

Fuselage Structural Integrity Forum – Regulatory Requirements for Design and Certification

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Objective of Panel

The purpose of this panel is to educate both the NTSB and public on the certification requirements and the acceptable means of compliance for those requirements, as related to design and certification of fuselage structure.

Overview of Presentation

- **How is a fuselage loaded?**
- **What are in-service, limit, ultimate, and residual strength loads and corresponding 14 CFR part 25 requirements?**
- **What are acceptable methods for validating loads?**
- **What are the static strength requirements and methods for demonstrating compliance to them?**
- **What are the fatigue management strategies that have been used for transport airplanes?**
- **What are the fatigue and damage-tolerance requirements and methods for demonstrating compliance to them?**



Fuselage Loads

- **Differential pressure, ΔP**
 - Difference between internal cabin pressure and outside ambient pressure
 - Generally increases with increasing altitude and depends on the cabin pressurization schedule.
- **Inertia (causes overall body bending, shear and torsion)**
 - Flight maneuvers (pitch, roll, yaw)
 - Gusts (vertical, lateral, head-on)
 - Landing
 - Ground taxi and turning
 - Ground handling
- **External aerodynamic pressure (+ or -)**

In-Service Loads

- **Typical loads expected in service**
 - Based on historical data (e.g., N_z spectra) and analyses (e.g., PSD gust) for airplane type
 - Accounted for in load sequences used for fatigue and damage-tolerance analyses and tests
- **Maximum in-service loads over an operational life are typically 60-80% of design limit, the majority of frequently repeated loads encountered from gust and maneuvers are much lower**

Limit Loads

- **Maximum “once in a lifetime” loads expected over an operational life**
- **Load conditions specified in § 25.365 (pressurized compartments) that are required to be evaluated include—**
 - (flight loads) + (ΔP from zero up to maximum relief valve setting) + (external pressure distribution in flight)
 - (landing loads) + (ΔP from zero up to maximum relief valve setting allowed during landing)
 - Maximum relief valve setting multiplied by a factor of
 - 1.33 (operation to 45000 feet)
 - 1.67 (operation above 45000 feet)

Ultimate Loads

- **§ 25.303 Factor of safety**

“Unless otherwise specified, a factor of safety of 1.5 must be applied to the prescribed limit load which are considered external loads on the structure. When a loading condition is prescribed in terms of ultimate loads, a factor of safety need not be applied unless otherwise specified.”

Ultimate = 1.5 x Limit unless otherwise stated

Residual Strength Loads

- **Associated with damaged structure**
- **Treated as ultimate (no 1.5 factor applied)**
- **Requirements specified in—**
 - § 25.365(e) for loss of pressurized compartment integrity (e.g., engine disintegration, inadvertent door openings)
 - § 25.571(b) for fatigue damage
 - § 25.571(e) for discrete source damage

§ 25.365(e) Residual Strength Loads

- **Used to show—**
 - Structure is capable of withstanding the sudden release of pressure
 - No failure of bulkheads, floors and partitions in occupied areas
- **Must evaluate ΔP loading due to sudden release of pressure through an opening in any compartment at any operating altitude combined with—**
 - 1G level flight loads and,
 - Any loads arising from emergency depressurization conditions

§ 25.571(b) Residual Strength Loads

- **Used for residual strength evaluations performed to—**
 - Establish fatigue damage inspections
 - Demonstrate freedom from widespread fatigue damage (WFD) (e.g., on full-scale fatigue test article)
- **Must evaluate separately—**
 - Specified limit flight conditions plus normal operating ΔP and expected external aerodynamic pressure
 - $1.15 \times [(\Delta P_{\max}) + (1G \text{ level flight external aerodynamic pressure})]$

§ 25.571(e) Residual Strength Loads

- **Used to show airplane can “get home”**
- **Flight loads at V_C at sea level or $.85 V_C$ at 8000 feet with impact with a 4 pound bird**
- **Reasonably expected loads during flight during which airplane experiences**
 - Uncontained fan blade impact
 - Uncontained engine failure
 - Uncontained high energy rotating machinery failure

Validation of Limit Loads

- **Required by § 25.301 unless analytical methods shown to be reliable**
- **Limit flight and ground loads validated by testing**
 - Calibrated production airplane
 - Critical in-flight and ground maneuver conditions flown
 - Measured versus predicted loads compared

Static Strength Design Requirements

- **§ 25.305 Strength and Deformation**
 - No detrimental permanent deformation at limit
 - No failure at ultimate

Static Strength Demonstration

- **§ 25.307 requires showing compliance with the strength and deformation requirements for each critical loading condition**
- **Static strength of basic airframe structure typically demonstrated by testing**
 - Early production airframe
 - Critical flight and ground limit conditions
 - Selected ultimate conditions sometimes applied
- **Static strength demonstrated by analysis for structure and conditions not covered in test and where methods are shown to be reliable**
- **§ 25.843 requires pressurizing the fuselage to the applicable pressure differential specified in § 25.365**

Fatigue Management Strategies

- **Structure will be retired and replaced at a pre-determined time (Safety-by-Retirement a.k.a. “Safe-Life”)**
- **Structure is designed to “talk to us” when it is in distress (Safety-by-Design a.k.a. “Fail-Safe”)**
- **Structure will be inspected at pre-determined intervals and replaced, repaired, or modified as necessary when cracks are found (Safety-by-Inspection a.k.a. “Damage-Tolerance”)**

Safety-By-Retirement (SBR)

- **Oldest regulation strategy (1945)**
- **Based on proactive replacement or modification at an established time, regardless of condition**
- **“Run and retire” without dedicated inspections for cracks**



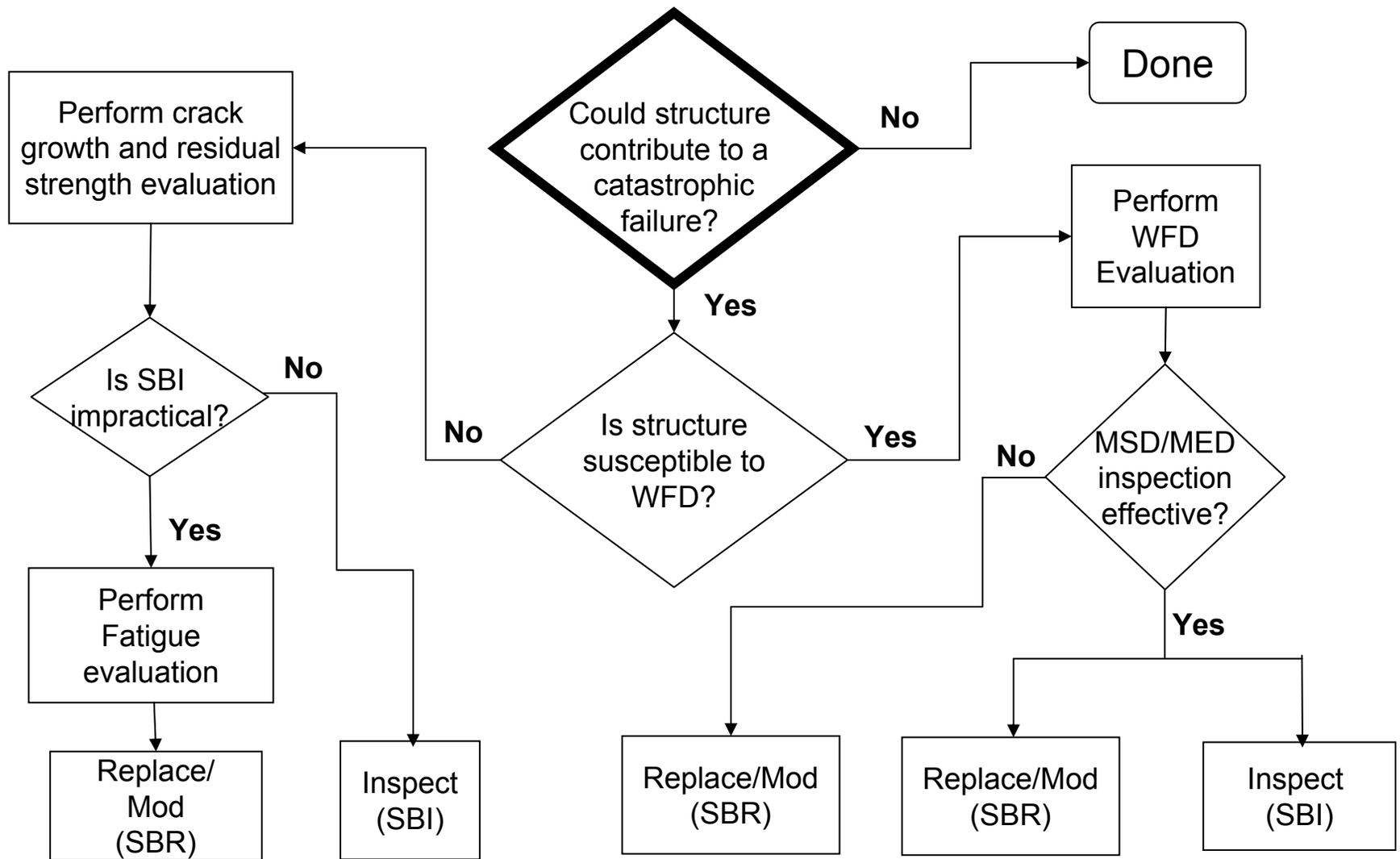
Safety-By-Design (SBD)

- **Second oldest regulatory strategy for addressing fatigue (1956)**
- **Premise: structure can be designed to have inherent characteristics so catastrophic failures will always be preceded by “obvious” and safe precursors**
- **Structure can remain in service until:**
 - Fatigue damage is obvious
 - Strength degrades significantly below ultimate
- **Removed from Part 25 in 1978 with Amdt. 25-45**

Safety-By-Inspection (SBI)

- **Newest regulatory strategy to address fatigue (1978)**
- **Based on detecting fatigue cracking before strength capability falls below specified level**
- **Requires evaluation of crack growth and residual strength characteristics**
- **Dependent on:**
 - Knowing where and how cracking will occur
 - Reliability of inspection system/process
- **May not be practical in some cases**

§ 25.571 Fatigue Management Strategy Roadmap



Fatigue and Damage Tolerance Requirements

- **Applicable to all structure that could contribute to a catastrophic failure**
- **Constitute evaluation requirements as opposed to design requirements**
- **Based on results of evaluations, maintenance actions (e.g., inspections or other procedures) must be established as necessary to ensure that the required residual strength is retained**

Fatigue and Damage Tolerance Requirements (cont'd)

- **Safety-by-inspection must be used for structure not susceptible to WFD unless shown to be impractical**
- **Safety-by-retirement must be used when SBI is shown to be impractical**
- **SBI may not be used as the primary line of defense for WFD susceptible structure**
 - Eventual replacement/modification is required to continue operating the airplane
 - Inspection may only be used to supplement eventual replacement/modification if determined to be effective

Fatigue and Damage Tolerance Requirements (cont'd)

- **It must be demonstrated that WFD will not occur prior to the LOV* established by the applicant**
- **§ 25.1529 and Appendix H require the LOV and all maintenance actions necessary to support it be included in the Airworthiness Limitations section of the Instructions for Continued Airworthiness (ICA)**

*Limit of validity of the engineering data that supports the structural maintenance program

Fatigue and Damage Tolerance Demonstration

- **WFD-susceptible structure**
 - Full-scale fatigue test (FSFT) evidence required
 - Post FSFT demonstration of strength capability
 - Residual strength loading; and/or,
 - Extensive teardown inspection
- **Structure not susceptible to WFD**
 - Linear elastic fracture mechanics based analyses supported by coupon and component tests

Summary

- **14 CFR part 25 includes a comprehensive set of requirements to help ensure long term structural integrity – both intact and damaged conditions must be evaluated**
- **14 CFR part 25 addresses the importance of the fuselage as a pressure vessel – special pressure only cases must be addressed in addition to design limit flight and ground conditions**
- **14 CFR part 25 requires substantial validation of limit loads and structural design attributes using production articles—**
 - Flight and ground loads testing (design limit loads validation)
 - Full-scale static testing (limit and ultimate strength capability)
 - Full-scale fatigue testing (freedom from WFD)