

Application of Flaw Tolerance Methodologies on Metallic Principal Structural Elements

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AIRBUS HELICOPTERS

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- Evolution of regulations regarding fatigue tolerance evaluation
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- Flaw tolerance evaluation of Single Load Path PSEs
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INTRODUCTION

The EASA Certification Specifications for large helicopters are CS29

- Objectives:
  - To substantiate the metallic structural parts to be evaluated in fatigue as part of CS29.571
  - To evaluate their fatigue tolerance considering the effect of flaws or accidental damage
  - To support the establishment of limitations

- Scope:
  - The structural parts concerned are limited to the metallic PSEs
  - The approach was applied on EC175 fuselage components
  - Substantiation methodology of metallic structures for compliance with CS 29.571 depends on the PSE identification: Single Load Path (SLP) or Multiple Load Path (MLP).

The presented substantiation approach was approved by EASA for EC175 certification.

INTRODUCTION

- Definitions

Acronym	Description	Definition	Example
PSE	Principal Structural Element	Principal Structural Elements are those structural elements that contribute significantly to the carrying of flight or ground loads and the fatigue failure of which could result in catastrophic failure of the rotorcraft	MGB Bars, Blade, pitch rod
CAT	Catastrophic	A catastrophic failure is an event that could prevent continued safe flight and landing	Loss of blade
BDF	Barely Detectable Flaw	Worst-case flaw that is expected to remain on the structure for its operational life	Light impact
CDF	Clearly Detectable Flaw	Worst-case detectable flaw that would not be expected to remain in place for a significant period of time without corrective action	Scratch, corrosion

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ACCEPTABLE MEANS OF COMPLIANCE

Evolution of regulations regarding fatigue tolerance

- Considering damage for fatigue evaluation is a requirement since FAR29 amdt 28.
- Revision of CS29.571 was done in CS29 amdt 3.

- CS29.571 amdt 2 prescribed 2 methods:
  - Flaw tolerant safe life evaluation
  - Fail safe (residual strength after flaw growth) evaluation

"Safe life evaluation" method can be acceptable if the use of either of the two other methods is shown to be **impractical**

- CS29.571 amdt 3

Safe life methodology needs to be supplemented by other methods to account for damage.

- "Safe life evaluation" method needs consideration of flaws in its determination
- Or complementary inspection intervals deduced from damage tolerance are needed

The target is to minimize the risk of occurrence of flaws that could result in catastrophic failure

ACCEPTABLE MEANS OF COMPLIANCE

Retained principles for EC175 fuselage

	Method	PARAGRAPH	Strategy	Analysis Category	Threat Assessment Results
A	Safe-Life Retirement	e.(6)(i)(A)	Retire	Crack Initiation	Not Included
	Safe-Life Retirement with BDF(s)	e.(6)(i)(B)	Retire	Crack Initiation	Not Including Cracks
	Safe-Life Retirement with CDF(s)	e.(6)(i)(C)	Retire	Crack Initiation	Not Including Cracks
B	Safe-Life Inspection for CDF(s)	e.(6)(i)(D)	Inspect	Crack Initiation	Included
C	Safe-Life Inspection for a failed element	e.(6)(i)(E)	Inspect	Crack Initiation	Included if Considered for all Elements
	Crack Growth Retirement	e.(6)(ii)(A)	Retire	Crack Growth	Included if Crack Bounds Damage
	Crack Growth Inspection	e.(6)(ii)(B)	Inspect	Crack Growth	Included

Figure 1: Figure AC 29.571B-1: Seven Fatigue Evaluation Methods

In AC29.571B

- (A), (B) and (C) are crack initiation methods
- (A) only is not sufficient

- No flaw considered in (A)
- Flaws considered in (B) and (C)

- (A) is leading to retirement time
- (B) and (C) are leading to inspection intervals

Retained principles for EC175 are:

- (A) and (B) for Single Load Path PSEs
- (A) and (C) for Multiple Load Path PSEs

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IDENTIFICATION OF PSEs

PSEs selection

- PSEs are structural elements or assemblies within dynamic and fuselage components
- Failure mode and effects analysis are used to determine the components, fatigue failure of which could lead to catastrophic consequences
- Selection of PSEs is done with elements contributing significantly to the carrying of flight or ground loads

Examples

- Main frames, MGB bars, suspension fittings, MGB fittings

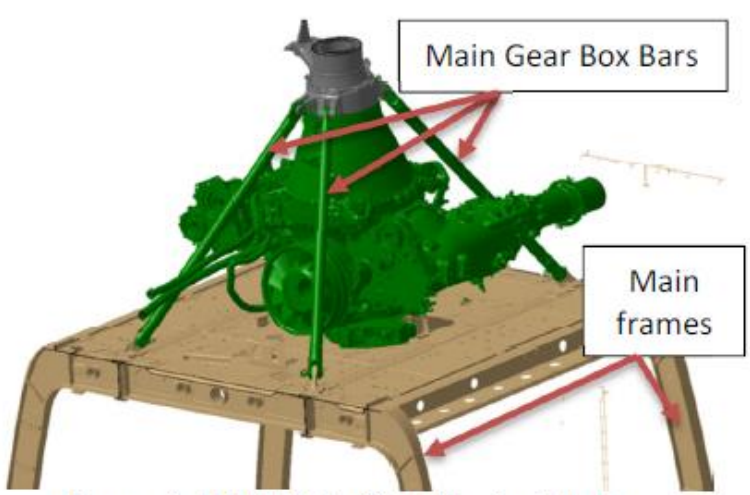

Figure 2: H175 Main Gear Box installation

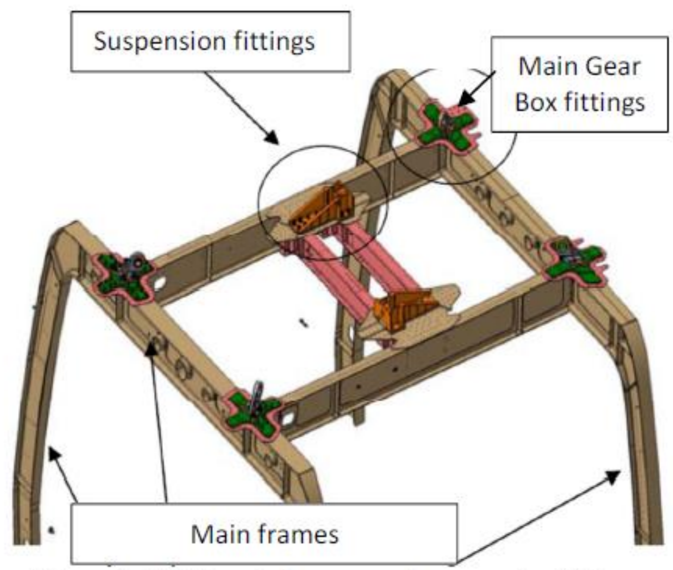

Figure 3: H175 main frames and suspension fittings

IDENTIFICATION OF PSEs

Threat assessment

Purpose: to define potential damages that could occur during manufacturing, maintenance, or in service and that could affect PSEs fatigue strength.

Various types of threats may occur on helicopter during service life. Main sources are:

- ✓ Exposure to corrosion : It is supposed that the surface treatment is damaged and consequently, there are corrosion pits.
- ✓ Exposure to impact damages
- ✓ Exposure to wear and scratches
- ✓ Loss of tightening torque (for bolted connection)
- ✓ Incorrect storage, Transport, Handling, Assembly and Maintenance aspects of the component.

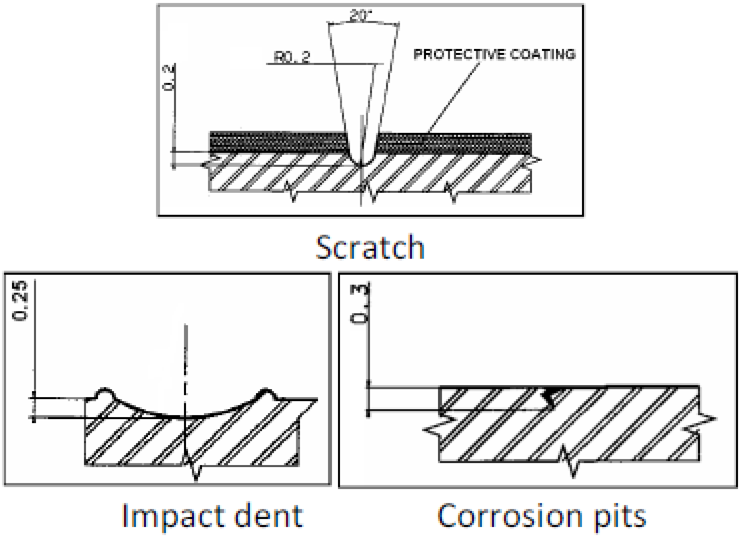

Figure 4: Standard flaws

- ✓ Standard sizes were defined to cover 90% of the flaw size distribution observed on fleet
- ✓ Effect of flaws on fatigue strength was quantified on each type of materials.

M. HERMAN – J-M. BESSON / 07/12/2016

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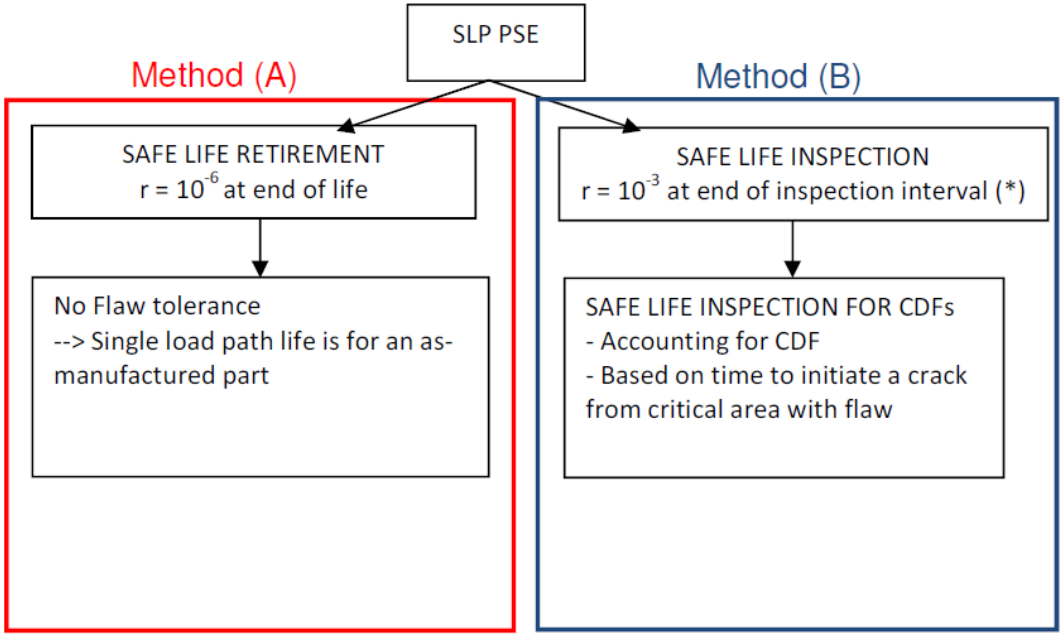
FLAW TOLERANCE EVALUATION

Flaw tolerance evaluation of Single Load Path PSEs

Single Load Path PSEs limitations are substantiated following (A) and (B):

- (A) Safe life retirement analysis → conventional fatigue methodology
- (B) Safe life inspection for CDF(s): Depending on the threat assessment results:
  - a CDF is applied on PSE
  - the time to initiate a crack from the CDF is computed to determine the inspection interval.



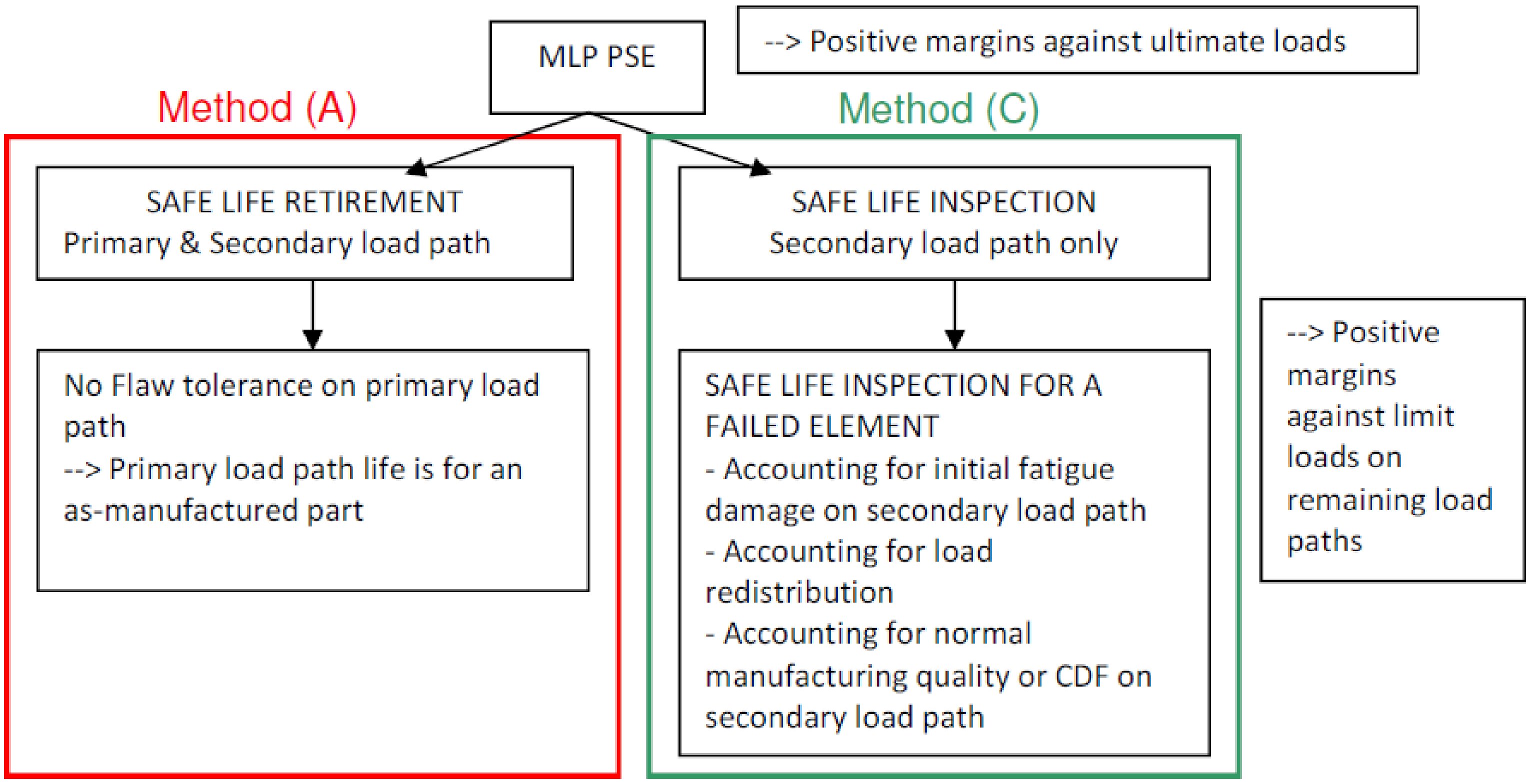
(*) associated to a flaw size covering 90% of the flaw size distribution observed on fleet

FLAW TOLERANCE EVALUATION

Flaw tolerance evaluation of Multiple Load Path PSEs

Multiple Load Path PSEs limitations are substantiated following (A) and (C):

- (A) Safe life retirement analysis → conventional fatigue methodology
- (C) Safe life inspection for a failed element



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FLAW TOLERANCE EVALUATION

Flaw tolerance evaluation of Multiple Load Path PSEs

Substantiation principles: example of 2 load paths

- One primary load path : path 1
- One secondary load path : path 2

the probability of complete failure of the MLP can be decomposed in

$$p = p1*p2$$

with
p1 the probability of failure of primary load path
p2 the probability of failure of secondary load path with inoperative primary load path

The analysis is processed as follows:

1. Fatigue analysis with the two paths loaded in normal conditions (path 1 & 2 operative)
2. Multiple load path demonstration: the initiation in the secondary load path will be analyzed assuming the effective failure of the primary load path.

Failure of primary load path has no catastrophic consequence :
The PSE is MLP

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FLAW TOLERANCE EVALUATION

Flaw tolerance evaluation of Multiple Load Path PSEs

Associated failure risk

Complete failure of the MLP (with 2 load paths) is extremely improbable considering:

- p1= 10^{-3} (at the end of retirement time) for the fatigue analysis
- p2= 10^{-3} (at the end of the inspection interval) for the fatigue analysis of path 2 and leading to the inspection interval.

The probability of complete failure of the MLP is equal to p1*p2 = 10^{-6}

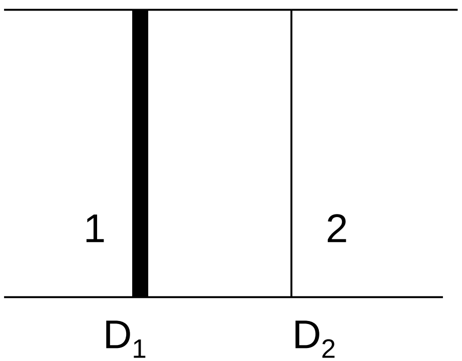
The cumulative failure risk at the end of MLP life will be equal to 10^{-6}

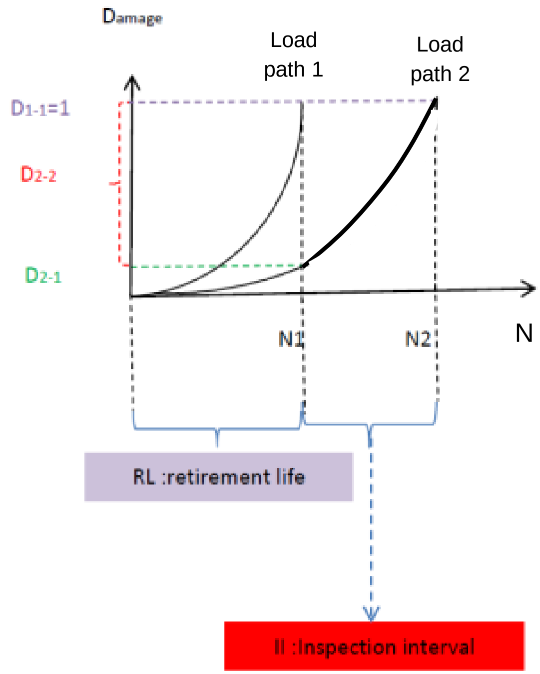
FLAW TOLERANCE EVALUATION

Flaw tolerance evaluation of Multiple Load Path PSEs

Analysis of fatigue damage [Di] of each load path [i]

At beginning of life ….

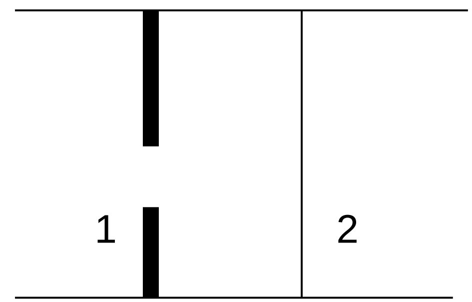




….. At N1

1 Failed

2 extraloaded



Considering Miner's rule at N1:

$D_1 = D_{1-1} = 1$

$D_2 = D_{2-1} << 1$

Considering Miner's rule at N2:

$D_2 = D_{2-1}+D_{2-2} = 1$

$D_{2-2} = 1- D_{2-1}$

D_{1-1}, D_{2-1} are computed considering a risk 10^{-3} at N1

D_{2-2} is computed considering a risk 10^{-3} at end of inspection interval

N1 is defining the PSE retirement time
ΔN = N2 – N1 is defining the inspection interval

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CONCLUSIONS

- Proposed means of compliance for fatigue and flaw tolerance requirements were successfully approved by EASA for EC175 certification.
- Fatigue substantiation was achieved by a combination of conventional Safe Life methodologies and Flaw tolerance approaches
- For metallic PSEs, two methodologies were proposed depending on SLP or MLP PSE identification

- Failure scenario should be considered very early in development to design PSEs
- Fail-safe concept with MLP PSE fatigue methodology is leading to:
  - Fail-safe design
  - Optimized weight
  - Optimized inspection interval

Defined means of compliance are leading to:
- Improvement of fatigue reliability of metallic PSE
- Optimized weight
- High safety level in service

Thank you for your attention

Any questions?