
  - increase the safety of low level flights,
- and to propose the necessary evolutions in the helicopter certification and operational rules.

The improvement in flight safety possible with the different appearing technologies was evaluated looking at past accidents. It was concluded that a significant percentage of the accidents with operational cause could have been avoided would

- an accurate Navigation System,
- an Obstacle Warning System (OWS), and
- a Ground Collision Avoidance System

have been available.
Systems like an accurate navigation system including a DGPS, moving maps, 3D displays, an OWS with a Head Up Display, a Ground Collision Avoidance System, and a visibility enhancement system are under development and will be flight-tested. The demonstrator is presently in lay-up for preparation of the first phase of the flight-test campaign.

Research on anti-icing/de-icing systems allowed the development of carbon heating mats, which offer an increased service life compared with the metallic mats. They are used on the NH90 and EC225 anti-icing systems, presently under development. Detecting icing conditions is also of importance. We are therefore looking at new systems allowing long distance detection of icing conditions.

5.4. Survivability

Despite all the past and present efforts, some mishaps will happen. Eurocopter is thus working at minimising the consequences of a crash. Some devices like crash-attenuating landing gears and fuselages, energy-absorbing seats, or crash-resistant fuel systems are already in service. Others like airbag are at the research stage.

5.5. REX improvement

REX being the keystone of our flight safety policy, a dedicated organization has been settled in order to increase its efficiency. People in charge of the analysis of the Major Incidents and of the definition of the conservatory and/or corrective measures have been brought together with those responsible for the maintenance documentation in Operational Groups. Those Operational Groups are hosted by the department in charge of the equipment/ component definition, which ensures the return of experience is taken into account in new designs. In addition quality indicators have been defined in order to closely monitor the efficiency of the process.

6. Conclusion

In many aspects helicopter safety is very similar to that of fixed-wing aircraft:

– After a sharp decline in the past decades, safety records tend to level off.
– Most of the accidents have operational causes.
– Thorough analysis of field feedback is the key to safer products.

But at the same time helicopters are not fixed- but rotary- wing aircraft. Some specificity entail and these specificity have to be taken into account when transposing a fixed-wing experience to helicopters.

Further safety improvements are at the same time more necessary and more difficult than ever. More necessary because accidents are more and more unbearable in a modern society in a permanent quest for an unreachable no risk situation. More difficult because of the maturity level now reached. The helicopter community has thus no solution but to continue making every endeavor to improve the flight safety.

Eurocopter has always been on the leading edge of safety, continuously developing innovative concepts which enhance the safety of its products. Its safety policy, based on a comprehensive analysis of the return on experience combined with a high safety oriented R & D activity, is the best warranty for a further continuous improvement of its safety records.

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