Composite and Metallic Fatigue Evaluation and Damage Tolerance

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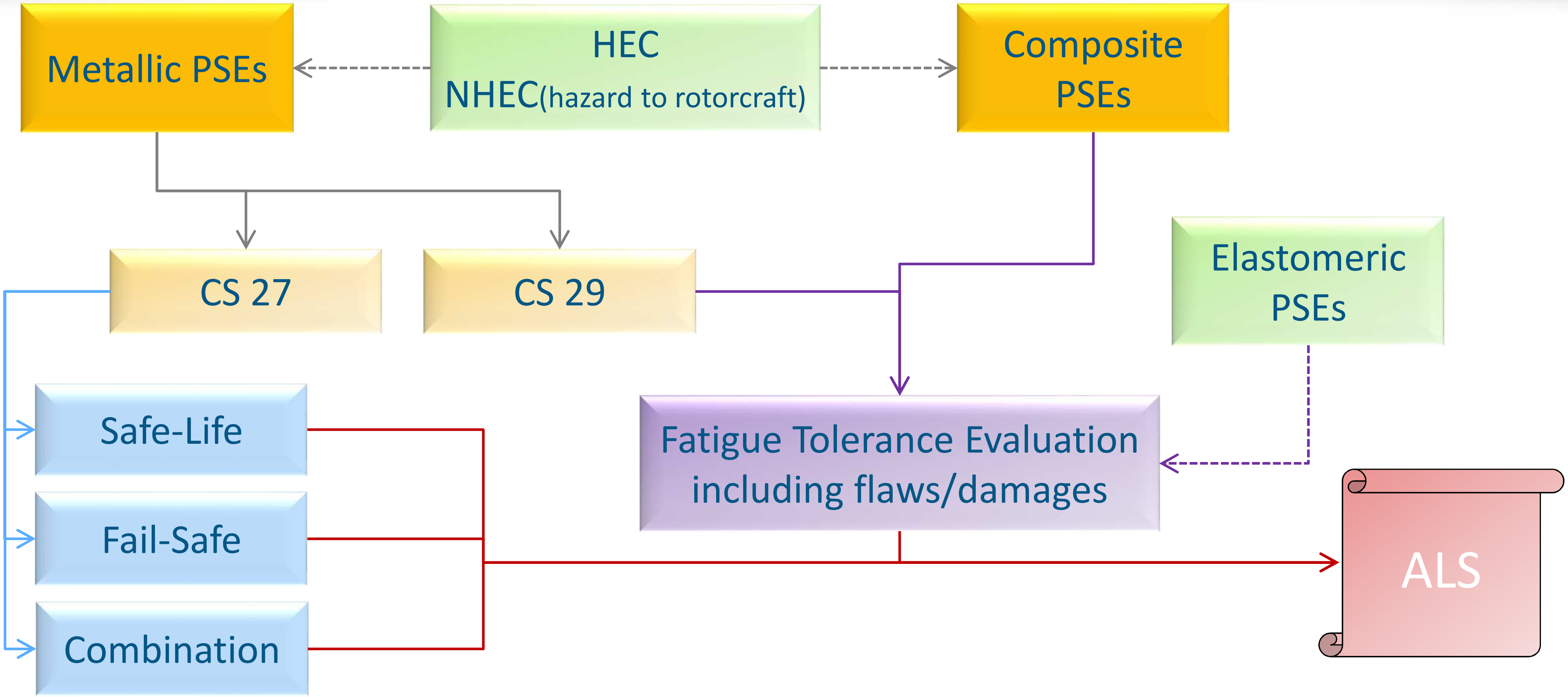
Fatigue and Damage Tolerance

- Requirements Overview
- Selection of Structure
- Fatigue Spectrum
- CS27.571 Fatigue evaluation of flight structure
- CS29.571 Fatigue tolerance evaluation of metallic structure
- CS27/29.573 Damage tolerance and fatigue evaluation of composite structures
- Hybrid

Requirements Overview



Selection of Structure

CS27.571

"Each portion of the flight structure (…) the failure of which could be catastrophic."

CS29.571 (AC29.571B)

PSEs: "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"

CS27/29.573 (AC27/29.573)

PSEs: "A structural element that contributes significantly to the carrying of flight or ground loads and **whose failure** can lead to catastrophic failure of the rotorcraft"

CATASTROPHIC FAILURE

"An event that could prevent continued safe flight and landing"

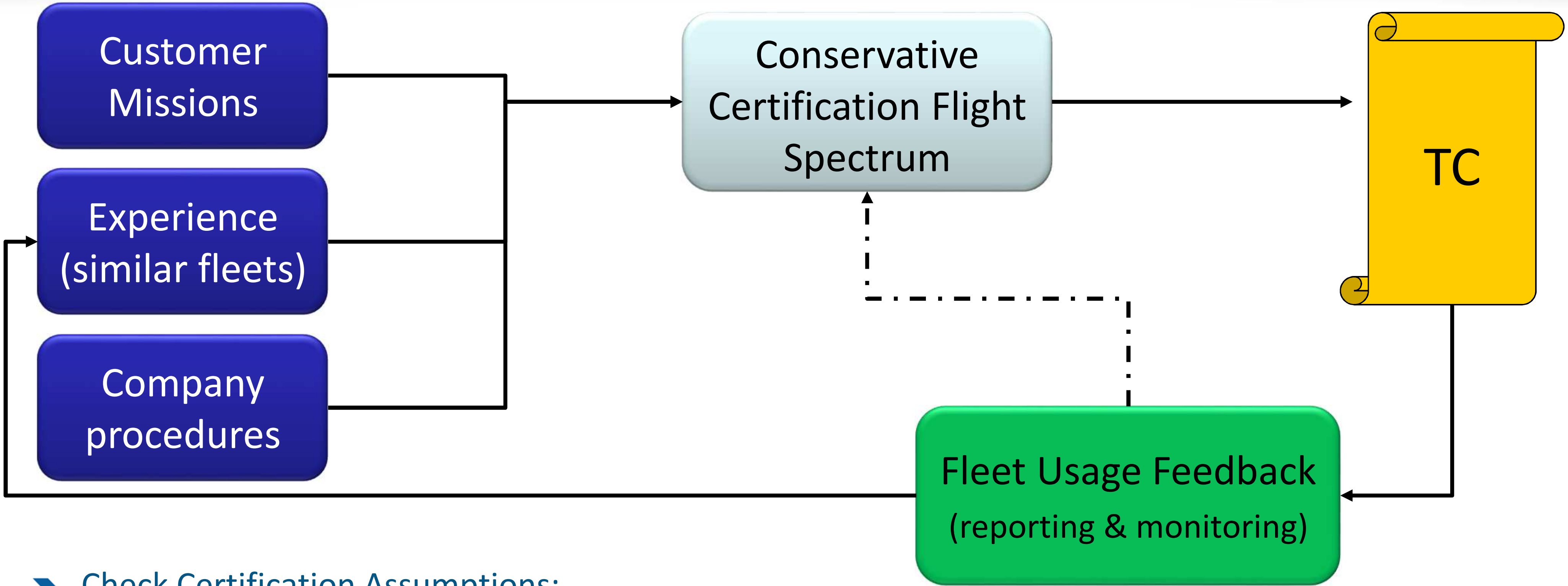
STC Applications:

Be aware of PSE structure when designing modification

- FMEA/FMECA, design assessment 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)

Fatigue Spectrum



- Check Certification Assumptions:

  (hoisting, external load, torque variation, training, flight cycles versus flight hours, variable NR assumptions, environment…..)

CS27.571: Safe Life and Fail Safe (Metallic)

- **Safe Life or Fail Safe or Combination**
- With or without replacement times or inspections
- Acceptable Sources of data:
  - Stress Concentration Factor (Kt):

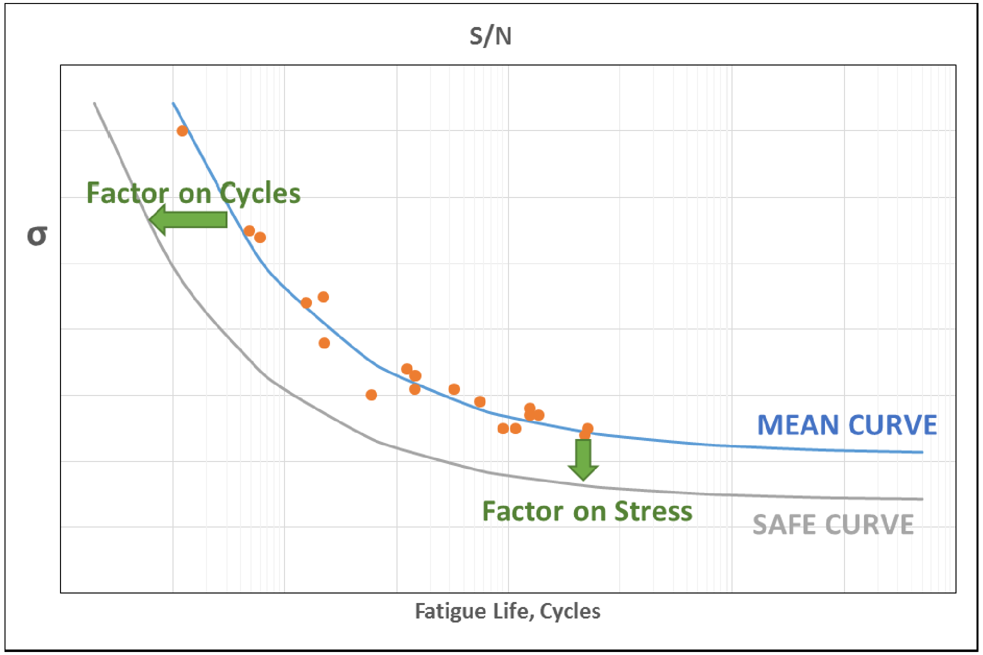
    Peterson, ESDU, Airframe Structure Design (Niu), HSB (Handbuch Strukturberechnung)

  - Factor of safety

    (typical)

    - Low Cycle: 5 on cycles
    - High Cycle: 3 on stress

    (Unless otherwise demonstrated)



CS29.571 History of Requirement

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

FLAWS

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 BASED

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

CS29.571: Threat Assessment (Metal)

FEEDBACK FROM MAINTENANCE CENTRES

INCIDENT/ACCIDENTS INVESTIGATIONS

OVERHAUL AND REPAIR

Intrinsic Flaws
(Manufacture)
Inclusions, cracks, forging laps, porosity

CRITICAL PARTS
Credit for frozen process

Discrete Flaws
(Maintenance & Operation)
Impacts, scratches, gauges, loss of bolt torque, spalling, fretting, wear

Environment
Corrosion, contamination, heat sources

Rolling contact fatigue

Probable Locations, Types and Sizes:

Specific work processes, operational environment and maintenance practices….

Selection of critical location

Fleet Usage Feedback
(reporting & monitoring)

CS29.571: Fatigue Tolerance (Metallic) AC29.571B Guidance MoC

Crack Initiation

Retirement Time

- **Safe-Life Retirement** — Needs to be supplemented with other methods for damage
- **Safe-Life Retirement with BDF(s)** — Needs to be supplemented with other methods to account for larger damage
- **Safe-Life Retirement with CDF(s)** — May preclude the need for any mandated directed inspections

Inspection Interval

- **Safe-Life Inspection for CDF(s)** — Directed visual inspections. Needs to be supplemented for smaller damage
- **Safe-Life Inspection for a failed element** — Limit load capability with failed element

Crack Growth

Retirement Time

- **Crack Growth Retirement** — May not need mandated directed inspections if all damage accounted for

Inspection Interval

- **Crack Growth Inspection** — Detection of damage before residual strength is reduced below limit load

CS29.571: Fatigue Tolerance (Metallic)

- CHALLENGES:
  - Barely Detectable Flaw (BDF) safe life:
    - Substantiation of conservative factors to cover BDF (intrinsic and discrete flaws)
      - Testing intrinsic flaws in critical areas can be challenging (e.g. inclusion at the critical depth and location)
      - Discrete flaws can be introduced in testing
  - Definition of CDF versus BDF:
    - Detectable flaw sizes and Inspection Method, validated under realistic conditions
      (CDF is readily detectable with defined inspection)
    - Defect sizes found in-service should be correlated with sizes used in certification
  - Safe-Life Inspection for CDF:
    - Needs to be supplemented to cover BDF, to cover crack initiation from BDF
  - Crack Growth:
    - Represent flaw with Bounded Equivalent Crack (BEC)
    - Dynamically loaded components
    - No crack growth: margin on threshold of propagation

CS29.571: Fatigue Tolerance (Metallic)

- Approved **Equivalent** Means (Indirect Detection)

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

CS29.571: Fatigue Tolerance (Metallic)

- Supplemental Procedures:

  Inspections for damages cannot be established within the limitations of **geometry, inspectability** or **good design practice**

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

Minimise the risk of acquiring damage and its consequences

CS§573 Fatigue Tolerance (Composite)

- CS27.573 and CS29.573 introduced in Amendment 3 (2012)
- Objective:
  - Retirement Time:

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

    Strength capability never falls below limit load
- Threat Assessment

CS§573 Threat Assessment (Composite)

FLEET FEEDBACK, MAP FROM METALS

Manufacturing Defects

voids, inclusions, bonding failures, ply gaps/overlaps, embedded foreign objects, warpage, incorrect ply sequence/ orientation, processing errors…

Impact Damages

Impact survey (tool drops, handling, vehicle collision, FOD, maintenance stands…)

Range of impactor energies and sizes

Identify damage severity and detectability

Environment

Corrosion, erosion, fluids, heat sources, thermal cycling, UV..

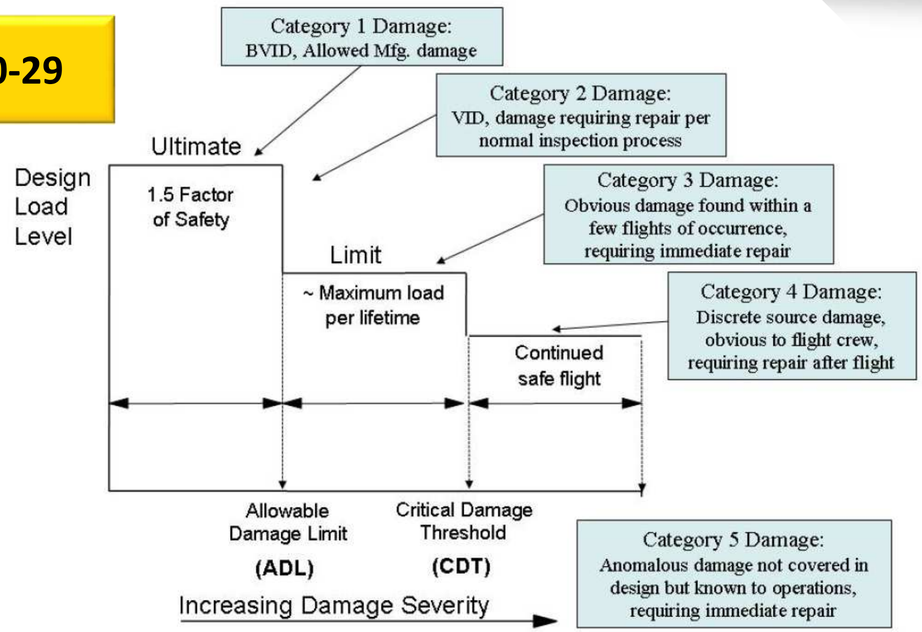
Discrete source events

Bird, lightning, hail…

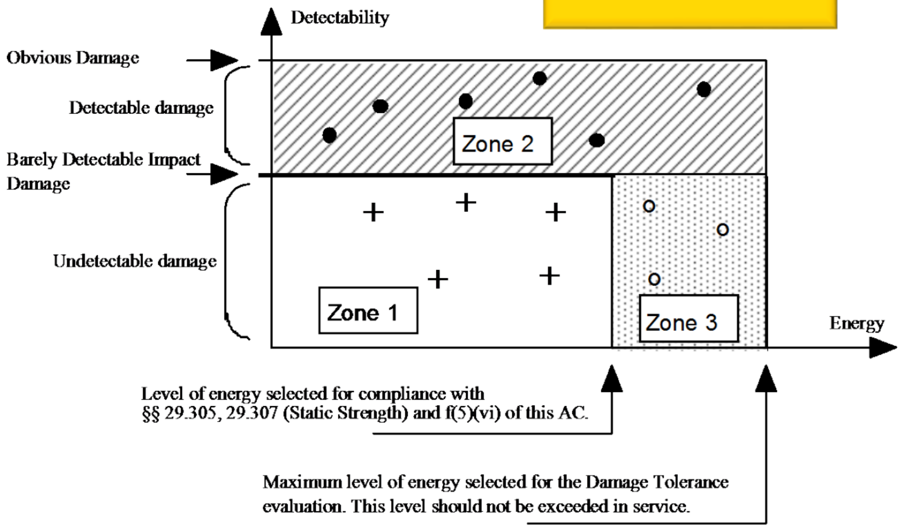
Fleet Usage Feedback (reporting & monitoring)

CS§573 Categories of Damage

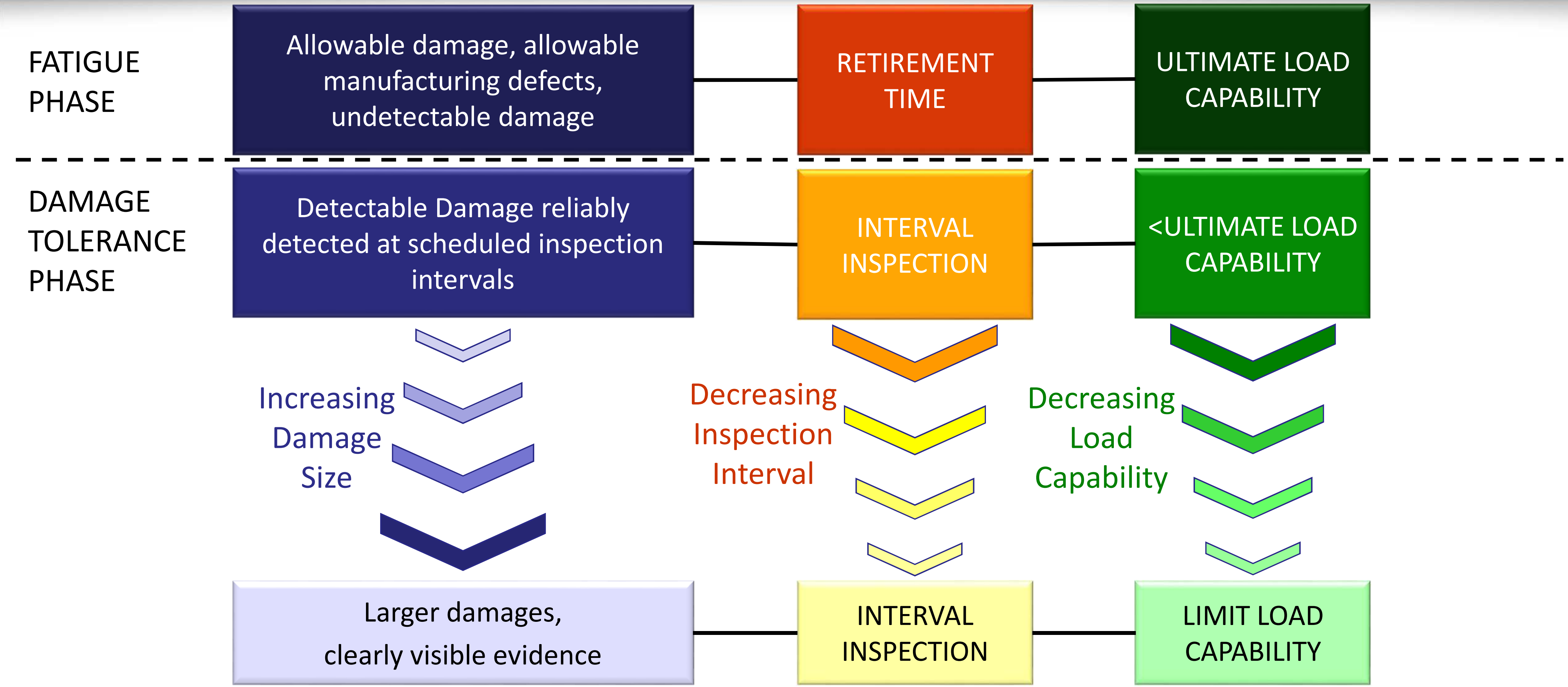
AMC 20-29



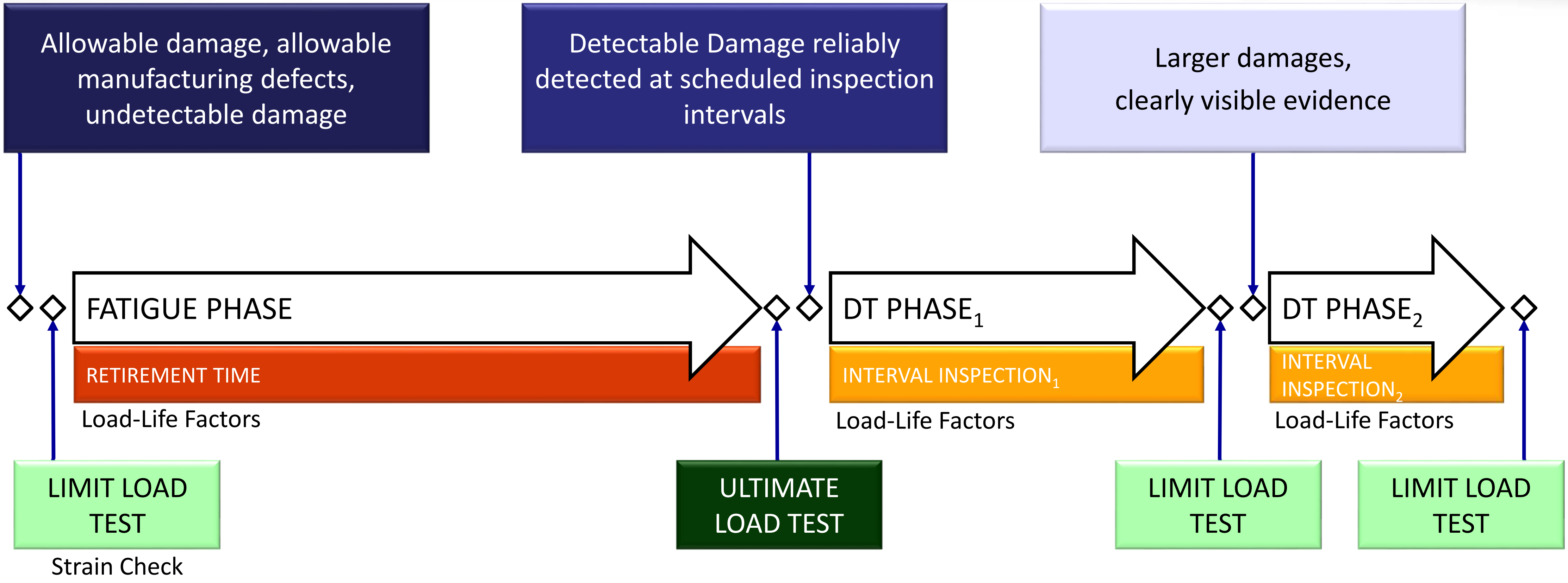
AC §573



CS§573 Damages



CS§573 Typical Test Procedure



Tests at critical temperature / humidity or appropriate factors applied, as applicable.

CS§573 Damages

Discrete source damages clearly detectable to flight crew

Flight operation limitations (e.g. speed)

Residual Strength: Limit load

Continued safe flight

Severe damage created by anomalous events

Event known to operations and requires immediate repair

Design for damage resistance

Define suitable inspections of load path

Safety Concept

CS§573: Fatigue Tolerance (Composite)

CHALLENGES

- Impact Damage
  - Categorisation of damage detectability (barely vs clearly vs obvious)
  - Dent relaxation can be significant
  - Location can influence damage detectability
  - Range of impact energy and type of impactor
- Definition of Factors
  - Environmental factors: hot-wet, cold-dry (from coupon/element, sub-component).
  - Load-Life Enhancement Factor (typical values from Certification Testing Methodology for Composite Structure, Northrop)
- Slow Growth Approach
  - **Slow, stable, and predictable damage growth** within inspection intervals
  - Inspection intervals and method to ensure time below ultimate load capability is minimized
  - Residual strength must not go below limit load
  - Stiffness, dynamic behaviour, loads and functional performance must be considered

Hybrid (Metallic & Composite)

- Challenges of hybrid structure substantiation:
  - Different test sequences for metallic and composite structure can be difficult to combine:
    - Factors applied to composite testing (LEF, environment) could be unconservative for metals or cause premature failure
    - Overloading of metals (plastification) must be avoided
  - Different thermal expansion properties:
    - Internal residual stresses due to thermal expansion mismatch
    - Dependent on size and temperature change
    - Effects in both composite and metal parts
    - Local stresses different (e.g. composite compression and metal tension) so cannot be easily addressed with a factor applied in test

Hybrid (Metallic & Composite)

- Possible strategies for addressing fatigue for composite/metal hybrids:

MULTIPLE FULL SCALE TESTS:
Demonstrate requirements for metallic and composite separately

DIFFERENT LEFs FOR DIFFERENT PARTS OF TEST SEQUENCE:
i.e. first LEF=1 to complete metal substantiation, followed by LEF>1 for composite compliance

COMBINED LOAD-LIFE APPROACH:
Apply different LEFs to different loads within the spectrum to avoid exceeding metal clipping level

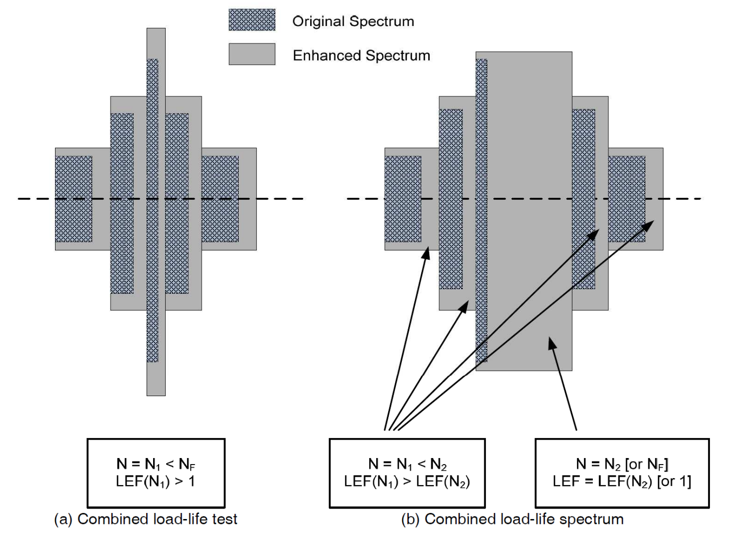


FIGURE 12.6.3.3(e) *Application of combined load-life approach.*

Conclusion

- Fatigue Evaluation for rotorcraft is complex and challenging
- Selection of Structure – always controversial
- Threat Assessment – key part of damage tolerance
- Feedback from the fleet (reporting and monitoring)
- Different approach for composite and metallic – similar objective
- Hybrid demonstration is challenging

EASA
European Aviation Safety Agency

Thank you for your attention!

Any questions....?