Fatigue Evaluation

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Requirements CS-22, CS-VLA (and CS-23)

- Requirements: CS-22, CS-VLA (and CS-23 Amdt 4)

  CS xx.627 Fatigue strength

  "The structure must be designed, as far as practicable, to avoid points of stress concentration where variable stresses above the fatigue limit are likely to occur in normal service."

  - It is accepted that it is not possible to avoid all points of stress concentration
  - Good design practices can minimise the effect:
    - AC 43.13 1B and 2B methods and practices
    - Surface Finish
    - Countersunk, edge margin, sharp edges
    - Designing against fatigue → Reduce stress concentrations
  - Design review alone is not sufficient to meet this requirement
  - Analysis supported by test, of design features with high stress concentrations or non-conventional design features is expected

Requirements CS-LSA and CS-VLA

- Parts of Structure Critical to Safety
  - CS-LSA Amendment 1:
  - ASTM F2245-12d Sub-chapter 6.2 Materials requests:

    "6.2 Materials—Materials shall be suitable and *<u>durable</u>* *for the intended use. Design values (strength) must be chosen so that no structural part is under strength as a result of material variations or load concentration, or both."*

    - This ASTM does not directly discuss fatigue, instead durability of the material

  - CS-VLA Amendment 1:
  - CS-VLA 572:

    "(a) Each part in the primary structure the failure of which can be regarded as safety critical and which could endanger the occupants and/or lead to loss of the aeroplane must be identified. (See AMC VLA 572(a).)

    (b) There must be sufficient evidence that each of the parts identified under subparagraph (a) of this paragraph has strength capabilities to achieve an *<u>adequate safe-life</u>**. (See AMC VLA 572(b).)"*

Requirements CS-LSA and CS-VLA

- AMC VLA 572 and CS-LSA AMC 1 provides additional guidance
  - Applicable structure, at least (AMC VLA 572(a)):
    - Wing main spar
    - Horizontal tail and attachments
  - AMC VLA 572(b) and CS-LSA AMC1

"The use of the following stress levels may be taken as sufficient evidence — in conjunction with good design practices to eliminate stress concentrations — that structural items have adequate safe lives:

Material used	Allowable normal stress level of maximum limit load
– Glass rovings in epoxy resin	25 daN/mm^2
– Carbon fibre rovings in epoxy resin	40 daN/mm^2
– Wood	According to ANC-18*
– Aluminium Alloy	Half of rupture tensile strength
– Steel Alloy	Half of rupture tensile strength

Higher stress levels need further fatigue investigation:

By a fatigue test, based on realistic operating spectrum

By a fatigue calculation using strength values which have been proved to be sufficient by fatigue tests of specimens or components"

Means of Compliance: CS-LSA and CS-VLA

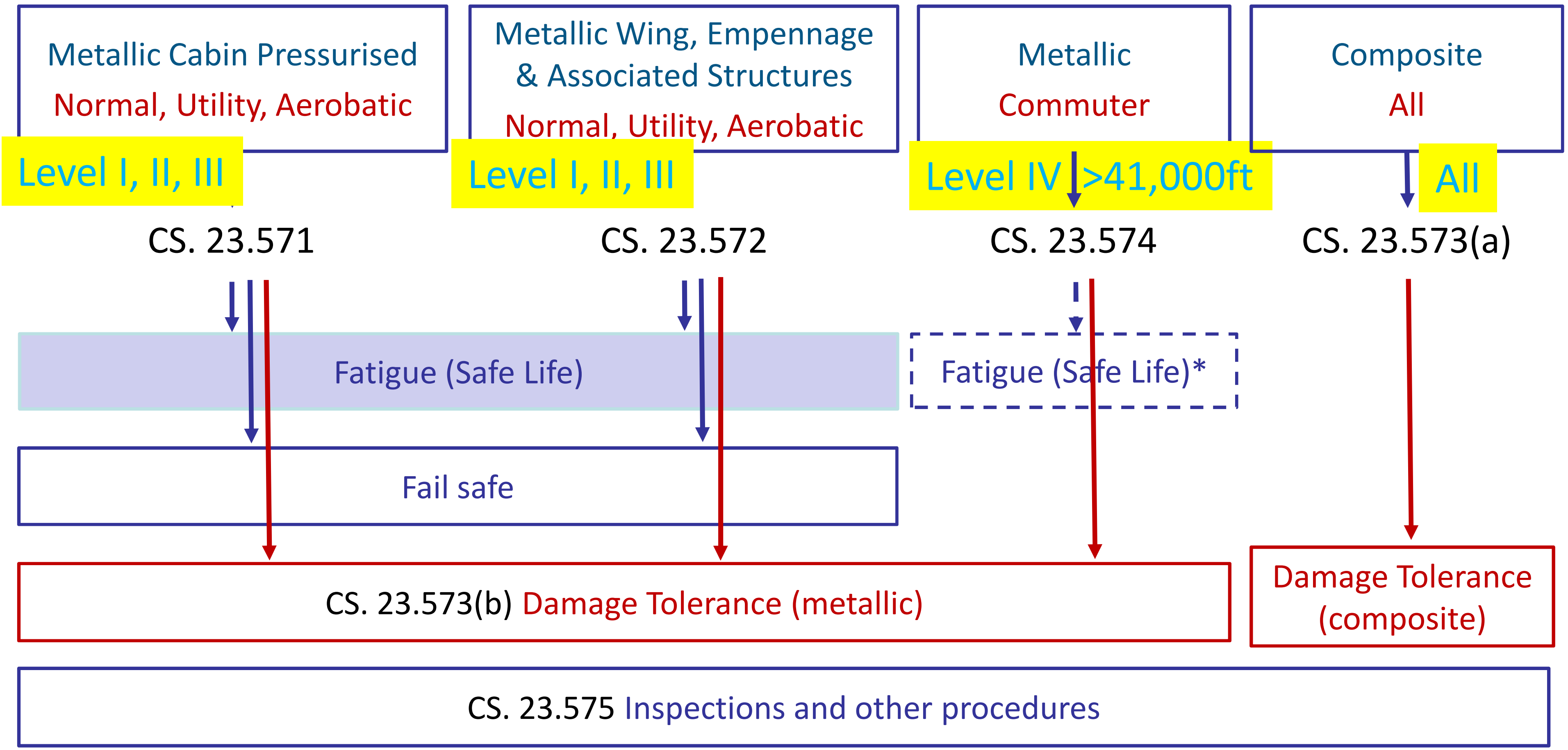
- Acceptable Means of Compliance (AMC VLA 572(a) and CS-LSA AMC1):
  - In the absence of a detailed structural analysis, the measurement of stress levels (or strain) in critical locations during full-scale structural static tests can be accepted
  - Notes:
    - This approach will require significant discussion with EASA to agree approach for good design practices, identification of critical locations, test protocol, stress measurement locations, analysis validation/correlation etc.
    - No certification test should be performed before the relevant test plan is accepted (or no EASA involvement is agreed) and conformity of the test specimen and test setup is ensured by accepted processes.
    - Use of AMC VLA 572(b)(1) or AMC CS-LSA 1 is not acceptable for aircraft in the aerobatic category; fatigue investigation is necessary
  - Alternatively for Metallic airframe, a test with a static overload factor could be discussed to address fatigue for CS-LSA and CS-VLA (and CS-22)
  - Composite Aircraft: Further guidance in Cert Memo CM-S-006

Means of Compliance: CS-22

- Acceptable Means of Compliance (CS-22):
  - Common approach is to refer to representative previous fatigue tests
  - If similarity to representative test is made, then the “referenced” structure or test should be assessed with regard to:
    - Operating stress levels (including all operational or life limits)
    - Load spectrum
    - Construction, detailed design including effects of stress concentration,
    - Materials, including variability, environmental effects and fabrication methods

Requirements CS-23 Amendment 4

- CS 23.571, 23.572, 23.573, 23.574, 23.575



* if it can be established that the application of those requirements is impractical for a particular structure

Level I metallic unpressurised as current CS-VLA

Requirements CS-23 Amendment 5

CS 23.2240 Structural durability

a) The applicant must develop and implement inspections or other procedures to prevent structural failures due to foreseeable causes of strength degradation, which could result in serious or fatal injuries, or extended periods of operation with reduced safety margins. Each of the inspections or other procedures developed under CS 23.2240 must be included in the Airworthiness Limitations Section of the Instructions for Continued Airworthiness required by CS 23.2625.

b) For Level-4 aeroplanes, the procedures developed for compliance with CS 23.2240(a) must be capable of detecting structural damage before the damage could result in structural failure.

c) For pressurised aeroplanes:

1) the aeroplane must be capable of continued safe flight and landing following a sudden release of cabin pressure, including sudden releases caused by door and window failures;

2) for aeroplanes with maximum operating altitude greater than 12 497 m (41 000 ft), the procedures developed for compliance with CS 23.2240(a) must be capable of detecting damage to the pressurised cabin structure before the damage could result in rapid decompression that would result in serious or fatal injuries.

d) The aeroplane must be designed to minimise hazards to the aeroplane due to structural damage caused by high-energy fragments from an uncontained engine or rotating-machinery failure.

ASTM F3115/F3115M Standard Specification for Structural Durability for Small Airplanes

CS 23: Applicable Structure

- Structure to be assessed for CS-23 as a minimum under 23.571, 23.572 and 23.573, 23.574:
  - Pressurised cabin
  - Wing, empennage, their carry-through and attaching structures:
    - Parts of the airframe structure whose failure would be catastrophic
  - For commuter:
    - Engine mounts
    - Landing gears and their related primary attachment
- ASTM F3115/F3115M
  - Unpressurized Level I Airplanes (Metallic):
    - Safety critical parts (primary structure, the failure of which can be regarded as safety critical and which could endanger the occupants or lead to loss of the airplane, or both.)

CS 23: Applicable Structure

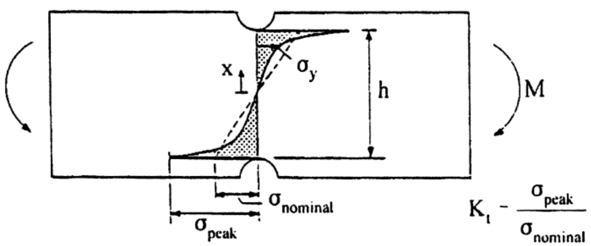
- Applicable Structure under 23.572
  - 23.572: The applicable metallic structure must be evaluated unless it is shown that the structure, operating stress level, materials and expected uses are comparable, from a fatigue standpoint, to a similar design that has shown satisfactory service experience
    - Design similarity can only be considered by comparison to aircraft or components with comparable complexity level and designed by the same manufacturer.
    - The compliance by similarity can be granted providing that the same or similar methodology for the fatigue demonstration has been used.
    - For high performance aircraft, similarity may not be accepted as the operating stress level and the expected use of these aircrafts may no longer be comparable to the conventional CS 23 aircrafts (increased performance, high altitude operation, high speed, extended range…).

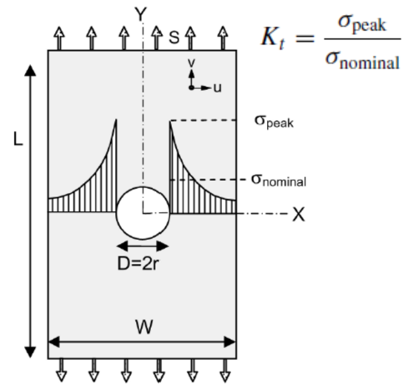
CS 23 (Metallic): Safe Life Evaluation

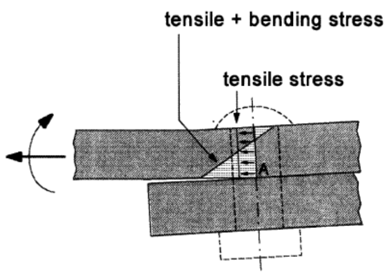
- Safe Life Fatigue Evaluation Overview
  - Aims at ensuring that the airplane and/or components will reach their life limit without crack initiation
  - Safe-life of a structure can be determined using full-scale testing, component testing, analysis supported by test evidence
  - Steps in evaluating safe-life:
    - Estimate or measure the expected load spectrum
      - AC 23-13A spectrum are accepted where applicable to the usage
      - Care should be taken when the aircraft is certified for different operational usages, e.g. aerobatics, mixed-usage, unlimited aerobatics, cargo
    - Conduct structural analysis, including determination of gross stress levels and determination of the stress concentration factors K_T
    - Conduct fatigue test(s) or fatigue substantiation by analysis
    - Determine reliable replacement times (use of fatigue scatter factors or other statistical approach)
    - Provide data for inspection and maintenance instructions and guidance to operators (CS 23.1529)

CS 23 (Metallic): Safe Life Evaluation

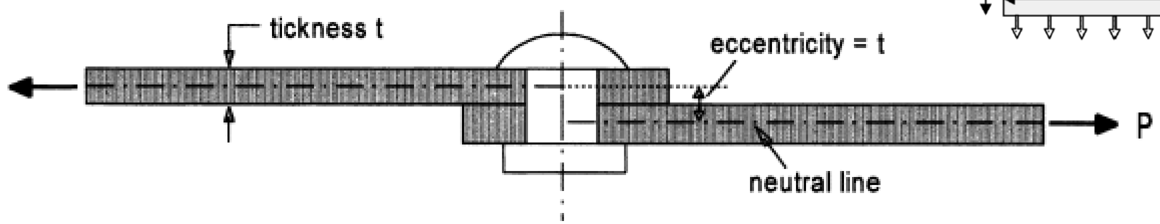
- Structural Analysis
  - Special attention focused on design details of important discontinuities, main attachment fittings, tension joints, splices and cut-outs such as windows, doors or other openings.
  - Stress concentration factors (Kt):
    - Kt is an important parameter for fatigue analysis (S-N curve for specific Kt)
    - Acceptable Sources: Peterson, ESDU, Airframe Structure Design (Niu), HSB







Eccentricity in complex joints (e.g. lap joint)



CS 23 (Metallic): Fatigue Tests

- Fatigue Tests
  - Full scale test is most reliable method:
    - Complete or nearly complete airframe
    - Or, a series of separate tests of the major sub-assemblies of the airframe where the load applied by the omitted structure will be simulated
    - Complete wing assembly
    - Empennage assemblies (HTP or VTP)
    - Pressurised Cabin Test
  - Component testing, e.g. attachment fittings and spars
  - Fatigue substantiation by analysis is also acceptable, provided that the data used (S-N or ε-N) is based on fatigue tests of similar structures or adjusted to account for differences
  - Advantage of fatigue test:
    - Lower scatter factor
    - Includes normal manufacturing tolerances
    - Detects unexpected high stress concentration

CS 23 (Metallic): Scatter Factor

- Scatter Factors:
  - Scatter factors apply to the tested or calculated fatigue life to account for:
    - Material variability
    - Load uncertainties
    - Amount of test evidence
    - Number of specimens
  - A minimum scatter factor of 5 is typical for structure supported by one full-scale test
  - Scatter factor of 5 also acceptable to landing gear and engine mounts when supported by one component test
  - FAA Advisory Circular AC 23-13A:
    - Also provides recommendations for scatter factors to be used in fatigue analysis and tests.
    - Concerning the scatter factors, the methodology adopted in the AC23-13A for scatter factors determination on safe life structure is also acceptable to EASA.

Conclusion

- **Fatigue approach**
  - Light aircraft
    - Good design practices to reduce stress concentrations
    - AMC VLA 572 and CS-LSA AMC allows comparison of stress level at limit load
    - Higher stress levels and aerobatic category need further fatigue investigation
    - For metallic airframe, a test with a static overload could be discussed
    - Common acceptable approach for CS-22 is to refer to representative fatigue tests
  - CS 23
    - Metallic normal, utility and aerobatic allows applicant choice for compliance: safe-life, fail safe or damage tolerance
    - Composite and commuter require damage tolerance
    - For CS-23 Amendment 5, operation >41,000ft also required damage tolerance
  - Safe life
    - Simple robust approach to address fatigue but not flexible – part replacement time
    - Does not account for the behaviour of cracks in the material
    - Corrosion, accidental damage are not addressed in fatigue evaluation
    - Inspectability and detectability of fatigue sensitive areas not systematically addressed
    - Difficult for STC to assess the impact on safe life for modified primary structure

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Thank you for your attention!

Any questions….?

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