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THE CONTRIBUTION OF THE EH101 TO IMPROVING PUBLIC TRANSPORT HELICOPTER SAFETY LEVELS

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The Contribution of the EH101 to Improving Public Transport Helicopter Safety Levels

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1. Introduction

This paper will consider the basic principles of safety and safety targets, and give an overview and commentary on the airworthiness requirements. It will consider the effect of perception of the market place on helicopter safety levels, and present a view of achieved safety levels and the effect of the operational environment.

This paper will also explore special problems faced by helicopters, how this affects overall safety, and how the helicopter industry is addressing these issues. Finally, the paper will examine the benefits of modern design principles and safety analysis techniques as applied in the EH101 on the probable future safety record of the helicopter.

2. General Observations on Helicopter Safety

Safety targets for aircraft design are enshrined in civil airworthiness requirements but are furthermore subject to public perception of achievement and need. For a design to be commercially successful both regulatory and public perception aspects of safety must be satisfied. The Airworthiness Authorities must be satisfied that the design meets their Requirements and therefore may be granted a Type Certificate, while the travelling public must feel that the design is safe for their use. It should be noted that for both aspects, not only must the aircraft design be considered, but the type of operation envisaged must also be taken into account. In the case of public perception not only those travelling within the aircraft are affected but also all those coming into contact with the aircraft during its operation.

The challenge of improving the technical contribution to safety within the constraints of weight, paramount on the vertical flight machine, is by no means small. Nevertheless the challenge must be accepted and the battle won.

2.1 The Public Viewpoint

It has been stated that the general public and the traveller presently perceive the fixed wing airliner to operate within an acceptable level of safety. Unhappily the same is not true of rotorcraft and this failing is probably largely responsible for the low level of success of the true public transport helicopter.

There are a number of reasons for this view:

1. The true public transport rotorcraft (ie: one used for regular scheduled passenger services) is still something of a rarity and, consequently, subject to suspicion and scepticism.

2. Relatively few people have actually travelled in a helicopter, compared with the countless thousands who travel with fixed wing airlines.

3. The machines appear noisy and intrusive and their appearance is not likely to excite or endear itself to the onlooker. (They look relatively fragile).

4. The degree of mechanical complexity may be worrying to the layman.

5. The passenger may be disconcerted by the vibration level and put off the experience by high noise levels.

The helicopter does not perform well in winning friends!

From this worsening position of perception, the public are presented with a variety of statistics on the safety of helicopter flying. Here again, the rarity issue has an effect. The statistical database for helicopters is much smaller than for fixed-wing aircraft. It is also normal practice for accident rates to be quoted per flying hour; this approach tends to favour the fixed-wing machine, with its long flight stage durations. With the short flight duration of the helicopter, a larger proportion of its flight time is spent in the critical phases of take-off and landing. Proponents of helicopter safety often argue that statistics should be presented on a "per flight" basis rather than "per hour". This might well show the helicopter in a better light, but it is not done and there are at present no criteria using this base.

However, from the public viewpoint it is enough to say that adverse statistics do exist, and much use is made of them, usually following a newsworthy accident.

2.2 The Regulatory Aspect

Airworthiness design regulations and operating standards are aimed towards establishing an acceptable balance between the severity of an effect and the likelihood of its occurrence. The principle is well known, and is illustrated diagrammatically in figure 1. It can be seen that frequent events should only result in Minor effects, whereas any event likely to be Catastrophic must be Extremely Remote.

Perhaps at this point it would be useful to examine the method by which the rotorcraft requirements evolved.

In the beginning, the authorities examined their historical records and determined that the probability of a Catastrophe for large fixed-wing aircraft was approximately once in every million flying hours, or 1×10^{-6}/hour. (Fixed-wing aircraft were initially chosen to be examined because there was more information available on this class). By a closer examination of the data, it was noted that about 10% of the

Catastrophes were caused by aircraft system failures.

Logically, then, for a newly-designed aircraft to be no worse than existing aircraft, the probability of an aircraft Catastrophe from all system causes should be not greater than 1 x 10^{-7}/hour. (Extremely Remote). In order to provide a workable probability target, the authorities assumed, arbitrarily, that there were 100 potential aircraft Failure Conditions that could cause a Catastrophe.

The result, if the allowable risk is apportioned equally amongst the Failure Conditions, is a probability for a Catastrophic Failure Condition that should be no greater than 1 x 10^{-9}/hour (Extremely Improbable). So much for the fixed-wing sector.

The view was taken that, for rotorcraft, target probabilities should be no different to fixed-wing targets. However, it was soon recognised that the attainment of fixed-wing levels of safety was limited by the state of the art on the design of a rotorcraft's "extra systems", principally the rotors and transmissions.

BCAR Paper G780 was the first paper to recognise that the attainment on these systems of probability levels less than Very Remote (numerically from 1 x 10^{-6}/hour to 1 x 10^{-7}/hour) was unlikely.

In consequence, the Safety Objectives for rotor and transmission systems are less severe than for other systems, and are one order of magnitude lower (ie: each Failure Condition must be shown to be less probable than 1 x 10^{-8}/hour, or, all Failure Conditions taken together must be no more probable than Very Remote).

This approach is currently reflected by those requirements which address safety assessment, eg BCAR 29.917, and it is recognised by FAR 29, which does not apply 29.1309 to these systems. There is, as yet, no officially released JAR 29, although it will be in place by the end of 1992, and will broadly follow the philosophy adopted by FAR.

3.0 The Problem with Helicopters

In establishing Safety Objectives for rotorcraft and their systems, it was decided by the Airworthiness Authorities that the overall Safety Objectives should be no different to those imposed for fixed-wing aircraft. This is obviously a reasonable expectation, as passengers transferring from one public transport aircraft type to another (from a long-haul airliner to a short-haul helicopter, for example) have every reason to expect a comparable level of protection. Similarly, a non-flying member of the public has every reason to expect comparable levels of protection from different types of public transport aircraft crash-landing in his/her back garden ! However, this approach presents the helicopter industry with a considerable challenge, which will be expanded upon later.

Another reasonable assumption to make in setting Safety Objectives for individual system Failure Conditions is that they be the same for both fixed and rotary-winged aircraft. After all, it could be argued that one aircraft system (a hydraulic system, for example) is pretty much the same whether installed in either an aeroplane or a helicopter.

This cannot be true, for the following reasons:

Helicopters have a number of unique properties when compared to fixed-wing aircraft, which can affect their overall safety and, in consequence their Safety Objectives. (See figure 2)

The first two items on the list are the obvious differences between the helicopter and any other aircraft, and draw attention to the fact that helicopters really are "flying machines", but these items do not have a great impact on the Safety Analysis process. The reason for this is that, for the most part, the highest severity of Failure Condition is associated with the relatively "normal" take-off/landing and cruise conditions.

The third item, vibration, makes a big difference. Inherent in the design of any helicopter is the potential for generating vibration. This is primarily due to the lift loading on a main rotor blade altering considerably as it passes through the advancing or retreating areas of the rotor disc.

The magnitude of the vibration is dependant upon a number of factors, such as speed and all-up weight, but it is fair to say that the vibration environment of the average helicopter is both much more severe and more variable than a comparable fixed-wing aircraft.

The reliability of system components will thus vary according to whether they are installed on a helicopter or an aeroplane. The American MIL-HDBK-217 recognises this, and assigns adjustment factors for application to reliability data. These factors vary, depending on whether the data is being applied to helicopters or not, and also what type of system is under consideration. Evidently, some systems are more susceptible to vibration than others. For information, the MIL-HDBK adjustment factors vary between zero and 50, so the effect can be significant. The net result of all this is that a component designed for use in a fixed-wing aircraft may not be sufficiently reliable for a helicopter, such that redesign of the system, or specification of more reliable components may be necessary. This will, of course, result in higher costs.

The fundamental nature of the helicopter means that it can operate from confined spaces where the provision of extended runways is impractical. Such sites include heliports on roof tops and on oil rigs. Not only must such sites be more difficult to operate from than the less confined airport, in their own right, but it seems that they are often surrounded by additional hazards. The city heliport (roof-top or at surface level) is surrounded by buildings and a dense surface population, and the oil rig is often located in extremely remote ocean areas with no convenient safe diversion site. These operating issues cannot be influenced by the aircraft designer - they are the market created by the particular abilities of his product. He can, however, bear them in mind in the design of his aircraft in an attempt to alleviate the effects.

From the Safety Analysis point of view, these distinctive operational capabilities will have the effect of increasing the severity of certain Failure Conditions in the Hazard Assessment, and thus, quite correctly, resulting in higher Safety Objectives.

Helicopters are, on the whole, much smaller aircraft than the average public transport airliner. Indirectly, this also has an effect on safety. It is a fact of life that the rotary-wing operators are smaller concerns and operate where economics are the essence of survival. This position is not helped by the fundamental nature of the helicopter. Maintenance is more critical because of their mechanical complexity. Once the rotary-wing aircraft becomes a really effective public transport device with dedicated market sectors, this position may change, but it will be some time coming.

The smaller overall capacity of helicopters in the public transport category has one direct effect on statistical safety levels, as opposed to the theoretical safety levels derived by the Safety Analysis process. This effect is an obvious but unsavoury one, which few like to think about, and the current safety requirements take only the most rudimentary notice of. It is that smaller aircraft carry less people, and if these aircraft have the same theoretical safety levels as the larger aircraft, then the statistical level of safety provided to the individual passenger is actually greater than for the large aircraft. Obviously, this is a simplistic view, but worthy of consideration, at least. This type of approach has actually been gaining more ground in recent years. (Some oil companies are examining the risk to their individual workers on each trip that they take to the oil rigs where they work. This evaluation takes in ALL forms of transport along the route, and, using this approach, different types of transport are compared on a "per trip" basis.)

The next point is included because the general public still believes that helicopters cannot "glide" because they have no wings. Mother Nature doesn't care about the general public, of course, and has been producing billions of sycamore seeds that fall gently to earth by autorotation for quite some time now! In this respect, helicopters have a distinct advantage over fixed-wing aircraft, as all flight-critical systems are normally powered by the main rotor gearbox. They can consequently carry out a power-off landing at a wide variety of small sites, such that total engine power failure is rarely catastrophic. However, this capability is not widely appreciated, and this affects the perceived safety level.

Due to the peculiar capabilities of helicopters, they do get used for some very odd operations at times, which could not be achieved by any other aircraft.

(For example, the Canadians regularly use helicopters in logging operations. The effect of this type of operation is difficult to quantify, and usually leads to large safety factors being imposed, with consequently severe life limitations.)

The last item on the list is another one that has a great effect on the helicopter's statistical (and actual) safety. Helicopters have extra systems when compared to fixed-wing aircraft. Principally, these are associated with the rotors and transmission, but there are other examples where much higher levels of integrity and/or capability are required. The Automatic Flight Control System (AFCS) is a good example of this.

4.0 Helicopters and Safety Objectives

In this section the effect of these peculiar characteristics on helicopter safety objectives will be examined, and an effort will be made to identify those systems that can be the most significant in terms of their contribution towards improving safety.

4.1 A Comparison with Fixed-Wing Safety Levels

As noted in paragraphs 2 and 3 above, there are problems in trying to compare fixed-wing and rotary-wing safety levels on a one-for-one basis. There are even good reasons why this may provide a false picture of true helicopter safety. However, the temptation is there, and even the Airworthiness Authorities fall foul of it, since there is now a stated aim to bring helicopter safety levels up to the "acceptable" fixed-wing standard.

There are a number of problems with this laudable aim. The first of these is that of determining the safety level achieved by "current" helicopters. A significant proportion of helicopters in service today are either ex-military, derived from military designs, or being used in unrepresentative conditions for direct comparison with fixed-wing aircraft. Therefore these aircraft have not been designed with solely the civil market in mind, and do not provide the optimum method of meeting civil requirements. Furthermore, the vast majority have not been subjected to formal safety analysis techniques, whereas a significant proportion of civil fixed-wing aircraft have been. In consequence, the safety levels of civil helicopters are lagging behind those of fixed-wing aircraft, and will continue to do so for some time, due to the continuing effect upon the safety data of the base of older helicopters. This is particularly true in a period of economic recession, when investment in new, sophisticated, safer but more expensive products will tend to be slowed down, and a tendency to retain old but serviceable helicopters will predominate.

The other main problem with this eagerness to compare helicopters with fixed-wing aircraft is that the natural desire to improve matters as quickly as possible may be attenuated due to the relatively small effect of any newly-introduced helicopters on the statistical database of existing types.

4.2 Rotorcraft Safety Levels

A first step in trying to assess the effect of any new helicopter on existing safety levels is to try and establish the existing safety levels. For this purpose, ref 1 was used. However, this document shows up one of the problems with trying to use statistical data relating to helicopter accidents, and this is that the sample size is too small. Looking at the total and fatal accident rates for UK helicopters above 2300Kg given in ref 1, we can observe that the accident rates from year to year vary considerably due to the (thankfully) small numbers involved. A brief look at the raw accident data behind these figures reveals that only one accident in the ten year period covered was both fatal and caused by Airworthiness (ie: technically attributable) shortfalls.

To show the shortfalls caused by the small database, it could be pointed out that, using ref 1 (which only covers 1.2 million flying hours in the 10 year period covered for rotorcraft over 2300kg), an Airworthiness Fatal accident rate of 8.9×10^{-7} per hour has already been shown. However, as this is based on only one event, the result is very questionable.

What this shows is the need for a greater sample size, and the one used (ref 2) covers a much wider range. World wide helicopter accidents, but unfortunately to a different weight category, ie: over 4550 Kg. However, it is probably the best source to try and determine the cause categories for helicopter accidents, and this is the use to which it was put. An examination of the data covering accident over the same ten year period as the accident rates extracted from ref 1 showed some interesting results. These are admittedly derived using subjective engineering judgement, due to the frequently sparse information provided on each accident. Nevertheless, it shows, in figure 3, that of the much larger sample size (251 accidents), some 47% could be said to be Airworthiness-caused, while Operational (ie: non-Airworthiness) and Unknown causes accounted for the remaining 53%.

It must be pointed out that even this sample size, although much larger than that to be found in ref 1, is still small enough to give rise to concerns about the validity of any mathematical conclusions drawn from it. However, it's all there is for civil helicopters in this size, so it will have to do.

A more extensive perusal of the data for Airworthiness accidents allowed the causal systems to be identified, although sometimes in only the broadest terms. The results of this analysis are shown in figure 4.

5.0 How to Improve Matters

The division of causal factors shown in figure 4 was a little surprising. However, it shows that substantial improvements in safety can be achieved by targeting certain specific systems/areas for improvement. For example, it can be seen that the engine, transmission and systems areas account for 82% of total airworthiness accidents, and for 80% of fatal airworthiness accidents. In consequence, improvements in these areas will result in the greatest improvements in safety of the aircraft as a whole.

Let us now look at each of these areas in turn, and see how the design of the EH101 helicopter has been optimised to bring about valuable improvements in safety, while still remaining a commercially viable aircraft.

In the following evaluations, an assessment was made of the causes of the particular accidents, their relevance to EH101 anticipated operations, and any EH101 design features that could have a positive effect. When no improvement could be foreseen, no benefit was claimed.

5.1 Engine Systems (See Figure 5)

The proportion of accidents revealed to have engine-related causes would no doubt not be agreed with by the engine manufacturers, and with good reason. The reason that this proportion is so much higher than that expected by common knowledge, is that, during the analysis of accident causes, it was noted that, although engine failures per se were not primary causes of accidents, they were secondary ones. For example, it was noted that a significant number of accident scenarios began with an engine failure or power loss. This did not immediately cause an accident, but began a chain of events that culminated in one. Frequently, following the engine failure or power loss, the helicopter experienced some other failure, or event (such as so-called pilot error) that did lead to aircraft loss or damage. The sequence of events thus became:

Power Loss -> Forced Landing -> Accident

Logically, had the engine failure or power loss not occurred, or had the results of such failure been attenuated, the subsequent accident might well have been avoided. This could only happen where sufficiently large power reserves exist, such that the effects of power failure can be effectively mitigated.

From this point of view, the EH101 is unique in modern civil rotorcraft in providing 3 engines, with virtually unrivalled power reserves. This approach would obviously not be valid in all cases. However, from an evaluation of the raw data, and a comparison of detailed accident causes with EH101 design features, it is believed that an improvement of the order of 86% over current generation rotorcraft will be achieved.

5.2 Transmission Systems (See Figure 6)

The largest proportion of failures associated with the transmission systems are shaft or gear tooth failures. The majority of these types of failures would be detected in good time by the use of Health and Usage Monitoring (HUM) systems. From a survey of those accidents reported upon in ref 2, and a comparison with the EH101 HUM capabilities, it was determined that 90% of fatal transmission accident causes should have been detected in sufficient time.

Another very common failure in ref 2 was loss of lubrication to the transmission. On EH101 the probability of this event has been reduced by the incorporation of dual independent oil systems, incorporating no external oil pipes and a dry running capability, allowing more time for appropriate action.

One other factor, which will have an effect on the integrity of the entire aircraft, but which is virtually unquantifiable, is the incorporation of ACSR (Active Control of Structural Response) into the EH101. This is an active vibration cancelling system, illustrated in figure 7. All the systems on the aircraft will benefit from the smoother ride given to them, but no credit is at present being claimed for this, even though its effect will be seen in the longer term.

Taking all of these factors into account, it is believed that an improvement of around 90% on fatal transmission-related accident rates will be achieved, and about 78% on all transmission-related accidents.

5.3 Main Rotor (See Figure 8)

Here the main accident causes associated with the Main Rotor were either detachment of the rotor blade, or failure of the blade itself. An additional failure that was sometimes present was bearing failure, although the instances of this leading to actual accidents was relatively rare.

In this respect we are benefiting from the onward march of technology, and the improvement in design and materials over the last decade or so. For the most part, this means the introduction of elastomeric bearings and composite materials, making possible dynamic components with multiple load paths and "graceful" failure characteristics. However, on the EH101 this has been augmented by careful design, which provides a multiple load path from the blade itself, through its attachment to the main rotor head tension link, via this to the main rotor head itself, with its dual load paths. These details, allied to composite materials' good resistance to impact damage, will, we believe, produce an improvement in safety of around 70%.

5.4 Flying Controls

The next most significant contributor is the flying control system, which largely tends to manifest itself by failure of flying control hydraulic power, or loss of tail rotor control (see figure 9). Both of these can be brought about by failure of the relevant hydraulic circuits, but loss of tail rotor control is usually the result of failure in the control runs to the tail servo.

Attention has been paid to both of these prime causes on the EH101 by the exclusive use of control rods in the controls (no cables are used), joined together by means of self-retaining bolts and double-lock nuts and the addition of a third hydraulic system, whose power can be switched in flight to the flying controls in the event of failure of one or more of the primary systems. In all of these systems, the hydraulic power supplies are integrated (ie: reservoir and pump in one unit), thus avoiding any potential leaks from hydraulic unions in this area. In addition, the main servos will survive jamming of their main control valve, without pilot action, although cockpit indication of valve jam is provided.

From a careful examination of accident data over a ten-year period (from 1981-1990), it is believed that in improvement of the order of 62% over current accident rates in this area will result.

5.5 Other Areas

At this point in the analysis, the small sample size is becoming a factor, and it is difficult to draw accurate conclusions regarding the causal factors for each of the remaining areas. However, for the following areas, some tentative conclusions can be drawn (see figure 10):

Tail rotor – the causal factors were fairly varied, but mostly involved either loss of the entire tail rotor, or part of it. For the EH101, benefits of the order of 50% improvement over current designs are expected due to the composite tail rotor design, with its improved failure characteristics, and the use of elastomeric bearings. Another factor that should be taken into account is that high reserves of tail rotor thrust are the result of the Navy operational requirements for operation from small ship decks.

Landing Gear – Several instances were noted of structural failure of the landing gear, usually due to higher than expected rates of descent on landing, but there were also two instances of inadvertent retraction. Both of these types of failure should be very much less likely to occur on EH101, due to the high descent rate capable undercarriage (12 ft/sec), and the provision of a safty interlock preventing undercarriage retraction while weight is carried on the wheels.

Structure – Also covered under this section are structural events, which, on the whole do not result in accidents. The only significant events related to structure that have caused accidents have been associated with the loss of fairings in flight, an eventuality that is now covered by BCAR/FAR requirements (fairing hinge pin retainment).

True structural failures do not seem to follow set patterns, and this is not too surprising, due to the small sample size, and the fact that structure is specific to type, thus cutting down still further the potential sample size. Nevertheless, some improvement over existing rotorcraft is expected for the EH101, due to the ruggedness of the structure (it having been designed to crash factors considerably in excess of previous civil requirements), and its multiple load path design.

From an evaluation of the admittedly limited acident data available in ref 1, it is believed that an improvement of 56% over existing accident rates attributable to this area is not unrealistic.

Electrics – Once again, data here is very sparse, and details few to nonexistent. In consequence, no detailed remarks concerning the basis upon which the EH101 is expected to be better can be made. Nevertheless, credit for the high level of integrity and redundancy of the electrical generation system has been claimed, by the assumption that a modest improvement of 50% over existing type would be reasonable. In any case, as mentioned at the top of this paragraph, the proportion of the total accident rate attributable to these areas is small, and so the effect of any claimed improvements is also likely to be small.

Maintenance - The proportion of accidents directly caused by a maintenance error is very small, but this area is included here as significant advances in technology have resulted in more complex aircraft with a higher degree of maintenance requirements. In direct consequence, methods and techniques for the analysis of maintenance, intended to both ease maintenance tasks and direct them towards safety dependent areas, have evolved. These types of analysis (MSG-3 analysis, Zonal Safety Analysis, and Logistic Support Analysis, for example) are fully implemented on EH101, and are expected to yield significant safety benefits, of the order of 75% over existing types.

6.0 Results of the Analysis

6.1 Airworthiness Accident Rates

The expected effect of the above analysis can be gathered together to form an impression of the extent of improvement in Airworthiness related accident rates that future users can expect from the EH101. This has been carried out in figure 11.

As can be seen in this figure, by assessing the individual predicted improvement in each of the areas identified in the analysis, and taking into account the proportion of the total accident rate that each area occupies, an estimate of the overall benefit can be made.

It can be seen that, for Airworthiness accidents, an improvement of the order of 76% for total rates, and 77% for fatal rates is predicted. To put it another way, an improvement factor of 4 to 5 is expected for total airworthiness accident rates, and a similar improvement factor for fatal airworthiness rates.

6.2 Total Accident Rates

In order to be able to make a assessment of the effect of the EH101 on total accident rates, (ie: not just Airworthiness rates) we have to make an assumption about the improvement in the rates of those accidents described as being of either "Operational" or "Unknown" cause.

For these accidents, it was assumed that these types have causal factors like any others, but are just not necessarily known about. Some 25% to 30% of these took place in conditions that are not applicable to EH101, and a similar proportion could probably have been avoided by some factor of the EH101 design (better power margins, landing gear closer to the pilot, high tail rotor, high descent rate undercarriage, wheels not skids, etc.). However, to be pessimistic, an improvement of only 65% was assumed (see figure 12). This compares with a predicted improvement of 75% to 77% for Airworthiness accident rates, so it is not overly optimistic.

These assumptions can now be input into the figures to provide a final overall expected improvement. As can be seen in figure 13, the final estimated improvement for the EH101 is of the order of 70% over existing helicopter types in the larger weight category (over 4550Kg).

7.0 Conclusions

At present, using the existing historical accident database, which evaluates accident rates on a "per hour" basis, the helicopter displays lower safety levels than large fixed-wing aircraft. This paper has explained why we believe the basis for comparison is of dubious validity, and why the rotorcraft is currently limited by its technology.

Nevertheless, examples have been given of feasible avenues of exploration for significant improvements in safety levels in all the safety-critical areas. This demonstrates that the helicopter industry is by no means complacent, and is actively engaged in researching methods of improving both its actual and its perceived safety record.

The type of analysis engaged upon in this paper is obviously open to many different interpretations. Likewise, it is dangerous to make predictions involving accident levels, as these can be misinterpreted to show that industry is complacent and is being "allowed" to be be. This is not the case. This paper has tried to show that, within the constraints of competitiveness and cost, industry is making vigorous efforts to improve the helicopter's safety record. The production of the EH101 is a major step forward in this respect.

References:

1. "Reportable Accidents to UK Registered Aircraft, and to Foreign Registered Aircraft in UK Airspace, 1990." - CAP 600 - Civil Aviation Authority

2. "World Helicopter Accident Summary" - CAP 457 - Civil Aviation Authority

3. "Systematic Safety" - E. Lloyd and W. Tye

FIGURES

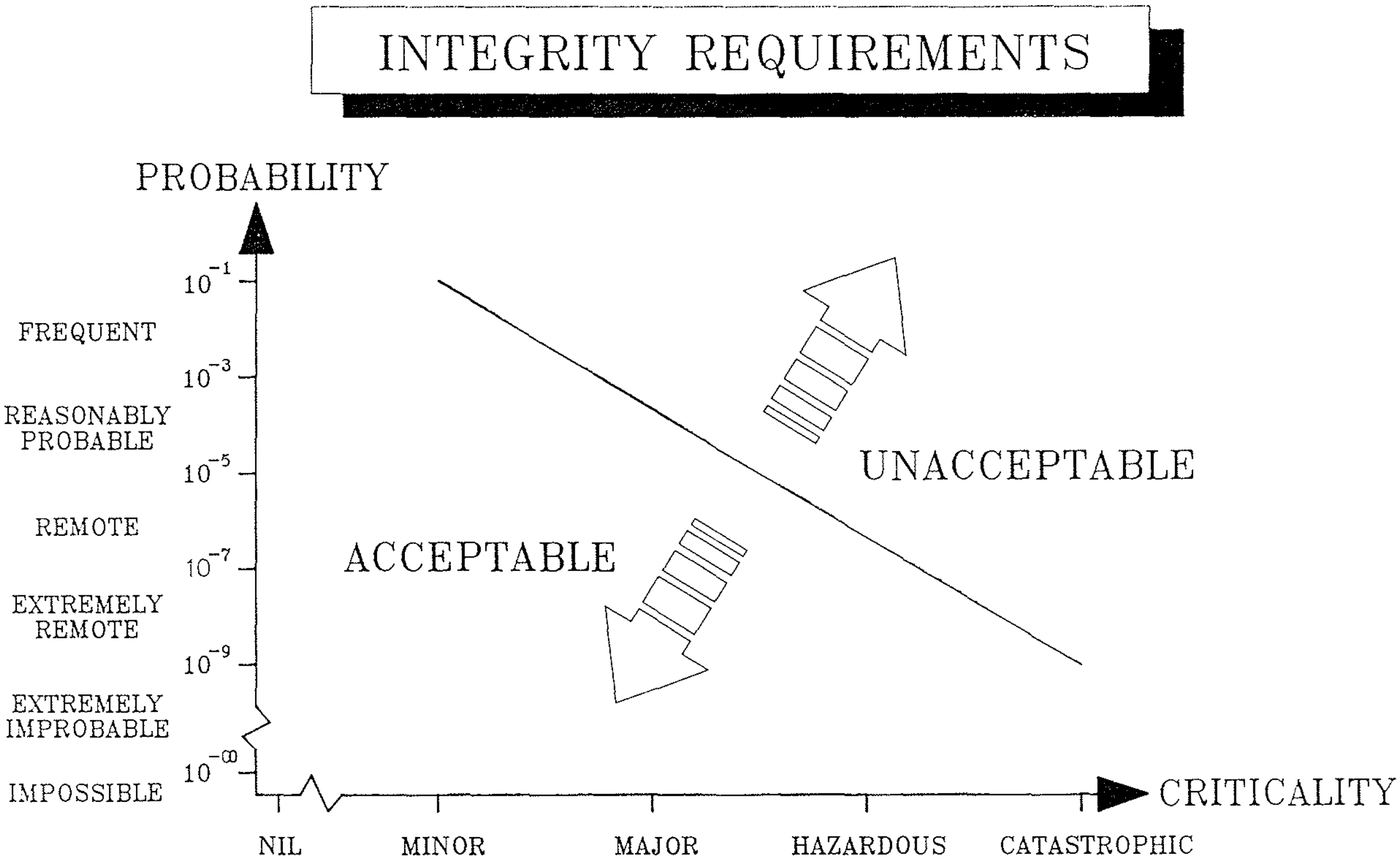

INTEGRITY REQUIREMENTS
PROBABILITY
10^{-1}
FREQUENT
10^{-3}
REASONABLY PROBABLE
10^{-5}
REMOTE
10^{-7}
EXTREMELY REMOTE
10^{-9}
EXTREMELY IMPROBABLE
$10^{-\infty}$
IMPOSSIBLE
UNACCEPTABLE
ACCEPTABLE
CRITICALITY
NIL
MINOR
MAJOR
HAZARDOUS
CATASTROPHIC

Figure 1

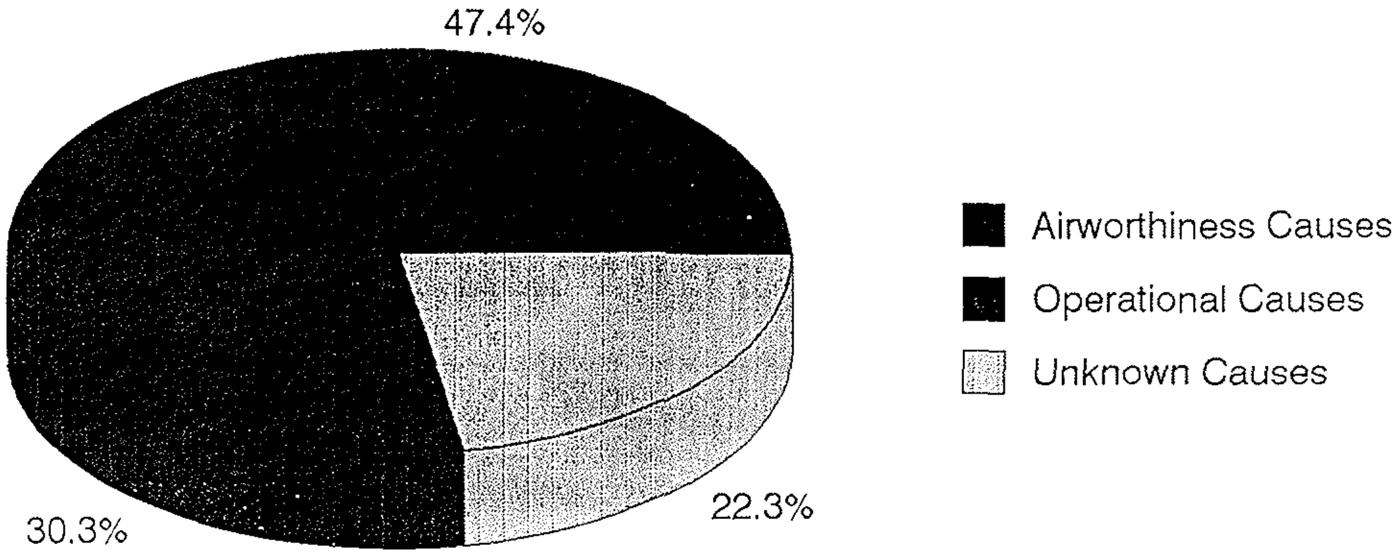
The Properties of Helicopters

1. They fly in any direction (not just forwards)
2. They fly at any speed (from 0 knots to V_{NE})
3. They vibrate (inherent in the design)
4. They operate in restricted environments
5. They're smaller (on the whole)
6. They CAN glide (autorotate) safely
7. They can be used for unconventional operations
8. They have extra systems

Figure 2

Distribution of Total Accident Causes

World-Wide Helicopter Fleet 1981 - 1990
(Helicopters over 4550Kg MTWA)



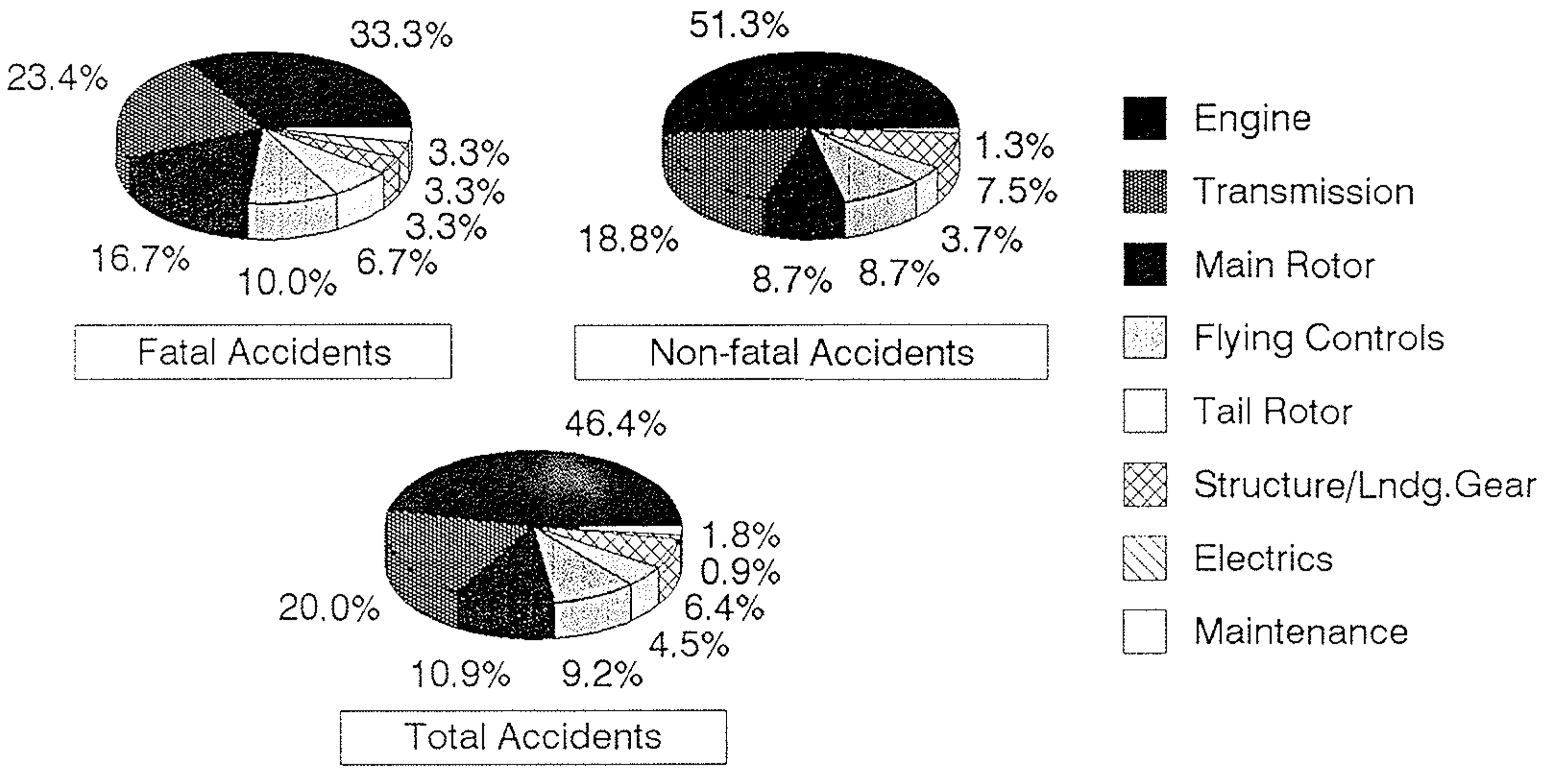
Ref: CAA World Helicopter Accident Summary

Figure 3

Distribution of Airworthiness Accident Causes

World-Wide Helicopter Fleet 1981 - 1990

(Helicopters over 4550Kg MTWA)



Unknown/Operational causes not included.
Ref: CAA World Helicopter Accident Summary (CAP 479)

Figure 4

Examination of Helicopter Accident Causes

World-Wide Helicopter Fleet 1981 - 1990

1. Engine

Failure Mode	Result	Compensating EH101 Provision
Loss of Power	Insufficient power to continue level flight. Forced landing required.	3 engined rotorcraft. Good power margins. Fuel system with twin boost pumps per tank, crossfeed capabilities, crashproof tanks. Well proven, reliable engine used (GE CT-7).
Engine Disk Burst	As above, plus collateral damage. Possible loss of other engines or systems. Forced landing required.	As above, plus: engines widely spaced, and positioned to minimise effects of disk burst.

Figure 5

Examination of Helicopter Accident Causes

World-Wide Helicopter Fleet 1981 - 1990

2. Transmission

Failure Mode	Compensating EH101 Provision
Shaft Failure Gear Tooth Failure	Majority detectable by HUM system in good time.
Lubrication Failure	Dual independent oil systems. Low oil contents indication in cockpit. No external (and vulnerable) oil pipes. Dry running capability of gearbox.
Others (Main Rotor Shaft)	Upper gearbox mounting strut attachments and main thrust bearing are located above the level of the main epicyclic ring gear, to cope with gross gearbox failure.
(Bearing Failure)	All gears straddle-mounted with bearings.

Figure 6

ACSR ACTUATOR INSTALLATION FOR EH101

E6726-10

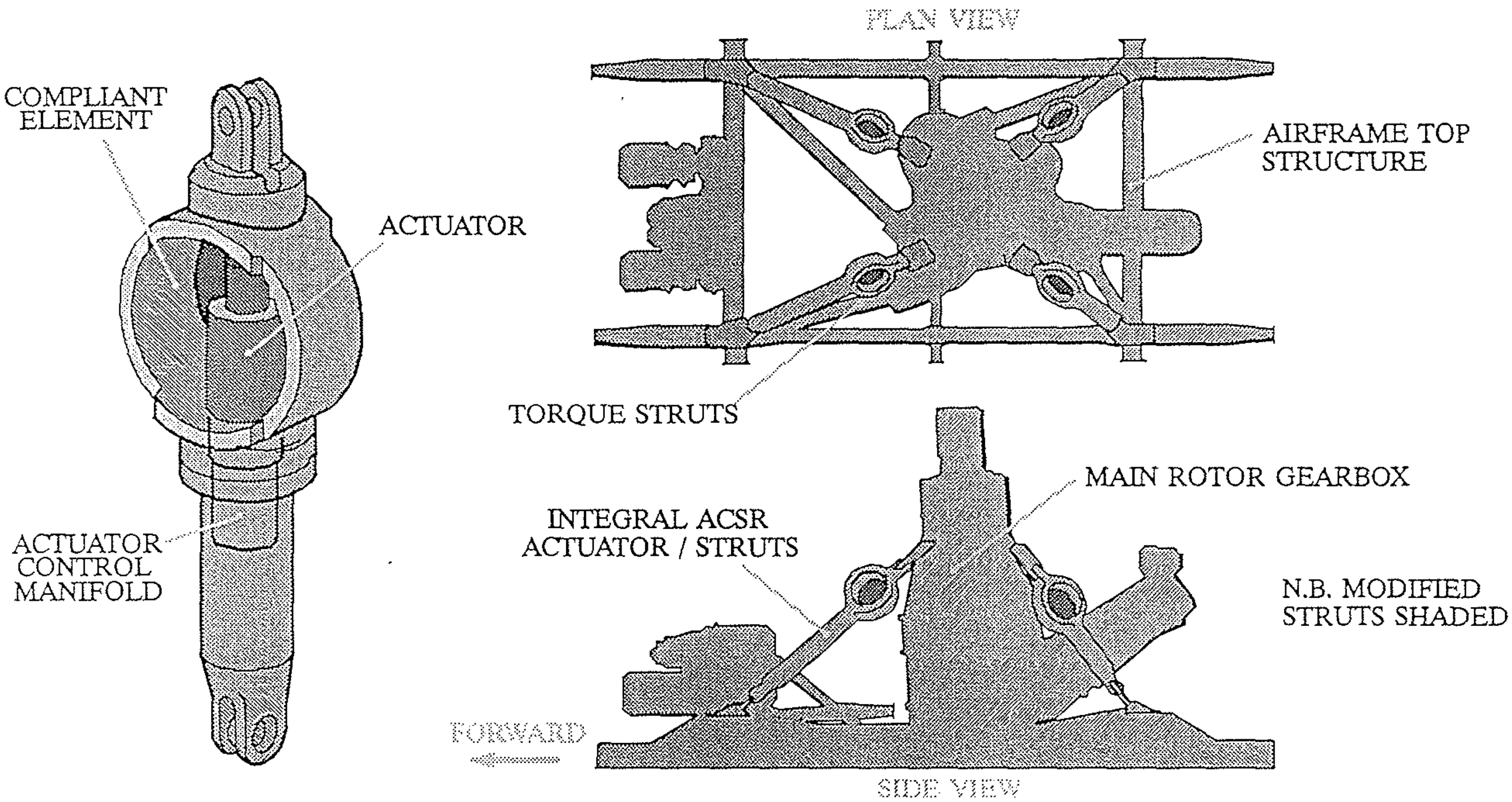


Figure 7

Examination of Helicopter Accident Causes

World-Wide Helicopter Fleet 1981 - 1990

3. Main Rotor

Failure Mode	Compensating EH101 Provision
Blade Detachment	Dual Load Path Main Rotor Head. Dual load path main rotor blade attachment pins. Composite Main Rotor Head (Graceful failure characteristics)
Blade Failure	Composite main rotor blade, tolerant to impact damage,
Bearing Wear	Elastomeric bearing design.

Figure 8

Examination of Helicopter Accident Causes

World-Wide Helicopter Fleet 1981 - 1990

4. Flying Controls

Failure Mode	Compensating EH101 Provision
Hydraulic System Loss	Duplex hydraulic circuits, even to tail rotor servo, and ability to use No 3 system after loss of primary circuits. Integrated Hydraulic Power Supplies, no separate pumps/reservoirs. Main and tail rotor servos will survive jamming of main control valve without pilot action. Indication of jammed valve given to crew.
Loss of Tail Rotor Control	Duplex hydraulics to tail servo. No cables in tail servo control run, composite rods used instead. Joints in control runs use double-locked self-retaining bolts.

Figure 9

Examination of Helicopter Accident Causes

World-Wide Helicopter Fleet 1981 - 1990

5. Other Areas

Failure Mode	Compensating EH101 Provision
a. Varied, involving loss of tail rotor assembly, and/or gearbox or blades.	Unable to make positive statement, due to small sample size in this category of failure cause. Some benefit expected due to robust tail rotor necessary for high thrust levels required for naval operations, and from composite blade design with elastomeric bearings.
b. Fairing detaches, hits tail or main rotor.	Higher integrity of attachment now required by BCAR/FAR.
Undercarriage collapse	12 Ft/sec capability undercarriage. Inadvertent retraction impossible due safety interlock.
Varied structural failures	Improvement expected due to rugged structure with multiple load paths and damage tolerant principles of structural design.
c. Unspecified Electrical	No positive statement possible due to lack of information. Improvement expected over existing aircraft due to high redundancy given by two independent main generators, plus essential services standby generator on APU.
d. Maintenance Error leading to system failure.	Benefit is expected due to provision of maintenance log on HUM system, and varied analysis techniques, eg: MSG-3 Analysis, Zonal Safety Analysis, Logistic Support Analysis.

Figure 10

Helicopter Airworthiness Accident Breakdown

Area/Category	Total			Fatal		
	Historical Proportion	Predicted Improvement	Aircraft Levels	Historical Proportion	Predicted Improvement	Aircraft Levels
Engine	46.4%	86%	39.9	33.3%	87%	28.97
Transmission	20.0%	78%	15.6	23.4%	90%	21.06
Main Rotor	10.9%	70%	7.63	16.7%	70%	11.69
Flying Controls	9.2%	62%	5.7	10.0%	62%	6.2
Tail Rotor	4.5%	50%	2.25	6.7%	50%	3.35
Structure/Landing Gear	6.3%	56%	2.78	3.3%	62%	1.46
Electrics	0.9%	50%	0.45	3.3%	50%	1.65
Maintenance	1.8%	75%	1.35	3.3%	75%	2.48
Airworthiness Percentage	100%	--	76%	100%	--	77%

Figure 11

Examination of Helicopter Accident Causes
World-Wide Helicopter Fleet 1981 - 1990

Failure Mode	Compensating EH101 Provision
Operational Issues	Some operational conditions not applicable to EH101 (25%) Others could be avoided with greater power margins (25%), or by some aspect of EH101 design (eg: good cockpit visibility, landing gear close to pilot, high tail rotor, compact main rotor for a/c size, wheels not skids, high descent rate undercarriage, etc.) 65% improvement assumed.

Failure Mode	Compensating EH101 Provision
Unknown Issues	Similar improvement assumed as for operational causes. 65% improvement assumed.

Figure 12

Estimation of Helicopter Accident Rates

EH101 Related Improvement Percentage

Accident Causes	Total Accidents		Fatal Accidents	
	Improvement	Contribution	Improvement	Contribution
Airworthiness (47.4%)	76%	36.0%	77%	36.5%
Operational (30.3%)	65%	19.7%	65%	19.7%
Unknown (22.3%)	65%	14.5%	65%	14.5%
Final Total	--	70.2%	--	70.7%

Figure 13