

Fatigue and Damage Tolerance

General

Presentation by:

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Rotorcraft Structures Workshop
18-19 February 2025

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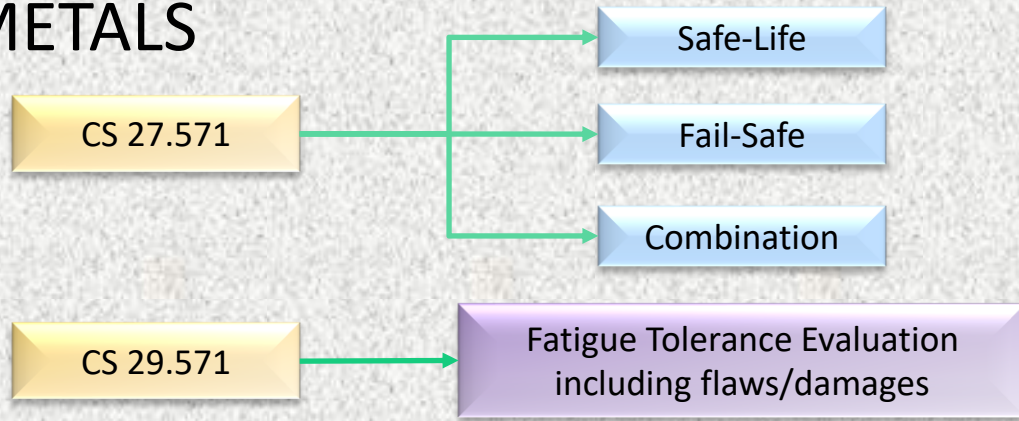
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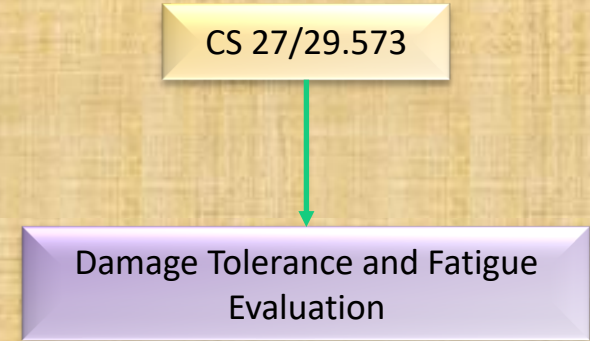
- Overview of Requirements
- Selection of Structure
- Fatigue Spectrum
- Lol and change classification

Overview of Requirements

METALS

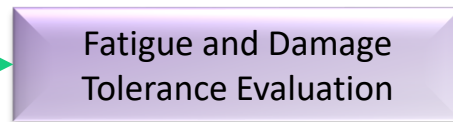
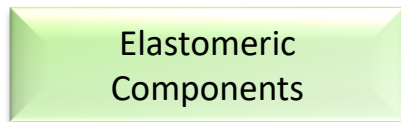


COMPOSITES

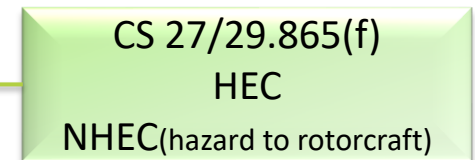


Life Limits &
Inspections

Life Limits &
Inspections

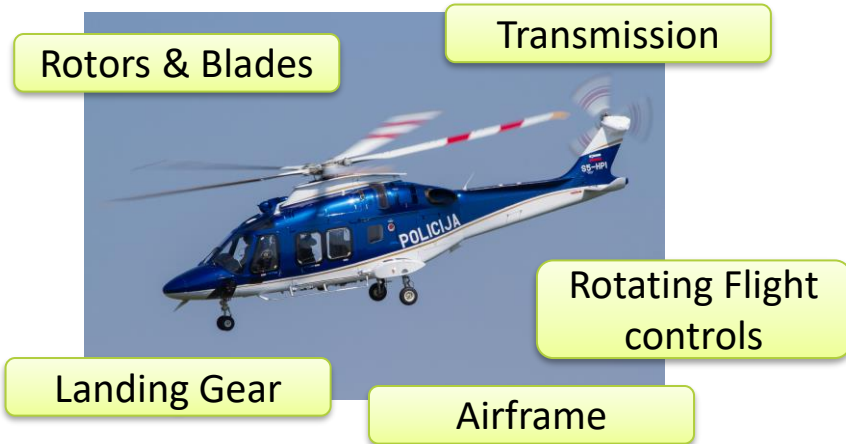


Inspections
(PSEs)



Selection of Structure

CS 27.571 Metallic	CS 29.571 Metallic	CS 27/29.573 Composite
Each portion of the flight structure (...) the failure of which could be catastrophic	A fatigue tolerance evaluation of each Principal Structural Element (PSE) (...) PSE: contribute significantly to the carrying of flight or ground loads and the (fatigue) failure of which could result in catastrophic failure of the rotorcraft	The damage tolerance evaluation must include PSEs (...)



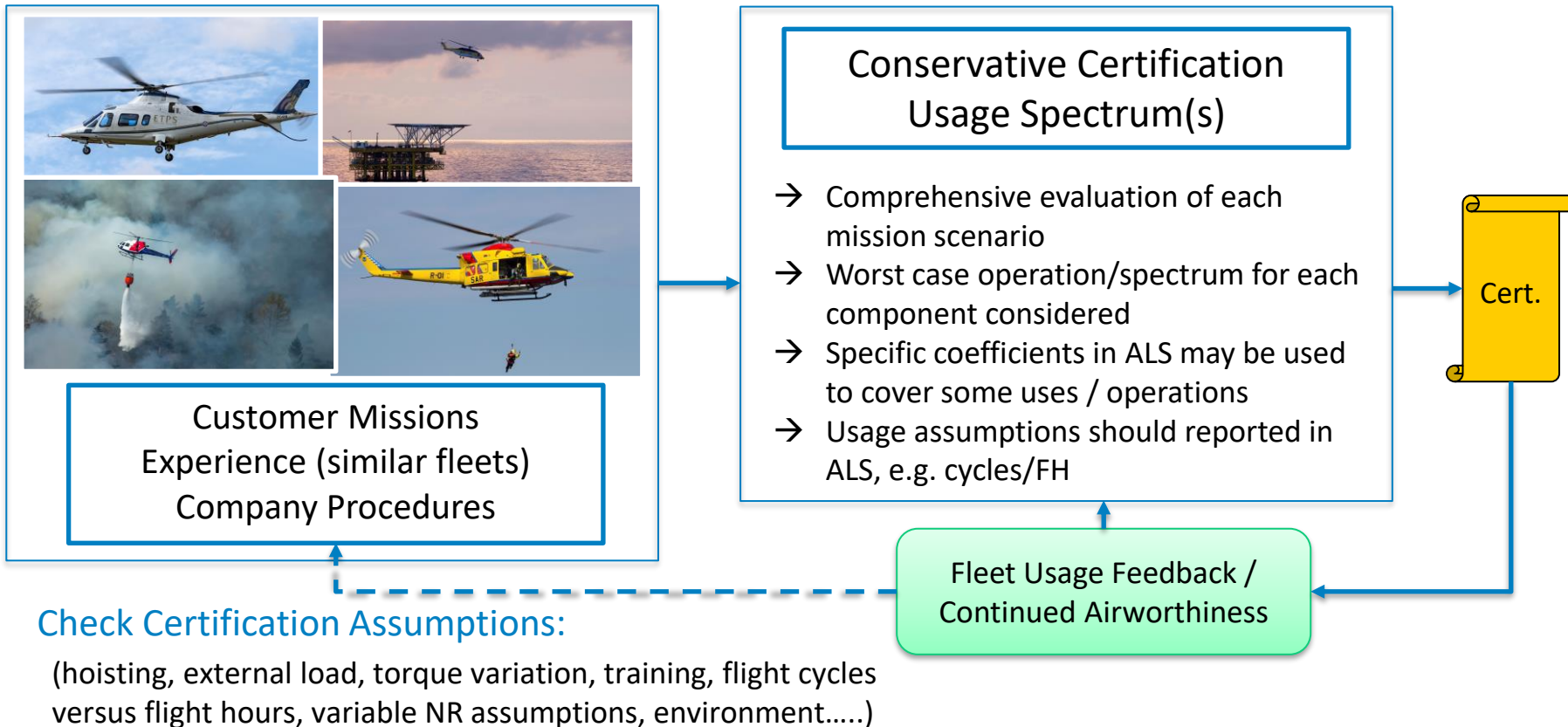
- FMEA, failure analysis or similar approach is acceptable
- Functional and structural aspects to be considered
- PSE selection should not take into account the compensating provisions
- The complete part should be considered as PSE
(Focus the substantiation on highly loaded, critical area)



STC Applications:

Be aware of PSE structure when designing modification

Fatigue Spectrum



Level of Involvement

Level of Involvement Criteria:



Novelty

- May be novel, depending on the Applicant experience.



Complexity

- May be Complex:
 - Defining appropriate methods of analysis and supporting test programmes for structures and materials with **multiple, and possibly interacting, failure modes**,
 - Accurate analysis and representative testing of **hybrid structures**,
 - Identifying and addressing the **location and potential effects of residual stresses**,
 - Decisions regarding the **acceptability of inspection techniques** in areas that are difficult to access



Criticality

- Critical, as this involves PSEs

Change classification

Change classification:



Major: Changes affecting fatigue or damage tolerance characteristics are major:

- (Re)-assessment of Interval Inspection or Life Limit
- New methodology
- New materials, process or methods of manufacture of PSEs that could impact mechanical properties or characteristics
- Updates to the ALS

Conclusion

- It is important to identify PSEs early in the compliance demonstration phase as this may affect the fatigue evaluations to be done (which may include tests)
- Spectrum should cover most severe loading for all operations
- Worst case operation for each component should be considered
- All relevant available data including fleet data usage and occurrence reports from CAW should be used by applicants to establish conservative spectrum for fatigue evaluations.
- Classification as Major and Critical for LoI

Fatigue and Fatigue Tolerance Evaluation of Metallic Structures

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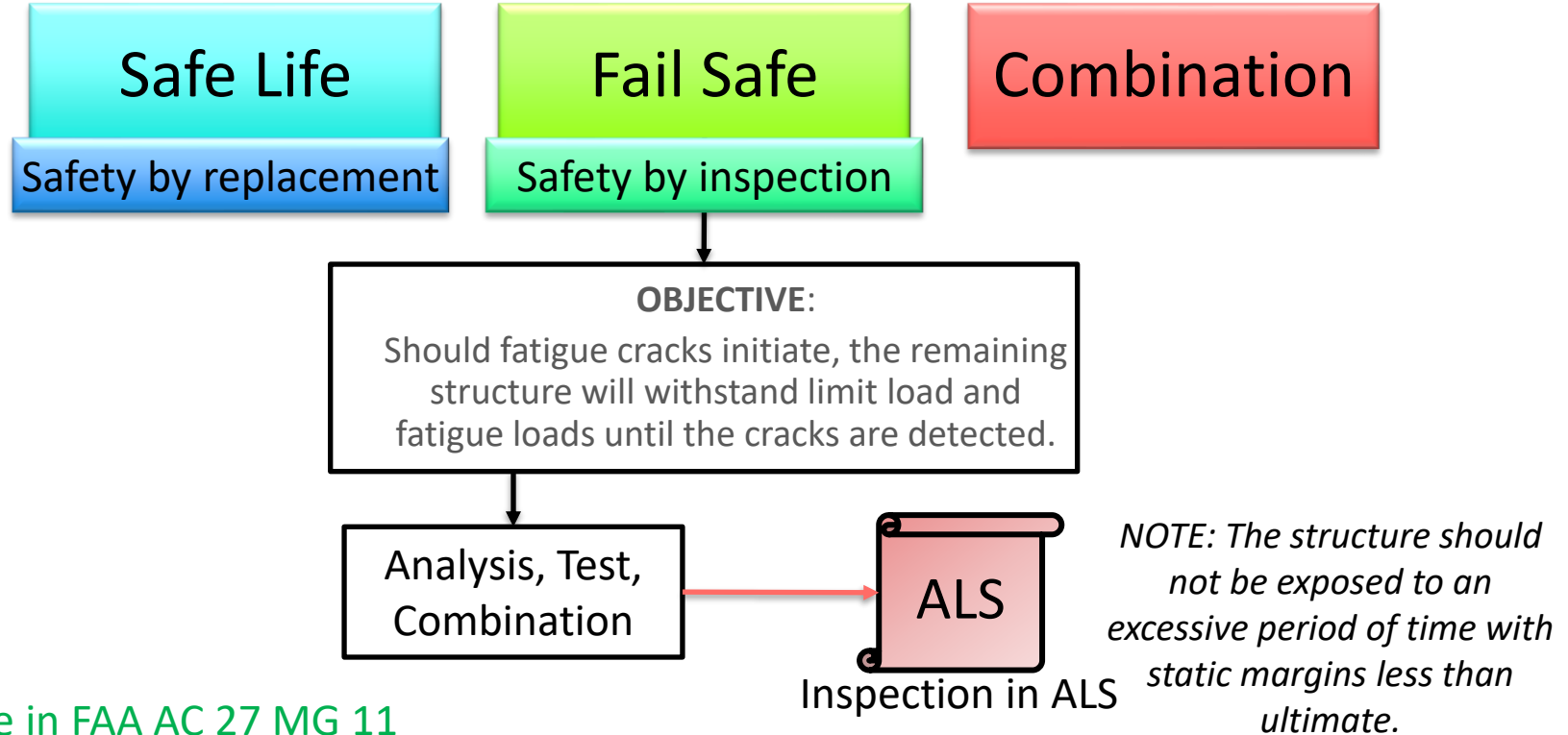
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Contents

- CS 27.571 Fatigue evaluation of flight structure:
 - Approaches
 - Simplified Safe Life Approach
 - Safe Life Approach
- CS 29.571 Fatigue tolerance evaluation of metallic structure
 - History of the requirement
 - Threat Assessment
 - Fatigue Tolerance Methods
 - Approved Equivalent Means
 - Supplemental Procedures
- Conclusion

CS 27.571 Approaches



Guidance in FAA AC 27 MG 11

CS 27.571: Simplified Safe Life Approach

Simplified Approach

Safety by replacement

MATERIAL COUPON
TESTING or PUBLISHED
DATA

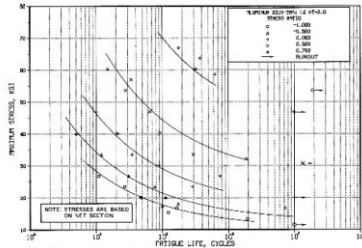
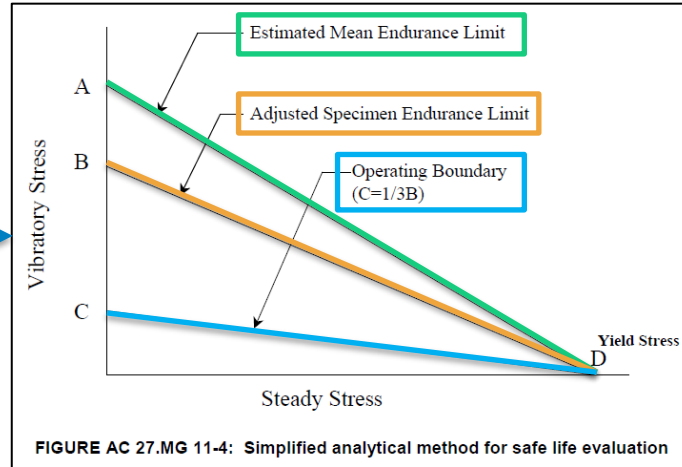


Figure 3.2.17.2.8(a). Best-fit S/N curves for notched, $K_t = 2.0$, 2219-T851 aluminum alloy plate, longitudinal direction.



Adjusted Endurance Limit:

- Surface conditions
- Fretting
- Size and Shape Effects
- Stress Concentrations
- ...

Operating Stress below Operating Boundary → no fatigue test → SLL not necessary

Operating Stress above Operating Boundary → fatigue test / other method

CS 27.571: Safe Life Approach

MATERIAL COUPON
TESTING, COMPONENT
TESTING or PUBLISHED
DATA

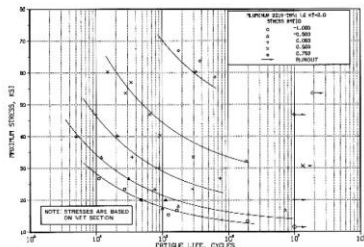
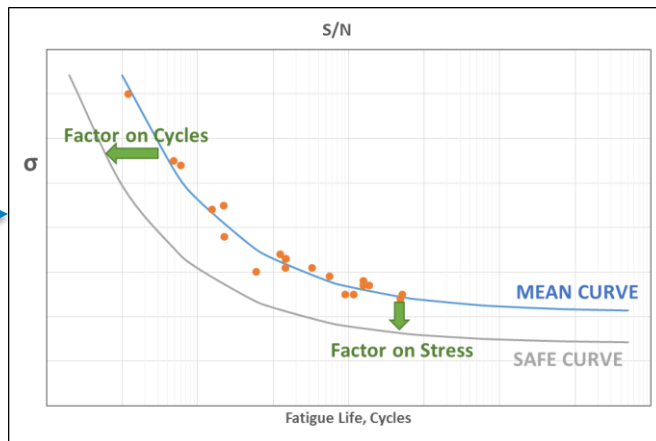


Figure 3.2.17.2.8(a). Best-fit S/N curves for notched, $K_t = 2.0$, 2219-T851 aluminum alloy plate, longitudinal direction.



Safety by replacement

Safety Factor depends on
number of tests and variability

Factor of safety (typical):

→ Low Cycle: **5** on cycles

→ High Cycle: **3** on stress

(Unless otherwise demonstrated)

Acceptable Sources of data:

→ Fatigue Curves:

MMPDS, HSB (Handbuch Strukturberechnung)

→ Stress Concentration Factor (K_t):

Peterson, ESDU, Airframe Structure Design (Niu),
HSB (Handbuch Strukturberechnung)



Service Life Limit in ALS

CS 29.571 History

FAR 29-4, Oct 1968

Fatigue evaluation of flight structure

- Safe-Life
- Fail-Safe
- Combination



FAR 29-28, Nov 1989 JAR 29
CH0, Nov 1993

Fatigue Evaluation of Structure

- Flaw Tolerant Safe-Life
- Fail-Safe
- Safe-Life



FAR 29-55, Jan 2012 CS29
Amdt.3, Dec 2012

Fatigue Tolerance

- Emphasise objective without specifying methodology
- Validation by analysis and test
- Both inspection and retirement time for PSEs (or approved equivalent means)
- **Threat Assessment**



OBJECTIVE:

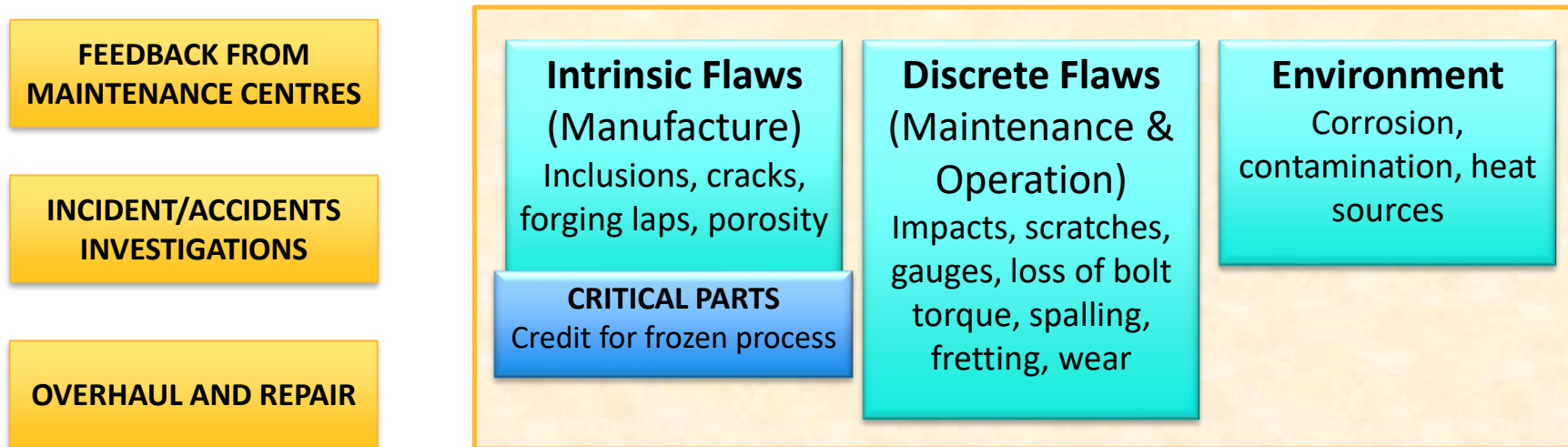
→ Retirement Time:

Baseline ultimate strength capability is not compromised during operational life: as-manufactured and with damages unlikely to be detected

→ Inspection Interval:

Strength capability never falls below limit load

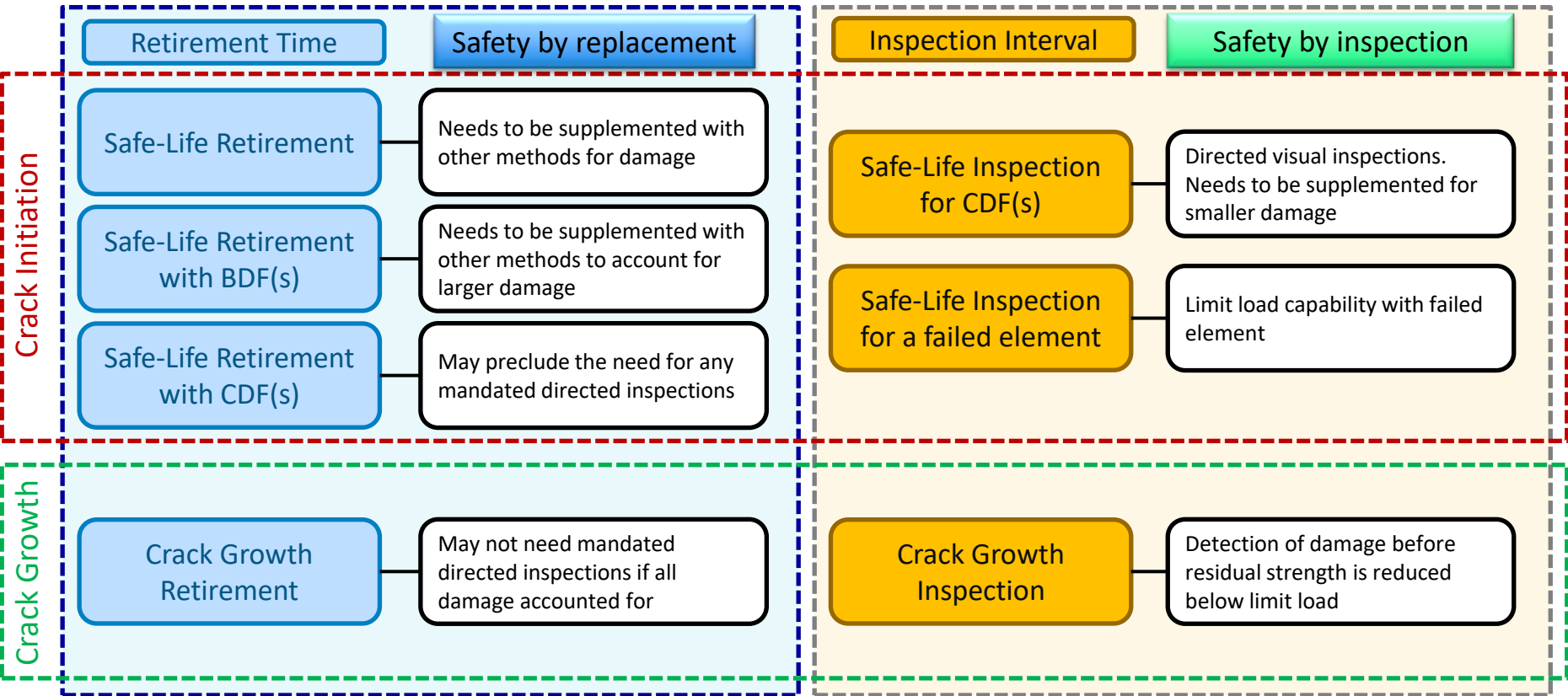
CS-29 Threat Assessment



- Probable Locations, Types and Sizes:
Specific work processes, operational environment and maintenance practices....
- Selection of critical location

Fleet Usage Feedback /
Continued Airworthiness

Fatigue Tolerance → Methods



Approved Equivalent Means

Approved **Equivalent** Means
actions to detect damage or flaws indirectly



e.g. Chip detection
in gearboxes

Threat assessment
necessary

Damage propagation
evaluation (initiation to
failure)

Time for detection must
be assessed

Reliability of the
detection means must be
demonstrated

Period of safe operation
with damage present
(initiation, detection and
corrective measure) to
be defined

Adequate level of
residual strength for
period of operation
concerned

Supplemental Procedures

Supplemental Procedures

If inspections for damage cannot be established within the limitations of geometry, inspectability or good design practice

Minimise the risk of acquiring damage and its consequences



Landing Gear

In conjunction with PSE retirement time

Threat assessment must be carried out: damage must be identified

Alternative measures:
Maintenance tasks (e.g. MSG3)
Shorter inspections / retirement time
Quality standards

Conclusions

→ CS 27.571:

- Safe-life, fail-safe or combination
- With or without replacement times or inspections in the ALS

→ CS 29.571:

- Objective Based
- Threat Assessment – key part of damage tolerance
- Crack Initiation and Crack Growth Methods
- Both small and larger damages should be addressed
- Approved Equivalent Means
- Supplemental Procedures



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