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# NH90 QUALIFICATION ACCORDING TO DAMAGE TOLERANCE

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**Key words**: ERF32[1], helicopter, rotorcraft, NH90, Damage Tolerance, SARIB, Spheriflex

**Abstract:** The NH90 is the first military helicopter in the world to be qualified in accordance with the FAR 29.571, Amendment 31, including Damage Tolerance requirements.
The term "Damage Tolerance" means here Fatigue Tolerance considering the effects of both fatigue and expected damages, as described below.

For all Principal Structural Elements[2], Authority approved Retirement Times and repetitive Inspection Intervals are included in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness.
Retirement Times are based on the conventional “Safe Life” concept and repetitive Inspection Intervals are established by applying one of the three available Damage Tolerance concepts: “Flaw Tolerance”, “Crack Tolerance”, or “Multiple Load Path”.

The advantage of this pragmatic approach is that repetitive Inspection Intervals, formally based on in-service experience, are now substantiated through full-scale tests and/or analysis. A significant improvement over what exists today, indeed.

This paper presents the necessary research program as it was undertaken by Eurocopter to deal with these new concepts. Examples of PSE qualification are provided.

It is concluded that Damage Tolerance approach is viable and that its application should contribute to the enhancement of helicopter flight safety.

## 1 INTRODUCTION

The new generation military helicopter NH90 is qualified in accordance with FAR 29, Amendment 31. As such, the NH90 complies with FAR 29.571 “Fatigue Evaluation of Structure” as introduced by Amendment 28. A safety analysis was conducted to identify all PSEs and these parts where then qualified by applying one of three available Damage Tolerance concepts: “Flaw Tolerance”, “Crack Tolerance”, or “Multiple Load Path”.

[1] This paper is presented at the 32nd European Rotorcraft Forum, Maastricht, Netherlands, September 2006
[2] Principal Structural Elements (PSE) are structural elements that contribute significantly to the carrying of flight or ground loads and whose failure due to fatigue can lead to the catastrophic failure of the helicopter.

In 2005 the NH90 has thus become the first helicopter in the world to be qualified according to these new Damage Tolerance requirements.

First of all NH90 helicopter is presented in the following chapter. Afterwards Damage Tolerance concept is explained briefly. The approved methodology used for the NH90 qualification according to Damage Tolerance is described subsequently. The necessary research program undertook by Eurocopter to support this methodology, is provided. Then examples are given to show the qualification of the dynamic components. At last, the influence on the accident rate of the application of Damage Tolerance regulation is discussed. After all, it is concluded that Damage Tolerance approach is viable and should contribute to the enhancement of flight safety of helicopters.

## 2 PRESENTATION OF THE NH90

The NH90 is a new generation military, medium class, helicopter (MTOW[3] 10,600 kg[4]) and is operated by a single pilot and a crew of 2. It is a twin-engine helicopter, equipped with Roll-Royce/Turboméca/MTU RTM322 or General Electric GE T700 depending on the choice of the Customers. It features Fly-By-Wire controls, a corrosion free and crashworthy carbon fibre fuselage with low radar signature, and is offered with 2 cabin sizes (standard (1.58m) and high (1.82m)). Depending on the version/variant it can be equipped with a rear ramp, automatic tail and blade folding, and de-iced main and rear rotors for operations in Continuous Icing Condition as required by DEF-STAN 000-970 regulations.

Thanks to its innovative design, modern technology and systems as well as Man-Machine Interface characteristics[5] , the NH90 is able to perform tactical transport (version TTH[6]), naval (NFH[7]), SAR[8], and “utility” missions by day or night and in adverse weather conditions (-40°C up to ISA + 35°C, rain, snow, wind and hail).


*(Photo EUROCOPTER – Patrick Penna)*

*Figure 1 : TTH version – High cabin*

[3] MTOW = Maximum Take Off Weight
[4] The NH90 may be operated at higher weight up to 11,400 kg under some conditions.
[5] Including Night Vision Goggles (NGV), Forward Looking InfraRed (FLIR), Weather Radar, Digital Map Generator, and Helmet Mounted Sight and Display.
[6] TTH = Tactical Transport Helicopter
[7] NFH = NATO Frigate Helicopter
[8] SAR = Search And Rescue


*(Photo EUROCOPTER – Patrick Penna)*
*Figure 2 : NFH version – Standard cabin – Folding phase*

NAHEMA[9] is the NATO Agency that represents the initial four participating Nations (France, Italy, Germany, and the Netherlands). Portugal joined the Agency in 2001. It controls the overall execution of the programme, is responsible for the qualification of the NH90 weapon system, and is the interface to the contractor for the negotiation, placing and administration of the Prime Contracts.

NHIndustries[10] is the joint venture created by Agusta, Eurocopter, Eurocopter Deutschland, and Stork-Fokker to carry out the NH90 industrial programme management. NHIndustries responsibility covers the design and development, the production, the marketing and sales, and the in-service support for the NH90 all over the world.

NHIndustries signed the NH90 Design-and-Development contract with NAHEMA on the 1st of September 1992. The first TTH version deliveries are planned for this year and the first NFH version deliveries are scheduled for 2007.

Currently the NH90 back-log consists of 357 firm orders, 122 options and more than 60 announced selections and it has been selected by 18 Armed Forces from 14 Countries (France, Italy, Germany, the Netherlands, Portugal, Greece, Finland, Norway, Sweden, Sultanate of Oman, Australia, New Zealand, Spain and Belgium).
The NH90 is becoming the true reference for the Armed Forces worldwide[11].

[9] NAHEMA = NATO Helicopter Management Agency
[10] NHIndustries = NATO Helicopter Industries
[11] More information may be found on website www.NHIndustries.com

# 3 DAMAGE TOLERANCE CONCEPT

The term "Damage Tolerance" means here Fatigue Tolerance evaluation considering the effects of both fatigue and expected damages. In this context, Damage Tolerance does not exclusively relate to "crack growth", as it is traditionally used.

## 3.1 FAR requirements

New civil FAR regulations were introduced to increase helicopter safety levels by mandating proof of Damage Tolerance per Amendment 28, dated 27 November 1989. Furthermore, an accompanying Advisory Circular (AC 29 MG11) was issued in 1995. Note that the Amendment 31, the certification basis stipulated in the NH90 contract is identical to Amendment 28, for as far as FAR 29.571 Fatigue evaluation of structure is concerned.

The Damage Tolerance approach was developed to mitigate cracking problems affecting components with pre-existing manufacturing deficiencies (e.g. scratch, flaw, burr, crack, etc...) or service induced damage (impact, scratch, loss of bolt torque, wear, corrosion, fretting corrosion, etc...) that were the root causes of fatigue failure.

The Damage Tolerance approach is based on the assumption that a fatigue crack in a component can be safely detected by the operators, through inspections, before it grows to the extend where the component can no longer carry limit loads.

It is now required to consider the effects of environment, intrinsic / discrete flaws and accidental damages in the fatigue evaluation, unless it is established that this cannot be achieved within the limitations of geometry, inspectability or good design practice for a particular structure. (A conventional Safe Life approach should be used in this case).

Two concepts were proposed to fulfil the Damage Tolerance requirements (*Figure 3*):

- Enhanced (Flaw Tolerant) Safe Life
- Fail Safe (Single or Multiple Load Path)

or a combination thereof.

These concepts are detailed below.

### *3.1.1 Enhanced (Flaw Tolerant) Safe Life Concept*

"Enhance Safe Life" (also named "Flaw Tolerant Safe Life" by ref. [6]) is understood as the capability of a flawed structure to sustain, without measurable flaw growth, the spectrum of operating loads expected during the service life of the rotorcraft or during an established replacement time.

### *3.1.2 Fail Safe Concept (Single or Multiple Load Path design)*

"Fail Safe" is understood as the capability of a structure with a standard crack (Initial Quality Crack) or a detectable crack (using a prescribed inspection plan) to sustain the spectrum of operating loads expected during the Inspection Interval.

Fail safe design can be provided through different concepts (*Figure 3*).

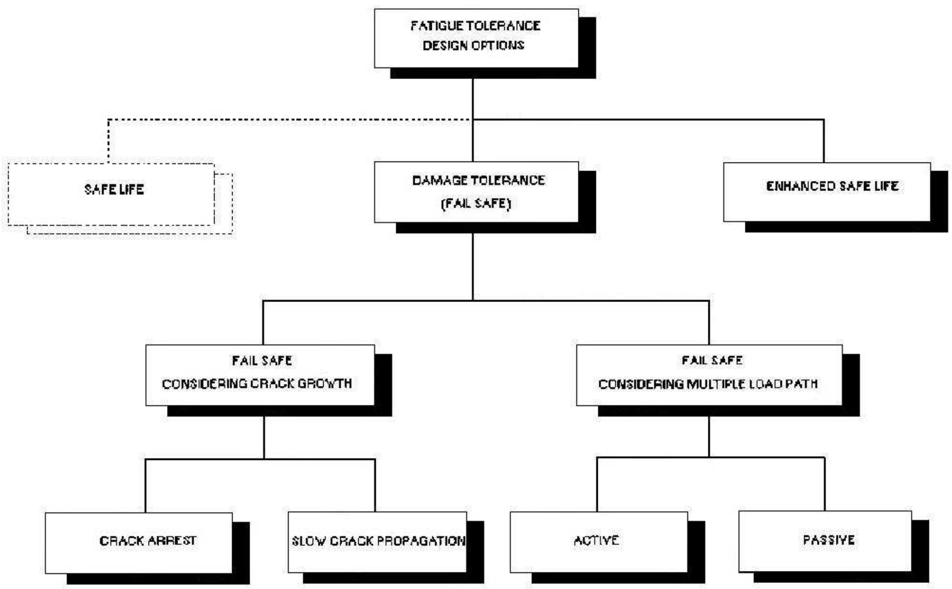



*Figure 3: Fatigue tolerance design options with the details of Fail Safe design methodology*

*Figure* 4 (Single Load Path design) and *Figure 5* (two active Multiple Load Path design) (extract from ref. [6]) explain how the repetitive Inspection Intervals are set (difference between the time when the damage becomes detectable and the time when the extent of the damage reaches the critical value for residual static strength).

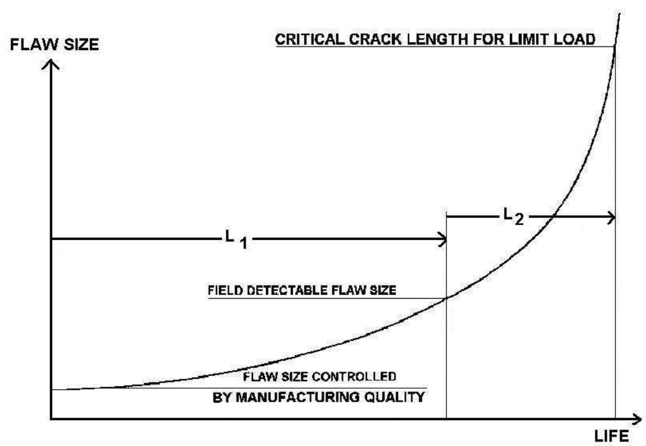



*Figure 4: Definition of the Inspection Interval based on L2[12] for Single Load Path design*

[12] Repetitive Inspection Interval set at $L_2/4$ (according to ref. [6])

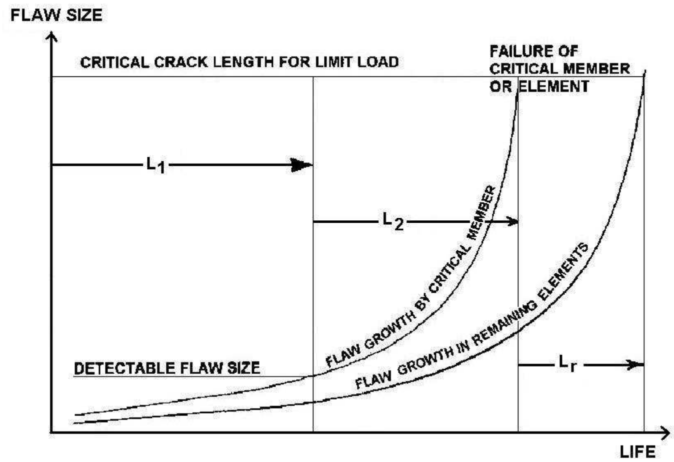



*Figure 5: Definition of the Inspection Interval based on (L2 + Lr)*[13] *for two active Multiple Load Path design*

### 3.2 Damage tolerance approach for the NH90

As the NH90 design and development phase was in its early stages, a working group called TOGAA[14] was commissioned by the FAA, after the U.S. Congress mandated that preventive actions be taken to minimise the occurrence of catastrophic failures due to ageing of fixed wing aircraft. Following discussions with fixed-wing aircraft manufacturers and FAA/JAA, this working group proposed a new FAR 25.571 paragraph that introduced the Damage Tolerance approach into the civil regulations for fixed wing aircraft.

From 1993 onwards, the TOGAA group discussed with the helicopter manufacturers and requested that the RCWG[15] provide TOGAA with a « White Paper » (cf. ref. [7]) on fatigue and Damage Tolerance that would form the basis for a revision of advisory circular 29 MG11 and, possibly, FAR 29.571, if duly justified.

After a very constructive co-operation with the helicopter manufacturers, a harmonised methodology for fatigue and Damage Tolerance focusing on metals was found and a « White Paper » was prepared and submitted to TOGAA for comments.

[13] Repetitive Inspection Intervals set at $(L_2+L_{r)}$ / 3 (according to ref. [6])

[14] TOGAA = Technical Oversight Group for Ageing Aircraft
This group, composed of high level figures from the U.S. aerospace community, was commissioned in 1989 following the ALOHA AIRLINES-BOEING 737 incident as a result of aircraft ageing. This was the well-known incident where a high-time commercial airliner lost 18 feet of the upper fuselage before landing safely. Beginning with fixed wing aircraft, TOGAA then expanded to include engines and finally to rotorcraft back in 1993. The TOGAA mission was to review ageing-related issues and recommend corrective actions. As part of its mission, TOGAA has expressed concerns regarding the current FAR 29.571 (Rotorcraft fatigue evaluation) and the associated Advisory Circular.

[15] RCWG = Rotorcraft Community Working Group.
This group composed of representatives from the major helicopter companies in the US and Europe, from the US (FAA) and European (JAA) airworthiness authorities and operators, was appointed to facilitate communication with TOGAA.

From 2000 to 2002, the 29WG[16] was solicited to prepare (1) a revised Advisory Circular for the current harmonised JAR/FAR rule 29.571, (2) a proposed new harmonised JAR/FAR rule 29.571 and (3) Advisory Circular to support the new rule.

At the beginning of the NH90 design and development phase, a harmonised methodology was prepared by the Industry and submitted to NAHEMA for approval. As the industrial partners (except STORK-FOKKER) of the NH90 were also members of RCWG and 29WG, this harmonised methodology was based on the « White Paper » and the proposed new harmonised JAR/FAR rule 29.571 and associated Advisory Circular.

This methodology requires the establishment of a conventional safe life (initiation of fatigue crack using as-manufactured[17] components) and repetitive Inspection Intervals based on one of the three equally concepts (Flaw Tolerant, Crack Tolerance or Multiple Load Path).

**Although the wording may appeared similar to the one used in the rule JAR/FAR 29.571, the approach is different and detailed below (these definitions are only for use in the context of this paper).**

### *3.2.1 Flaw Tolerance Concept*

"Flaw Tolerance" is understood as the capability of flawed[18] structures to sustain, without measurable flaw growth or fatigue crack initiation, the spectrum of operating loads expected during the established Inspection Interval.
This repetitive Inspection Interval is derived from the time to initiate a fatigue crack from a detectable flaw (see *Figure 6*).

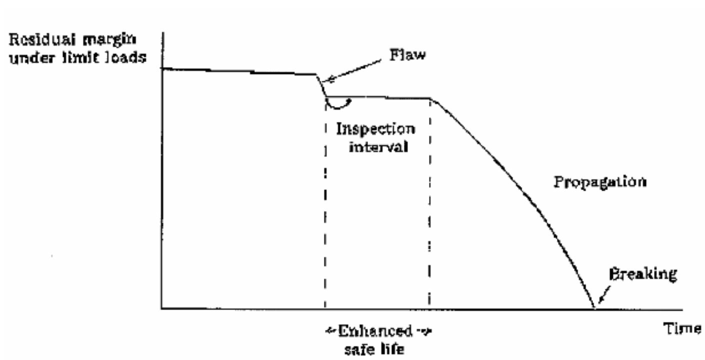



*Figure 6: Definition of the Inspection Interval for Flaw Tolerance*

At the time of the periodic interval, the part may be retired without inspection, returned to service if no flaw is found, retired or repaired if a flaw is detected.

The inspection generally is a detailed visual inspection and more (Non Destructive Examination) if a doubt exists.

[16] 29WG = Working Group tasked by ARAC to address the FAR29.571 "Damage tolerance and fatigue evaluation of the metallic structure. ARAC (Aviation Rulemaking Advisory Committee)

[17] Condition of a component that is produced as a result of a nominal performance of manufacturing processes specified for that component.

[18] A flaw is a localised defect or anomaly related to manufacturing or service use.
In metals this includes corrosion, fretting, nicks, dents, scratches and gouges, ...
In assemblies, this includes loss of bolt torque, ...

### *3.2.2 Crack Tolerance Concept*

"Crack Tolerance" is understood as the capability of a single load path structure with a detectable (using a prescribed inspection plan) fatigue crack to sustain the spectrum of operating loads expected during the established Inspection Interval.
This repetitive Inspection Interval is derived from the time for a detectable crack to grow to critical size under limit load (see *Figure 7*).

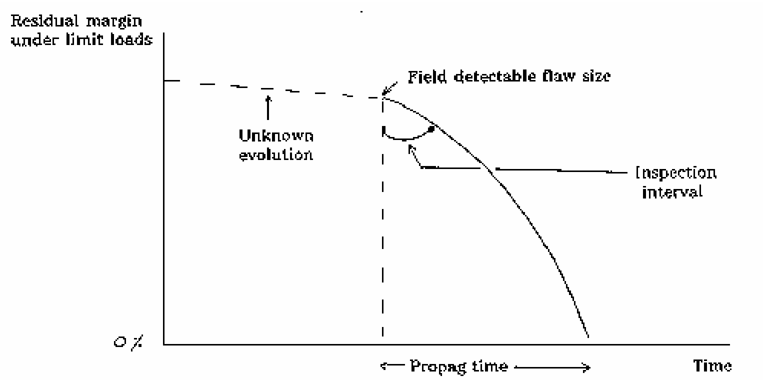



*Figure 7: Definition of the Inspection interval for Crack Tolerance*

At the time of periodic interval, the part may be retired without inspection, returned to service if no crack is found, retired or repaired if a crack is detected.

The inspection will generally involve a Non Destructive Examination.

### *3.2.3 Multiple Load Path Concept*

"Multiple load path" is understood as the capability of a (N) Multiple Load Path structure with (n) detectable (using a prescribed inspection plan) failed load paths to sustain the spectrum of operating loads expected during the established Inspection Interval.
This repetitive Inspection Interval is derived from the time to initiate a fatigue crack in any remaining load path (when a primary load path is broken) as a result of loading redistribution (see *Figure 8*).

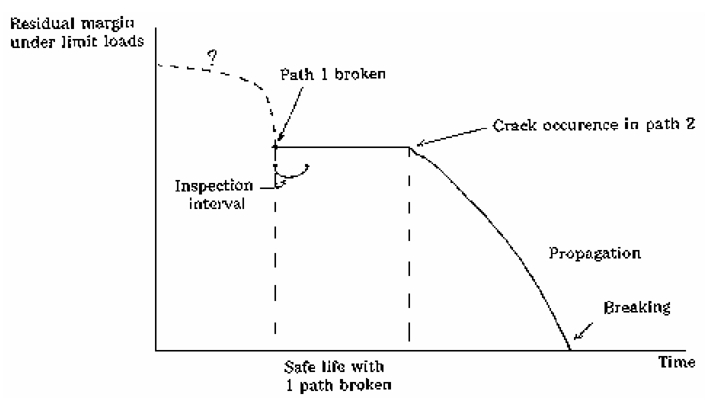



*Figure 8: Definition of the Inspection interval for (N= 2) Multiple Load Path structure*

If a failed load path is found at the time of periodic inspection, all components of the affected load path will be retired; but if no failed load path is found, the parts may be returned to service.
If some parts are found with flaws, these parts may be retired or repaired individually.

The inspection will generally involve a visual inspection to detect the failure of one load path.

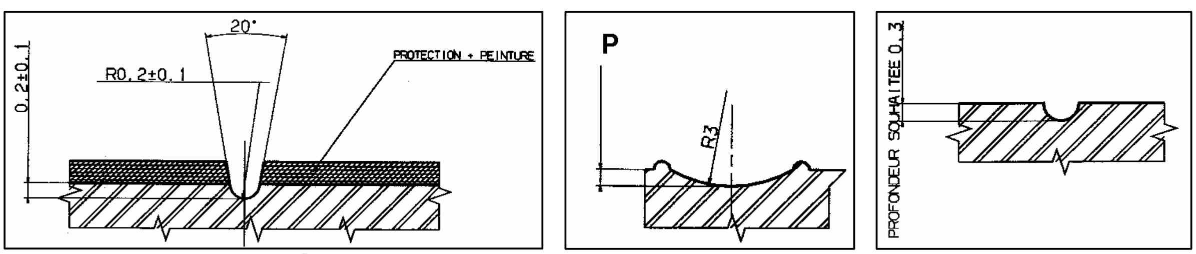
In this concept, full-scale fatigue tests are performed with the remaining load paths (N-n) with as-manufactured parts, and the Inspection Interval is based on the initiation of a fatigue crack in the remaining overloaded load path.

## 4 RESEARCH PROGRAM

Eurocopter has undertaken significant research studies to improve its knowledge and experience concerning crack propagation and to constitute a material database ( crack growth rate versus stress intensity factor range curves and fatigue curves with flaws). These studies were funded by Eurocopter itself and by the European Union under the BRITE/EURAM[19] and 5th PCRD[20] programs.

### 4.1 Flaw tolerance

First, the type and size of flaws encountered in service were identified from available literature and from Eurocopter's own experience (based on detailed investigation related to overhauls, major incidents[21] and accidents[22] in flight). The main flaws were identified to be scratch, impact, corrosion, fretting, wear and loss of tightening torque. The standard flaw size was defined to cover 90% of the flaw size distribution.
As an example, for steels, the standard depths are shown to be 0.2 mm (≈ 0.008 in) for scratch, 0.25 mm (≈ 0.010 in) for impact and 0.3 mm (≈ 0.012 in) for corrosion pits (see *Figure 9*).




Scratch Impact Corrosion

*Figure 9: Standard flaws*

[19] BRITE EURAM - « DAMTOL »
Contract n° BREU-0123
DAMageTOLerance on helicopter metallic parts (1990-1993)
[20] 5th Programme Cadre de Recherche et Développement - « ADMIRE »
Contract n° G4RD-CT-2000-0396
Advanced Design concepts and Maintenance by Integrated Risk Evaluation for aerostructures (2001-2005)
[21] Every malfunction which could interrupt, cancel or delay significantly the mission or endanger the crew (loss, failure or damage of critical safety components, use of emergency procedures (engine failure, abnormal heating that might start a fire)
[22] Accident with loss of life, hull damage, full or partial destruction of the helicopter

In practice, on the components to be tested in fatigue with flaws, the scratches were machined, and the impacts were applied through an impactor dropped from a pre-defined height or hit with a hammer. The corrosion was obtained by exposing the components (without corrosion protection) during 750 hours in a salt spray atmosphere.

Fatigue tests were performed on specimens made of different kinds of material (steel, stainless steel, titanium, aluminium alloys and magnesium alloys) with these standard flaws (see *Figure 10*), in order to complete the material database with data for the materials used for the NH90.

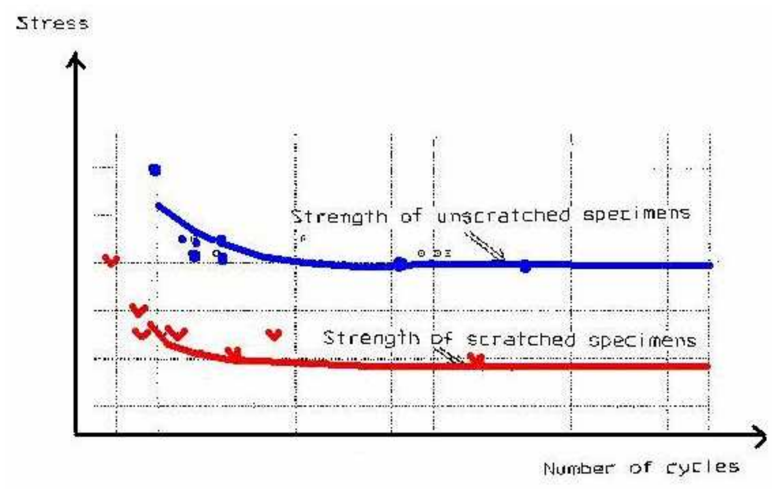



*Figure 10: Typical fatigue curves (with and without flaw)*

## 4.2 Crack tolerance

Particular tests were performed to establish crack growth curves (da/dn[23] versus ΔK[24]), specifically near threshold, for different R[25] ratios, in order to complete the material database with data for the materials used for the NH90 (see *Figure 11).*

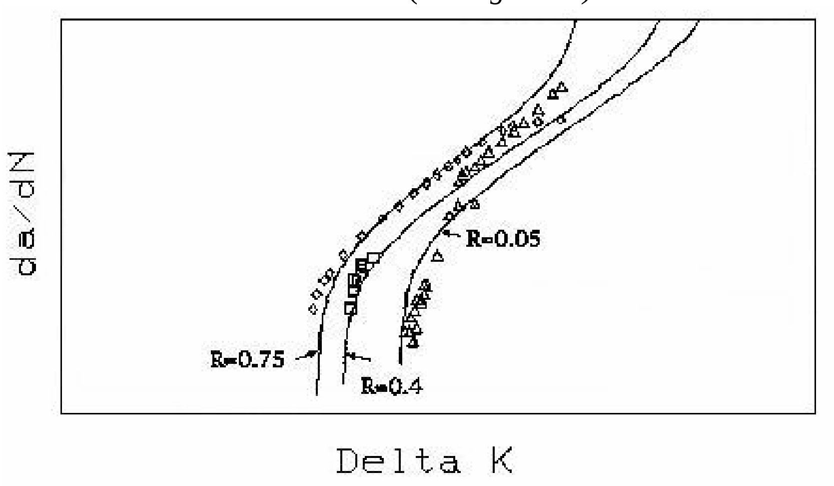
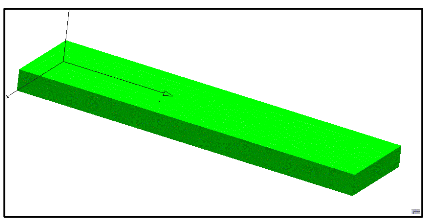



*Figure 11: Typical crack growth curves*

[23] da/dn = crack growth rate
[24] ΔK = Stress Intensity Factor range during a loading cycle ($K_{max}$-$K_{min}$)
[25] R = $K_{min}/K_{max}$

To evaluate the accuracy of the theory, methodology, tools and material database used by Eurocopter, analysis results were compared with experimental results. Analyses were performed using the in-house software package PROPAK, which has been derived from ESACRACK and PREFFAS (cf. ref. [1]) as developed by EADS-CCR[26]. Experimental results were obtained for two materials (aluminium alloy and titanium), simple geometry (with and without stress concentration factor kt = 1.6), under simple loading (CAL)[27] and complex loading (simplified Helix32 spectrum[28]), both in tension and bending.

Hereafter 2 examples are provided that show the rather good correlation between prediction (time to propagate an initial circular 0.380 mm ( = 0.0015 in) radius crack to failure versus the maximum nominal stress) and test results (see *Figure 12* and *Figure 13*).



100 X 25 X 6

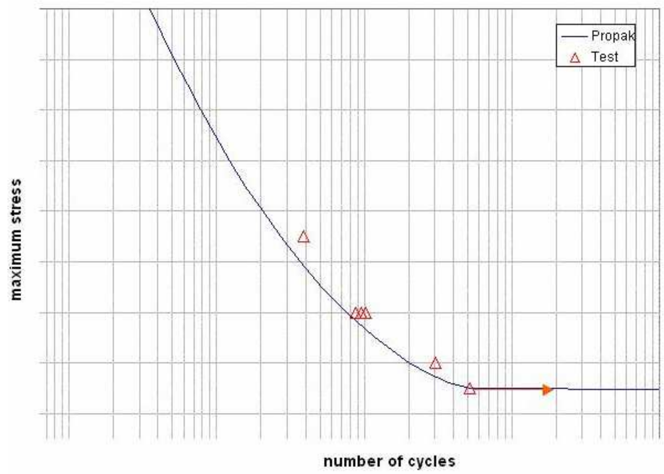
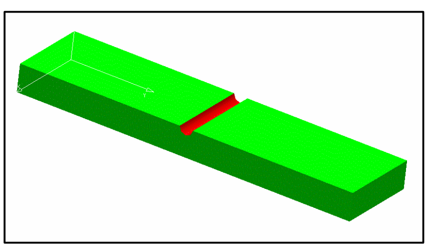



*Figure 12: Specimen without stress concentration - Titanium -Bending - CAL - R = 0.7*



100 X 25 X 8
(groove radius = 2 mm)

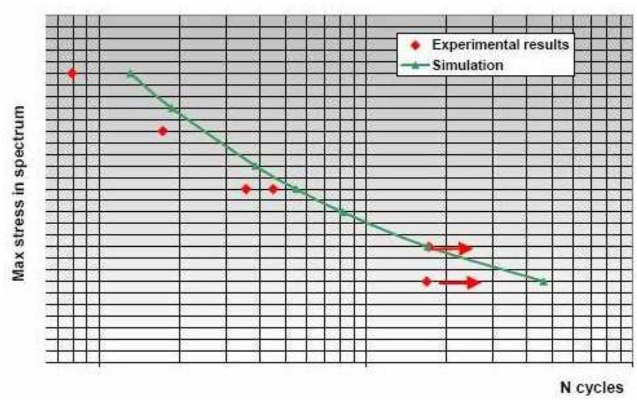



*Figure 13: Specimen with stress concentration - Aluminium - Tension - Helix32*

[26] CCR = Centre Commun de Recherche (Common Research Centre)
[27] CAL = Constant Amplitude Loading
[28] Helix is a standard loading sequence that relates to the main rotor of helicopters with a hinged (articulated) rotor (cf. ref [3], [4] and [5]). The purpose of this standard loading sequence is twofold. Firstly, it provides a convenient tool for gathering fatigue data under realistic loading, readily comparable with data obtained by other organisations. Secondly, it can be used to provide design data.
Helix has been developed by a collaborative group consisting of MBB, IABG, LBF from Germany and NLR from the Netherlands.
Helix32 is a shortened version of Helix.

## 5 EXAMPLES FROM NH90 QUALIFICATION

For as far as new designs are concerned, the Damage Tolerance aspects have to be considered at a very early design stage.

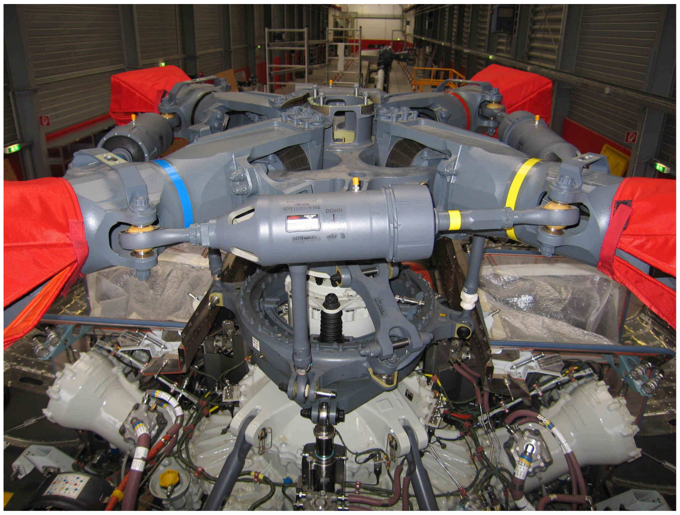
The NH90 design is based on proven concepts, and the number of structural components and bearings is minimised by design practice (amongst others, through the use of a spherical elastomeric thrust bearing and supercritical tail rotor drive shaft).
Lessons learned from in-service experience were utilised and accounted for to improve upon these known concepts. Some critical parts/functions have been designed more tolerant by using Multiple Load Path design. Examples are a Tail Gear Box attachment with 4 bolts instead of the 3 that are generally used and the Main Gear Box being supported by 4 instead of 3 struts.

In addition, design efforts were made to prevent flaws or to mitigate their influences, at the component level itself. For example, critical components that are usually made of steel (rotor hub, sleeve, bolts,…) are now made of titanium, or stainless steel to prevent corrosion. Deposits resistant to fretting or wear have been used on most critical interfaces. Moreover, anti-shock paint has been applied on most components.

NH90 achieved NAHEMA qualification early 2006. However, in terms of stress and fatigue its qualification was complete by the end of 2005. Thus, the NH90 is the first military helicopter to be "Damage Tolerant" in the world.
Hereafter 3 examples are presented that illustrate the Damage Tolerance qualification process.

### 5.1 Lead-lag damper

The four-blade main rotor is a Spheriflex™ design, with laminated elastomeric spherical bearing providing flapping, lead-lag and pitch variation functions through elastomeric deformation. The main rotor blades feature curved down and swept high-speed tips. The lead-lag damper is mounted between two adjacent sleeves (see *Figure 14*).



*(Photo EUROCOPTER – Patrick Penna)*

*Figure 14: NH90 Main Rotor Hub*

The lead-lag damper is loaded axially due to a relative blade motion as well as radially due to the centrifugal load.

The outer part of the component is made of aluminium alloy and the inner part is of stainless steel. An elastomeric part is located in between the two. Two lugs are screwed into the adapter at both ends.

The inspections intervals are based on Flaw Tolerance (for inner and outer parts), on Crack Tolerance (for the elastomeric part), and on Multiple Load Path (for inner part/lug and outer part/lug links).They were established from fatigue tests on flawed components.

Damages accounted for during qualification are impacts, scratches and corrosion (for outer part), as well as complete loss of tightening torque (see *Figure 15*).

*(Photo EUROCOPTER)*

*Figure 15: Flaws on lead-lag damper*

The following table summarizes the retirement life and the Inspection Intervals, for the TTH version.

| Retirement Time | Damage Type | Inspection Interval | |
|---|---|---|---|
| | | Calculation | Maintenance Manual |
| 10,000 h | scratch | unlimited (*) | 900 h recommended |
| | impact | unlimited (*) | 900 h recommended |
| | corrosion | 500 h | 500 h mandatory |
| | Visible Crack (in elastomeric part) | 50 h | 50 h mandatory |
| | Tightening torque | unlimited (*) | 900 h recommended |

(*) means > 10,000 h

## 5.2 TTH Sleeve

The TTH Sleeve is loaded through the blades (lift and drag loads, centrifugal force, flapping and drag bending moments), as well as by loads coming from lead-lag damper (leading and trailing edge), and from pitch rod (via the pitch horn).

The sleeve is made of titanium.
The inspections intervals are based on Flaw Tolerance (for sleeve), and on Multiple Load Path (for pitch horn/sleeve, spherical bearing/sleeve, lead-lag damper/sleeve links). They were established from fatigue tests on flawed components.

Damages accounted for during qualification are impacts and scratches (for sleeve), complete loss of tightening torque (spherical bearing/sleeve and lead-lag damper/sleeve links), and the loss of one bolt out of four of the pitch horn/sleeve link (see *Figure 16*).

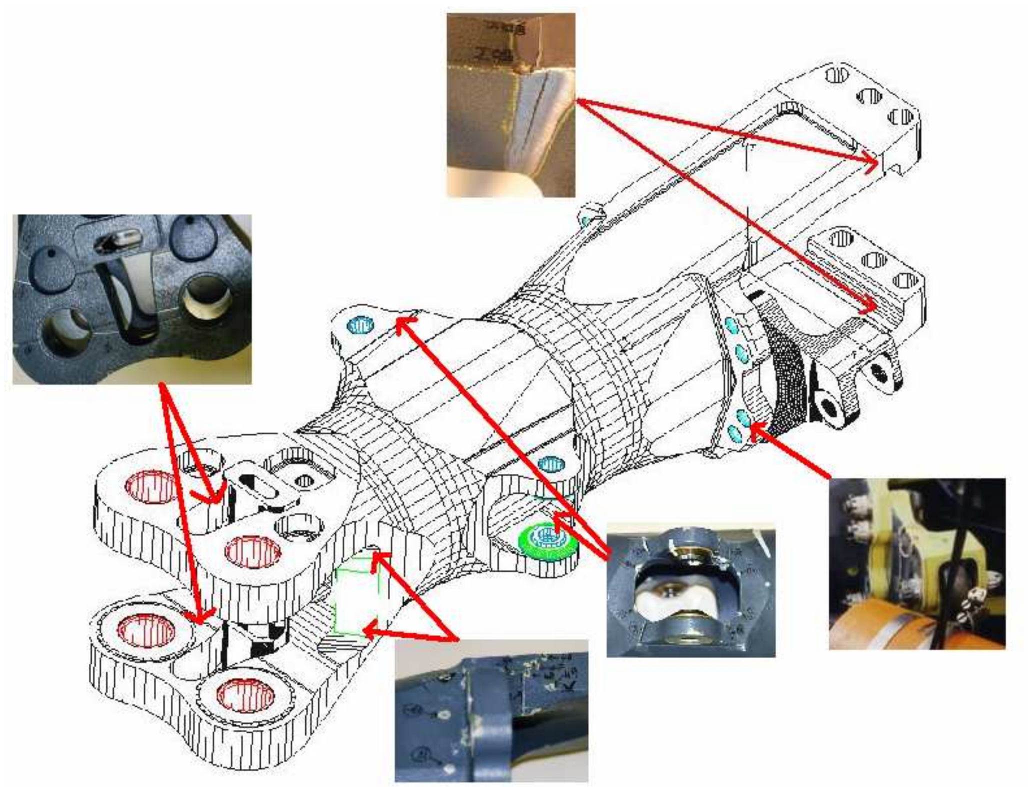


*Figure 16: Flaws on sleeve*

The following table summarizes the retirement life and the Inspection Intervals.

| Retirement Time | Damage Type | Inspection Interval | |
|---|---|---|---|
| | | Calculation | Maintenance Manual |
| 1,700 h(*) | scratch | 650 h | 650 h mandatory |
| | impact | 711 h | 650 h mandatory |
| | Missing bolt | 410 h (*) | 410 h mandatory |
| | Tightening torque | 240 h (*) | 240 h mandatory |

(*) additional tests to be performed to increase Retirement Time and Inspection Intervals[29].

### 5.3 SARIB fitting

The SARIB™ [30]suspension system is an anti-resonance isolation system, which consists of 4 individual units, equally spaced around the Main Gear Box (see *Figure 17*). The struts transmit the vertical static and dynamic main rotor loads to the structure through the rigid part of the flexible beams, the SARIB fitting, and conical laminated bearing. The suspension system allows for small rotations of the Main Gear Box. The flexible beams are connected to the Main Gear Box via elastomeric bearings and provide the required elastic stiffness in a plane perpendicular to the mechanical deck. The flapping arms provide the link between the flapping masses and the flexible beams.
The stiffness of these parts is chosen such as to have the best transfer of inertial loads coming from the flapping masses. The adjustment of the flapping masses, in combination with the geometry of the system, is optimised to reduce the transmissibility of the 4 per rev dynamic loads coming from the main rotor.

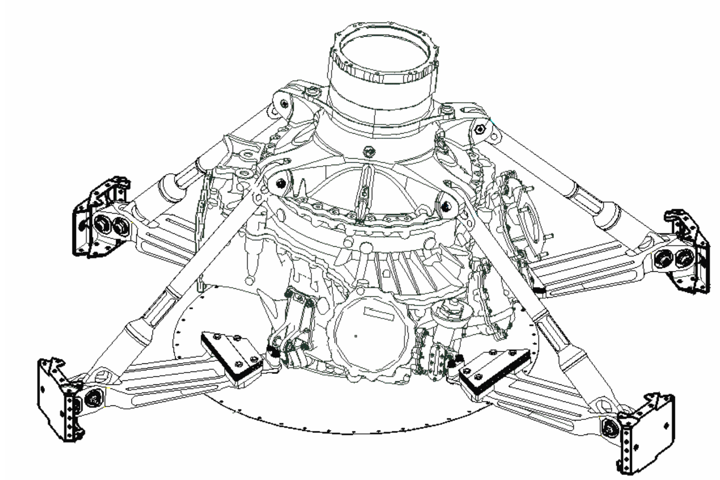


*Figure 17: SARIB™ suspension system*

[29] In fact, the reduced working curve used safety factors which decrease when the number of fatigue test increases.
[30] SARIB = System Anti-Resonance Integrated in the Bar

The SARIB fitting is loaded by a static and dynamic strut load, in conjunction with a dynamic inertial load from the flapping mass.

The SARIB fitting is made of titanium.

The inspections intervals are based on Flaw Tolerance (for the SARIB fitting), and on Multiple Load Path (for SARIB fitting/structure link). They were established by combining fatigue tests using as-manufactured components with analysis to account for flaws through usage of representative stress concentration and dynamic notch factors, obtained from the German Aerospace material Properties Handbook.

Damages accounted for during qualification are impacts and scratches (for the SARIB fitting), and the loss of four bolts out of twenty four of the SARIB fitting/structure link (see *Figure 18*).

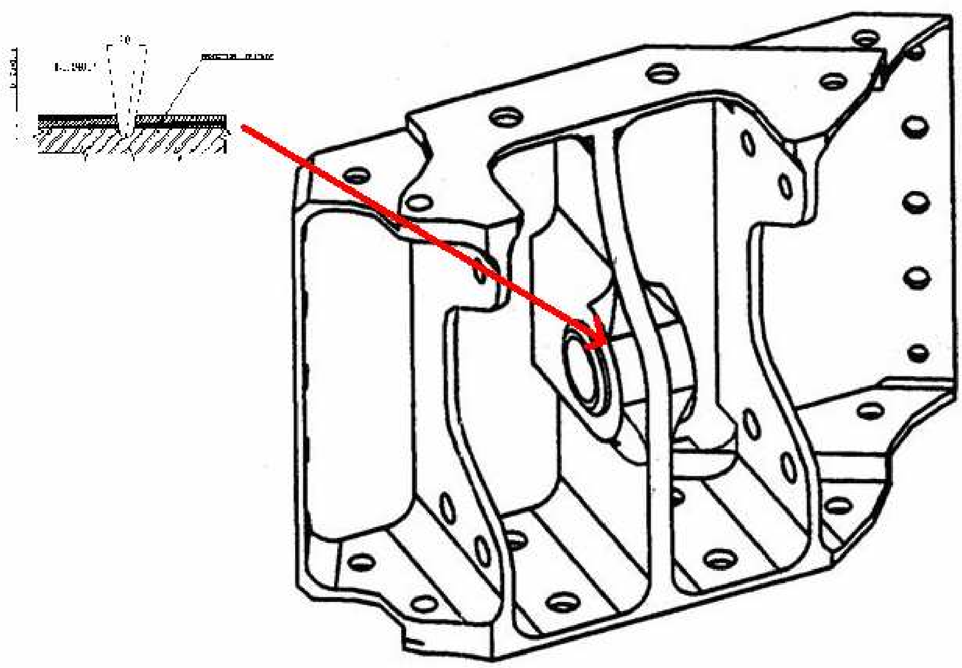


*Figure 18: Flaws on SARIB fitting*

The following table summarizes the retirement life and the Inspection Intervals.

| Retirement Time | Damage Type | Inspection Interval | |
|---|---|---|---|
| | | Calculation | Maintenance Manual |
| unlimited | scratch | unlimited (*) | 900 h recommended |
| | impact | unlimited (*) | 900 h recommended |
| | Missing bolt | unlimited (*) | 900 h recommended |

(*) unlimited means > 10,000 h

### 5.4 Experience from the NH90 qualification

Damage tolerance may be achieved by using the new proposed harmonised FAR/JAR29.571, as recommended by the 29WG.

Inspection Intervals can be established, area by area, by selecting the most suitable concept amongst Flaw Tolerance, Crack Tolerance and Multiple Load Path.

Finally, Inspection Intervals specified in the Maintenance Manual as required by the rule may either be mandatory or recommended.

## 6 EXPECTED INFLUENCE OF DAMAGE TOLERANCE

Beyond the strict application of the regulation, we can ask ourselves what the influence of Damage Tolerance approach on the present accident rate of helicopters will be.

### 6.1 Root cause of accidents

Helicopters are highly complex systems, tricky to pilot, and often used for demanding missions in hostile environments. Although dramatic improvements were achieved over the last 30 years, the turbine helicopter accident rate remains however much higher than that of large air carriers, and has been levelling off for some years (cf. ref. [2]). It is noteworthy that turbine helicopter accident rate is similar to large air carriers, if only transport of passengers is considered.

For the last five years (2001-2005), on a world-wide/all mission basis, the Eurocopter average rate of accidents is 33.8 per million flight hours (out of which 10.7 were fatal).
The analysis of the root causes of accidents in flight shows that (see *Figure 19*):

- 76.5 % were due to "Operational conditions and environment". This includes poor estimation of distance with fixed or moving obstacle, poor piloting (no reaction to weather condition worsening, fuel shortage, non observance of flight manual limitations, wrong behaviour upon non catastrophic events or failure), non qualified pilots (helicopter type qualification, weather condition qualification) and pilot's physical inability to perform the required tasks.

- 10.8 % were due to "Incorrectly performed maintenance". This includes misassembly, omitting components, not implementing a mandatory modification, assembling of components not approved by manufacturer, polluted fuel, non detection of a clearly detectable damage

- 1.4 % was due to "Vehicle". This includes poor design, non conformity of component, and fatigue crack.

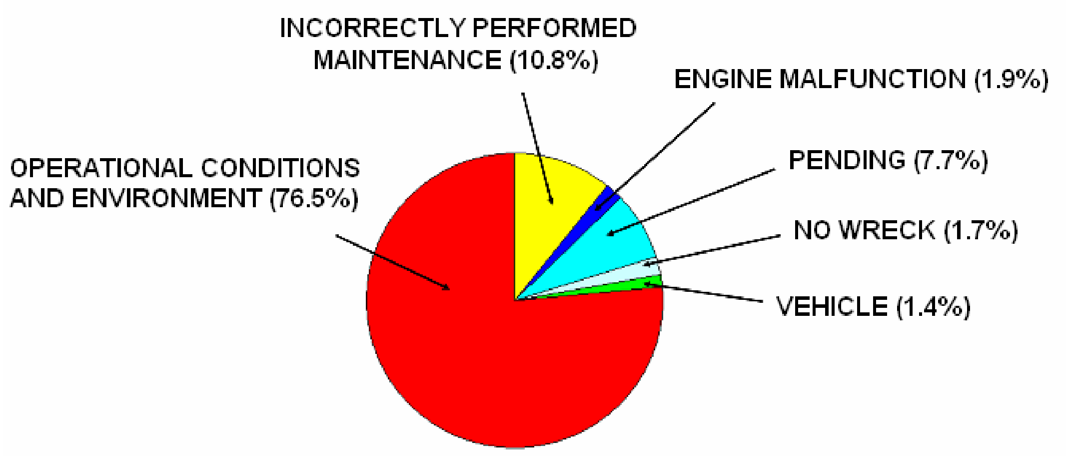



*Figure 19: Root cause of accidents*

Another analysis performed on all the accidents within the Eurocopter fleet showed that the Damage Tolerance rule could have influenced less than 20 accidents (over 43 million flight hours).

It can be concluded that conventional safe life (fatigue tests on as-manufactured parts, in-flight load measurement, conservative usage spectrum and high load and life safety factors) is successful in providing a high safety level.
This safety could be slightly improved by applying a Damage Tolerance approach.

### 6.2 Customer behaviour

To date, neither the Authority nor manufacturers are able to predict how the application of Damage Tolerance principles will influence the state of mind of the users. Some dramatic events in the past have shown the possible consequences of an excess of trust in the state of the art. We just have to refer to the Titanic story, for example. As the ship was widely considered "unsinkable", a series of fatally bad choices were made and clear warnings ignored, just because from the Captain to crew members, they simply did not think that serious problems could happen.

Another point is related to the mandatory and recommended inspections. Will the customer still perform the recommended ones, as he used to in the past, even under continuous economic pressure?

### 6.3 Conclusion

The new Damage Tolerance regulation should slightly contribute to enhance the safety of helicopters. However, its true effect should be carefully monitored by the helicopter community (Customer, Authority and Manufacturer) over the next few years.

In addition to the Damage Tolerance approach, other important improvements are also being developed by Eurocopter to attempt to decrease the accident rate (for more details, report to ref [2]).

## 7 CONCLUSION

This paper shows that Damage Tolerance may be achieved by using the new proposed harmonised FAR/JAR29.571, as recommended by the 29WG.

Inspection Intervals can be established, area by area, by selecting the most suitable concept amongst Flaw Tolerance, Crack Tolerance and Multiple Load Path.

In 2005, the NH90 became the first military helicopter in the world to be qualified according to these new Damage Tolerance requirements.

The new Damage Tolerance regulation should slightly contribute to enhance the safety of helicopters. However, its true effect should be carefully monitored by the helicopter community (Customer, Authority and Manufacturer) over the next few years.

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