Structural Analysis Substantiation

To Support
Modification Certification Efforts

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ACD Conference 2019
Atlanta, Georgia

Structural Substantiation

- Structural Analysis Substantiation has been an integral part of Commercial Certification for a long time:

- **<u>Air Bulletin 7A (1934)</u>** – *"A stress analysis supplemented by test data if necessary, covering an investigation of all primary structural members for compliance with the requirements outlined in theses regulations".*

- **<u>CAR 04 (1937)</u> –** *"Structural analyses will be accepted as complete proof of strength only in the case of structural arrangements for which experience has shown such analyses to be reliable".*

- **<u>CAR 4B.202 (1953)</u>** – *"Proof of compliance by means of structural analysis shall be acceptable only when the structure conforms to types for which experience has shown such methods to be reliable."*

- **<u>FAR 25.307 (a)(Present)</u>** – *"..Structural analysis may be used only if the structure conforms to that for which experience has shown this method to be reliable."*

Structural Substantiation

- Structural Analysis Substantiation has likewise been a requirement for certification of modifications of existing type designs. In addition, guidance by the Airworthiness Authorities has been :

- **FAA AC 20-14 Section 5-3 Substantiating/Compliance Data**

d. Structural analyses establish mathematically that the appropriate structural strength requirements have been met. These analyses build on the basic loads and material allowable data and may include: static stress, fatigue, fail safe, damage tolerance, etc. The applicant should assure that the analytical methods and assumptions used are applicable, that all pertinent loading conditions have been addressed , and that appropriate margins of safety have been shown for all structural elements.

Structural Substantiation

- Modifications to certified aircraft/rotorcraft are a prominent part of the commercial aviation industry.
- Modifications are made to all certified types and for all types of reasons.
  - Presently Over 70,000 FAA Supplemental Type Certificates
  - STCs for Large Aircraft, Small Aircraft, Rotorcraft
  - STCs for Engines and Propellers
- Due to nature of many STC's, the structural substantiation can be extensive and sometimes difficult for the applicant to determine both the applicable approach and the extent required.
- Choice of substantiation method can have significant impact on schedule, cost and certification of STC.

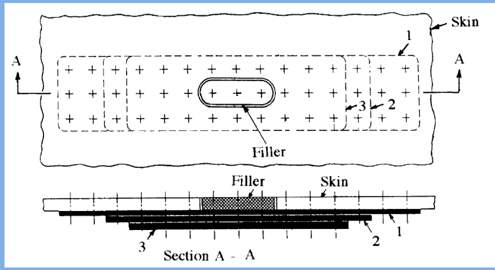
Structural Substantiation

- Some examples of STC's are
    - Increased GW
    - Antennas and Radomes
    - Special Mission
    - Cargo Doors
    - Winglets

- Typical Methods of Substantiation:
    - Equivalent Strength
    - Finite Element Analysis
    - Industry Standard Methods

Structural Substantiation

- Static Strength Substantiation
  - Analysis by Equivalent Strength



Equivalent Area

- Pros:
  - Does Not Require External Loads
  - Does Not Require Internal Loads
  - Design is based on Equivalency
  - Usually Based only on Mech Props
  - Equiv. Sect Props & Materials
  - Limited Effort Required

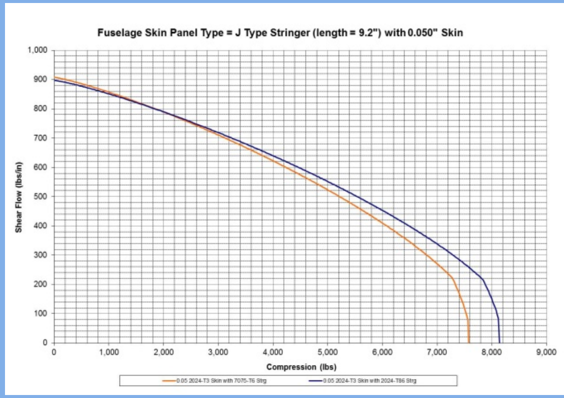
- Cons:
  - Cannot account for load redistribution
  - Difficult to account for structure reliant on combined allowables
  - Difficult to address Non-linearities
  - Difficult to check all failure modes
  - Results in heavy design

- Certification Limitations
  - Generally limited to Repairs
  - Can be used on modifications without major load redistribution
  - Cannot be used for Cargo Door or Large Cutout Modifications

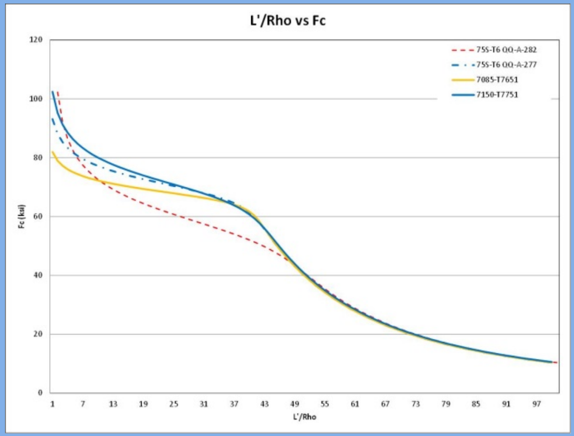
Structural Substantiation

- Static Strength Substantiation
  - Examples of Items Difficult to Address thru Equivalent Strength:

- Example 1:
  - Skin & Stringer Panel Replacement
    - Different Stringer Shape
    - Different Skin Material
  - Panel Allowables generally based on post buckled behavior & test data



- Example 2:
  - Beam Column Type Structure
  - Allowables based on Strain and Modulus
  - Simple Mechanical Properties Comparison is not Valid



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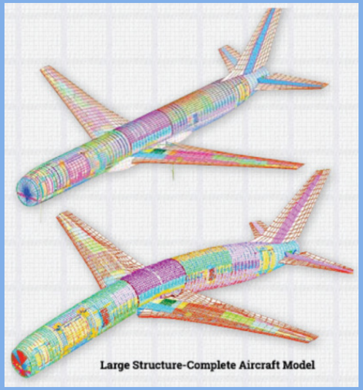
Structural Substantiation

- Static Strength Substantiation
  - Substantiation by Finite Element Analysis

- Pros:
  - Provides Detailed Internal Loads
  - Can Provide Detail Stresses
  - Accounts for Load Redistribution
  - Provides Details Part Analysis
  - Reduces Conservatism
  - Interfaces with CAD Design Models
  - Can be Readily Modified

- Cons:
  - Requires External Aircraft Loads
  - Requires Substantial Dwg Data
  - Requires Validation/Test Data
  - Difficult to Handle Non-Linearity
  - Stress Models Difficult to Correlate
  - Must be Within 10% Correlation
  - Time Consuming

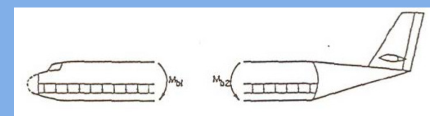
- Certification Limitations
  - Results Must be Validated
  - Results Must Correlate within 10% of Test Data
  - Complex Validation for Non-Linearity/Stress Models



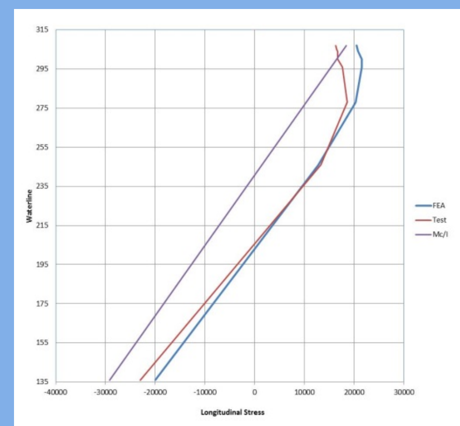
Full Airframe FEM

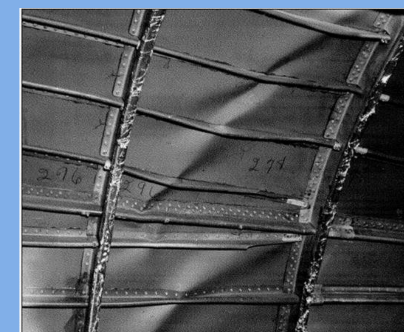
Structural Substantiation

- Static Strength Substantiation
  - Examples of Items Difficult to Address thru FEA:

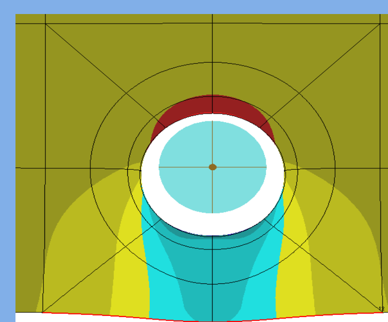


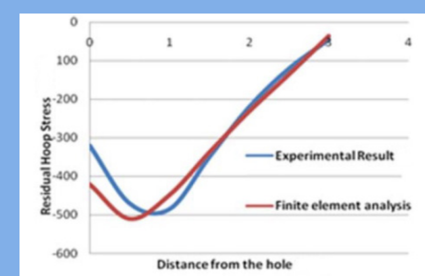
- Example 1:
  - Skin & Stringer Panel
    - FEM correlates well with test shear lag behavior
    - FEM does not conservatively predict compression due to panel post buckled properties behavior





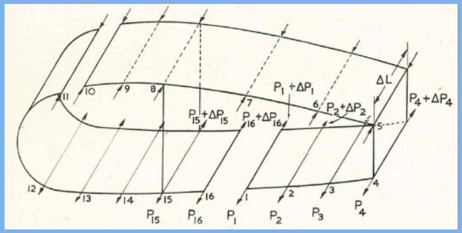
- Example 2:
  - Cold Working of Fastener Hole with Short Edge Distance
  - Amount of Interference, Contact, Non-Linearity all make this a Complex Analysis
  - Test Validation is Non-trivial





Structural Substantiation

- Static Strength Substantiation
  - Substantiation by Industry Classical Methods



Cozzone Unit Beam

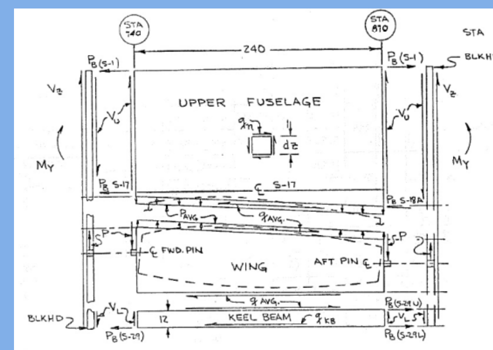
- Pros:
  - Large Number of Methods Available
  - Methods are Industry Accepted
  - Methods have been validated by test
  - Methods Support both Linear and Non-Linear Issues

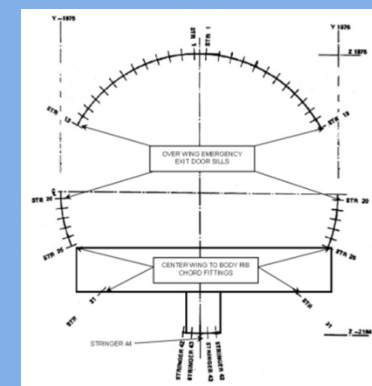
- Cons:
  - Requires External Aircraft Loads
  - Requires Basic Design Data
  - Method Produces Conservative Results
  - Limited Support for Large Load Redistribution Data
  - Methods can be cumbersome if not automated

- Certification Limitations
  - Accepted for Most Projects
  - Limited Acceptance for Large Cargo Door Modifications depending on approach

Structural Substantiation

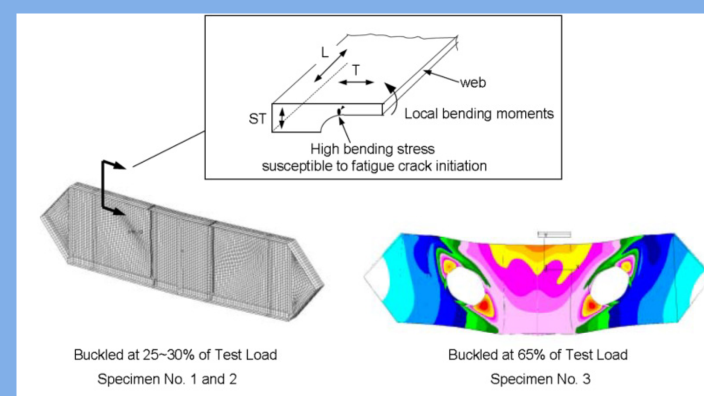
- Static Strength Substantiation
  - Examples of Items Difficult to Address thru Industry Classical Methods:





- Example 1:
  - Center Wing / Fuselage Intersection at Side of Body Rib to Skin/Stringer Attach
    - Complex Loading
    - Large Stiffness Effects
    - Overlapping Assumptions are Required

- Example 2:
  - Cutout in Floor Beam Web
  - Stresses in Post Buckled Web
  - Multiple Gradients
  - Very Few Standard Solutions Available



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Structural Substantiation

- Static Strength Substantiation - Summary
- Structural Substantiation Must Meet Certification Requirements:
  - Must be Based on Approved Loads and Material Data
  - Must be Proven to Be Reliable
  - Must be Validated (ie Test)
- Applicant Should be Cautious in Selecting Substantiation Approach Based on the following:
  - Certification Requirements
  - Scope of Effort in Terms of Cost
  - Extent of Effort in Terms of Schedule
- Proper Selection of Substantiation Approach can Lead to both a Successful Approach as well as Meeting Project Goals

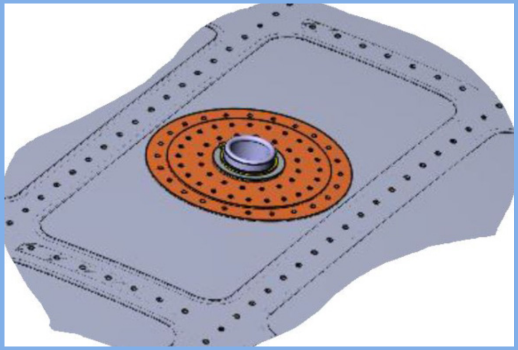
Structural Substantiation

- Fatigue and Damage Tolerance (FDT) Substantiation
  - Several Types of Modifications can Directly or Indirectly Affect the Fatigue and Damage Tolerance Capabilities of the Basic Airframe
    - Direct Impacts:
      - Modifications that Hide Existing Inspection Areas
      - Modifications Creating New Critical Details
    - Indirect Impacts:
      - Modifications that Affect the External Loads of the Aircraft
      - Modifications to the Mission Usage of the Aircraft
  - Fatigue and Damage Tolerance Substantiations Include Various Methods – Two Examples Compared:
    - Simplified Once per Flight Stress Cycle (Ground-Air-Ground)
    - Flight by Flight Spectra

Structural Substantiation

- FDT Substantiation – Direct Impact Examples
  - Radome that covers fuselage skin from visual inspections
  - Antenna penetration thru fuselage skin with external doubler
  - Cabin Interior Equipment that attaches to fuselage frames and floor structure
  - Wing External Pod that attaches to spars and lower wing skin

- External Radome
  - Covers Fuselage Crown
  - Impacts Visual Inspection of Skin
  - Alternate ICA Procedures Needed



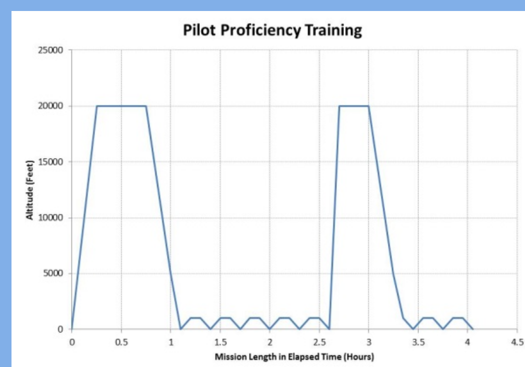
- Feed-thru Doubler
  - Hole in Fuselage Skin
  - Doubler Covers the Fuselage Skin
  - New Structural Detail Needs Inspection

- Wing Sensor Pod
  - Adds Additional Aero Loads to Wing
  - Attaches to Spars and Wing Skin
  - Creates new Structural Details
  - Requires Multiple Additional Inspections

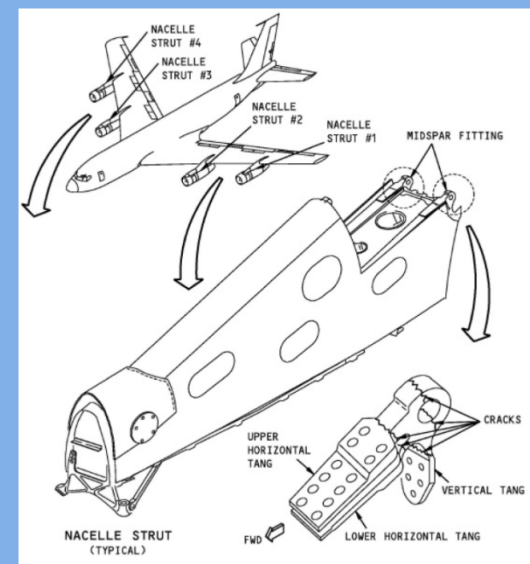
Structural Substantiation

- FDT Substantiation – Indirect Impact Examples
  - Increased Gross Weight Modification
  - Engine and/or Thrust Reverser Modification
  - Change to Mission Profiles and Usage

- TO GW Increase
  - Longer time at MTO Thrust
  - Increased Exposure to Sonic Loads
  - Sonic Fatigue Life of Aft Structure Impacted
  - Inspections and/or Life Limits in ICA must be revised



- Mission Usage Change
  - Increased Pilot Training
  - Impact to Number of Landing Cycles
  - Change to existing ICA required



- Hush Kit Mod
  - Weight and CG Changes
  - Changes Pylon Attach Loads
  - Impact to Blueprint Midspar Fittings
  - AMOC required due to existing AD

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Structural Substantiation

- FDT Substantiation – Various Methods
  - Simplified Once per Flight (GAG) Stress Cycle Example
    - Based on Regulatory Guidance Material
    - Based Solely on Ftu Capability
    - Does Not Distinguish between Hours or Flights
    - Is Not Consistent with Usage Data

$$\sigma_{1G,max} = (F_{tu}/1.5 - \Delta PR/2t)/N_z$$

t = thickness = 0.063 inches
Ftu = tension allowable = 63 ksi
Delta P = fuselage pressure = 8.47 psi
Nz = 2.5g for Limit Maneuver
R = fuselage radius = 78 inches

$$\sigma_{1G,max} = 14703 \text{ psi}$$

$$\sigma_{max} = \Delta PR/2t + 1.3\sigma_{1G,max}$$

$$\sigma_{max} = 24357 \text{ psi}$$

$$\sigma_{min} = \Delta PR/2t - 1.3\sigma_{1G,max}$$

$$\sigma_{max} = -13871 \text{ psi}$$

$$\sigma_{RES} = \Delta PR/2t + N_z\sigma_{1G,MAX} = 42 \text{ ksi}$$

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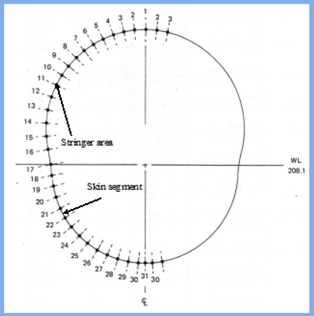
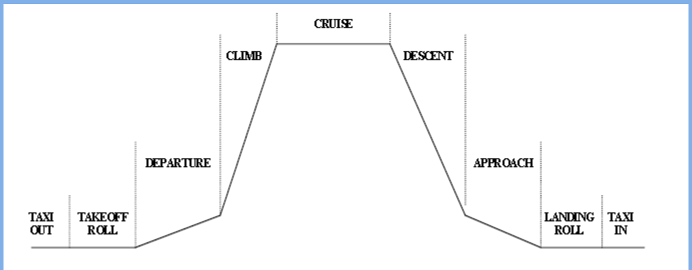
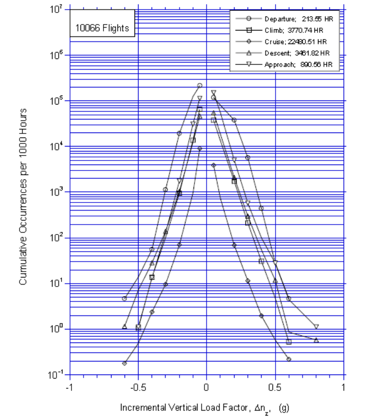
Structural Substantiation

- FDT Substantiation – Various Methods
  - Flight by Flight Spectrum Example
    - Utilizes Specific Aircraft Usage Data
    - Uses Aircraft Fatigue External and Internal Loads
    - Accounts for Mission Profiles and Usage

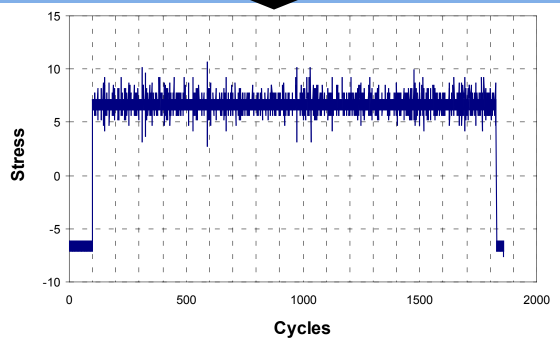




DESCRIPTION OF FLIGHT PROFILE PHASES

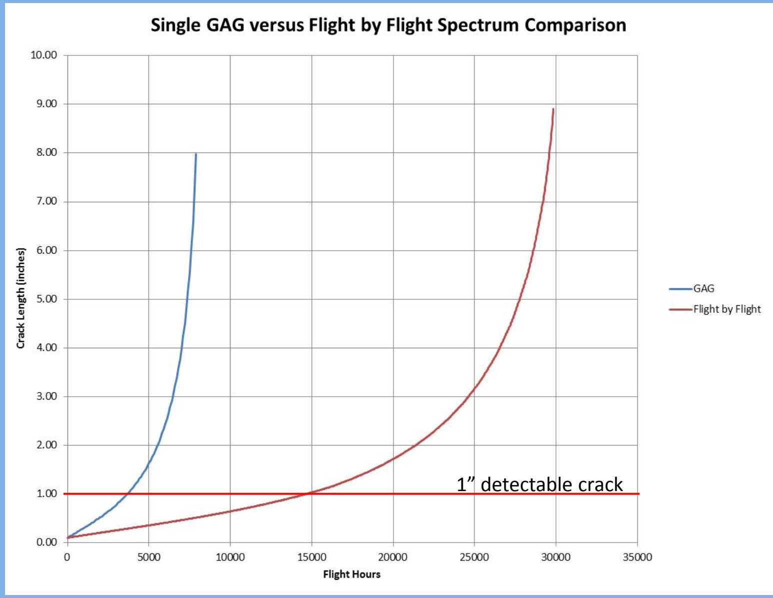


CUMULATIVE OCCURRENCES OF INCREMENTAL VERTICAL MANEUVER LOAD FACTOR PER 1000 HOURS BY FLIGHT PHASE



Structural Substantiation

- FDT Substantiation – Comparison
  - GAG versus Flight by Flight



  - Inspection Threshold:

    GAG = 7800/2 = 3900 hours — FBF = 29800/2 = 14,900 Hours

    Retardation Not Possible — with Retardation FBF = 39600/2 = 19,800 Hours

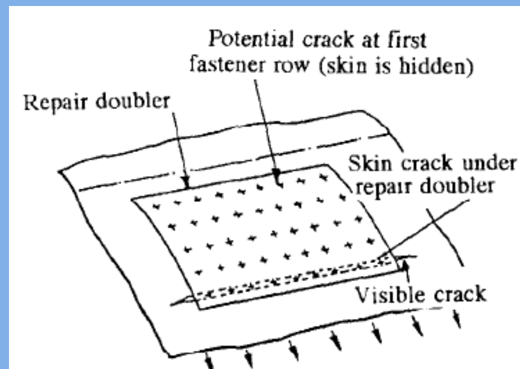
  - Inspection Interval for 1” crack:

    GAG = (7800-3700)/2 = 2050 Hours — FBF = (29800-14685)/2 = 7550 Hours

    Retardation Not Possible — with Retardation FBF = (39600 – 19650)/2 = 9980 Hours

Structural Substantiation

- FDT Substantiation – Comparison
  - GAG versus Flight by Flight



- ICA Impact:
  - GAG Method: Eddy Current Buried Layer every 2050 Hours
  - FBF Method: Eddy Current Buried Layer every 9980 Hours

- GAG Limitations:
  - Based solely on material capability not aircraft size, configuration or type
  - Can only produce 1 Hour/ 1 Cycle Inspections
  - Does not address changes in usage
  - Unreliable for use in failure analysis in support of SBs and AMOCs
  - Overly conservative for some aircraft, typical for a few but also un-conservative for others
  - Produces costly and sometimes needless inspections

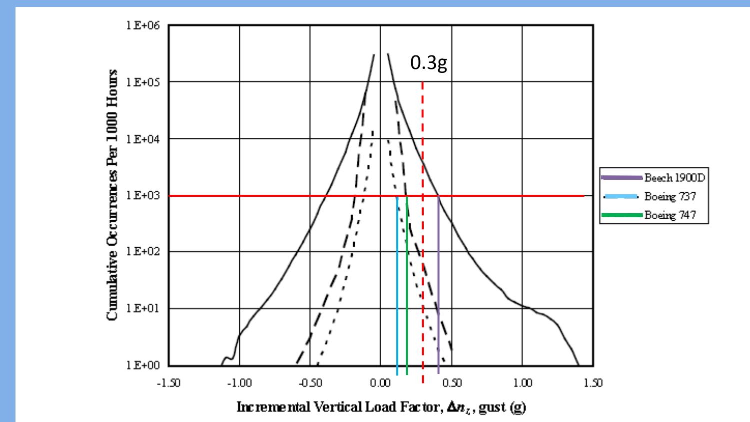


Figure A-122. Comparison of cumulative occurrences of incremental vertical gust load factor per 1000 hours, BE-1900D vs. B-737-400 and B-747-400 for cruise

Structural Substantiation

- SUMMARY

Prior to Initiating an STC Modification Project, it is important to identify the path for structural substantiation which meets both certification and project schedule as well as cost requirements.

- Some Relevant Items to Review in Determining the Substantiation Method
  - Is this a One Time STC or Multiple STC?
  - Is this a Large Complex STC with impact to the basic airframe structural stiffness or load path?
  - Are there impacts or changes to the aircraft mission?
  - Is testing planned as part of the project?
  - Are there existing AD's in the area of the STC which require AMOCs?

Structural Substantiation