FAA Research on Large-Scale Test Substantiation

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Damage Tolerance and Maintenance Workshop
Rosemont (Chicago), IL
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Research Program Objectives

Primary Objective

Demonstrate acceptable means of compliance for fatigue, damage tolerance and static strength substantiation of composite airframe structures

Secondary Objectives

- Evaluate existing analysis methods and building block database needs as applied to practical problems crucial to composite airframe structural substantiation
- Investigate realistic service damage scenarios and the inspection & repair procedures suitable for field practice

Goals of the Program

- Produce a guideline FAA document which demonstrates a “best practice” procedure for full-scale testing protocols for composite airframe structures with examples

DOT/FAA/AR-xx/xx

Office of Aviation Research
Washington, D.C. 20591

Guidelines for Damage Tolerance Testing and Analysis Protocols for Full-Scale Composite Airframe Structures

Date XXXX-XXXX

Final Report

This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

Candidate Research Tasks

1. Load Enhancement Factor Approach and Fatigue Life Assessment
   - Various approaches which have been or are currently being used
   - Guidance on Cycle Truncation
   - Address Environmental Factors used during testing
   - Full-Scale Validation and Examples
2. Damage Tolerance and Repair Substantiation
   - Categories of damage
3. Analysis Methods
   - Define procedures necessary to support testing and building block approaches

Transport Aircraft Applications

We all think about these applications … but …

Other Applications of Advanced Materials

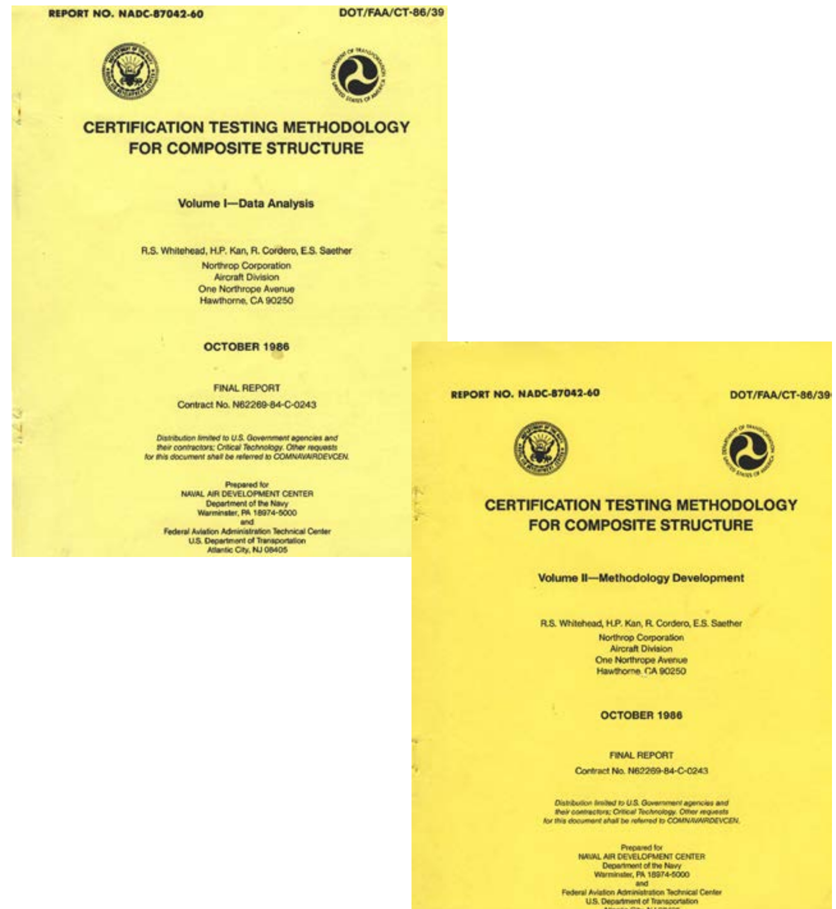
Initial Working Group

- Federal Aviation Administration
  - Peter Shyprykevich & Curtis Davies
    - FAA William J. Hughes Technical Center, NJ
  - Larry Ilcewicz
    - FAA/Seattle Aircraft Cert. Office
  - Lester Cheng
    - FAA-Small Airplane Directorate
  - Evangelina Kostopoulos
    - FAA ACO - Chicago
  - David Ostrodka
    - FAA ACO – Wichita

- Industry Members
  - Jason Russell
    - Liberty Aircraft Co.
  - Ric Abbott
    - Abbott Aerospace Composites
  - Paul Brey
    - Cirrus Design Corp
  - Jerry Housner
    - AlphaStar
  - Pierre Harter
    - Adam Aircraft
  - Matthew Miller
    - Boeing

Load Enhancement Factor Approach and Fatigue Life Assessment

- Background – most test programs reference the Navy/FAA reports by Whitehead, Kan, et. al. (1986) and follow that approach
- Most test programs have used the conclusions developed in this report regardless of design features, failure modes and/or materials
- EADS-CASA study (used for A340 aircraft) approach (2001) but redefined the shape factors



REPORT NO. NADC-87042-60 DOT/FAA/CT-86/39

CERTIFICATION TESTING METHODOLOGY FOR COMPOSITE STRUCTURE

Volume I—Data Analysis

R.S. Whitehead, H.P. Kan, R. Cordero, E.S. Saether
Northrop Corporation
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One Northrope Avenue
Hawthorne, CA 90250

OCTOBER 1986

FINAL REPORT
Contract No. N62269-84-C-0243

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Prepared for
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Department of the Navy
Warminster, PA 18974-5000
and
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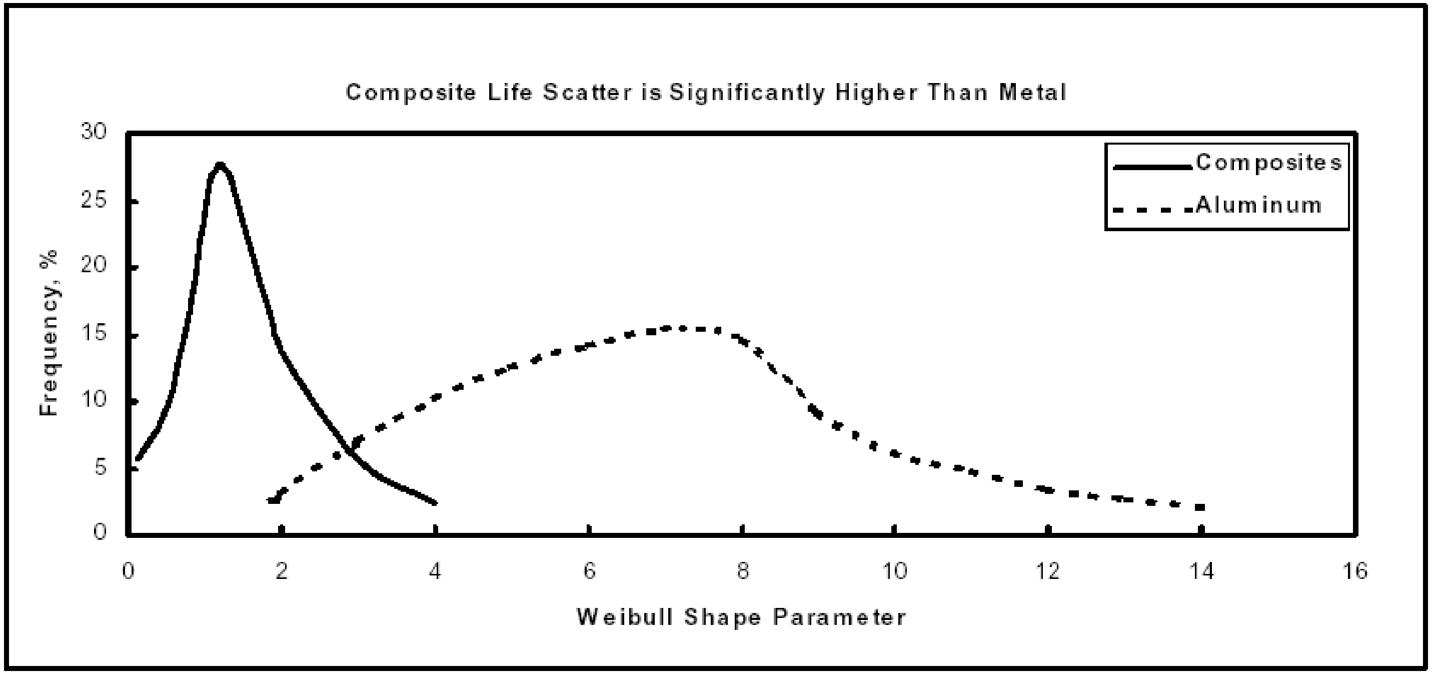
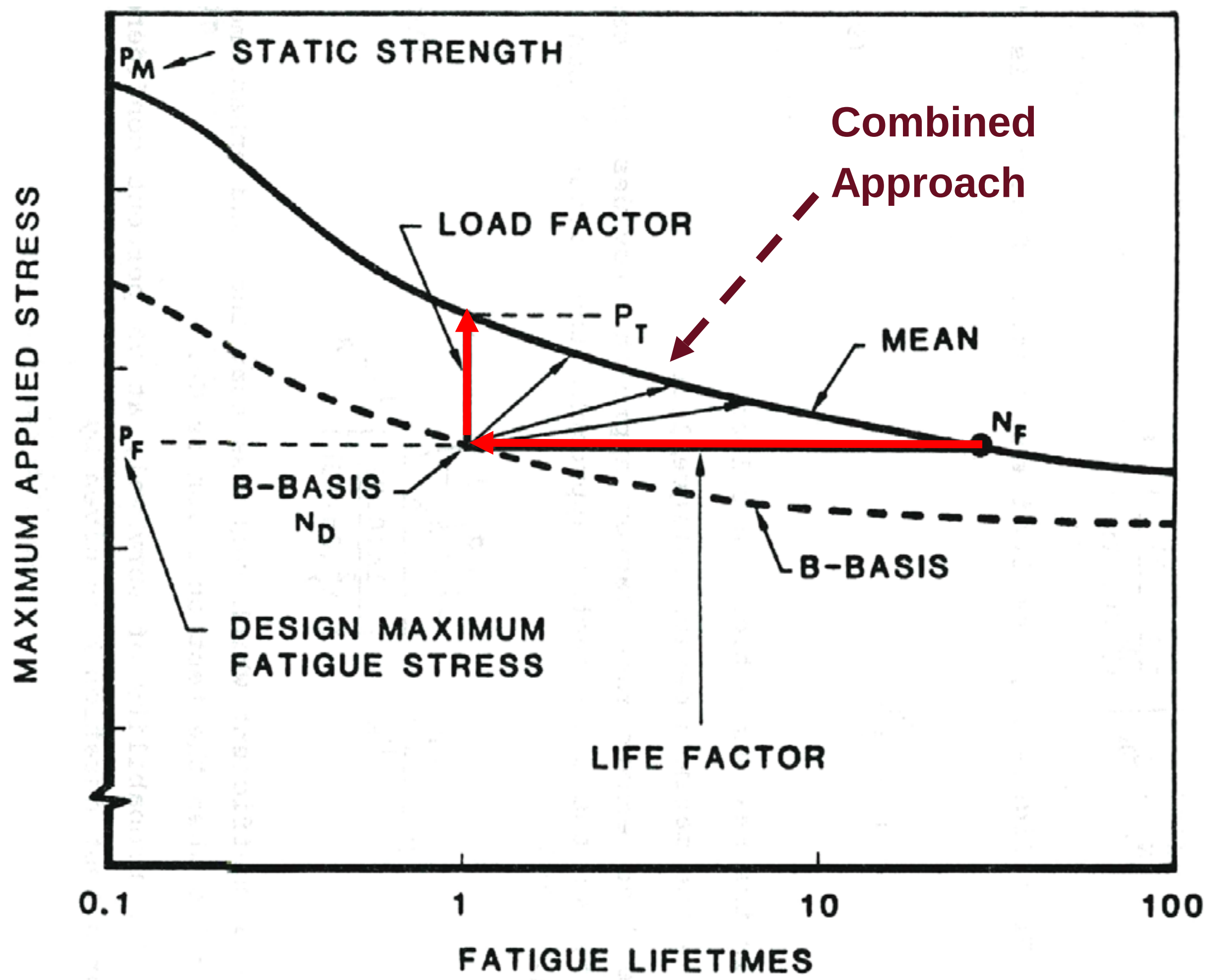
LEF - Overview of Methodology



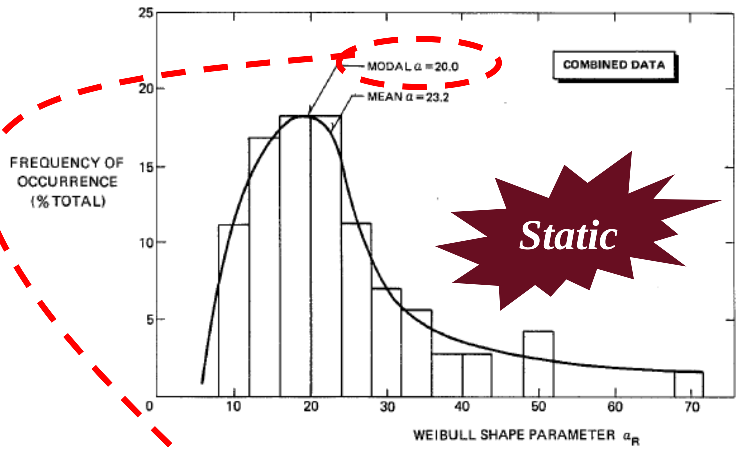
Comparison of graphite-epoxy and aluminum fatigue life scatter distributions

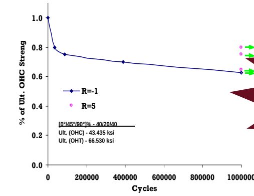
data was pooled on the basis that the life scatter is not significantly influenced by load level, loading mode, laminated layup, fatigue life and failure mode

Load / Life Tradeoff



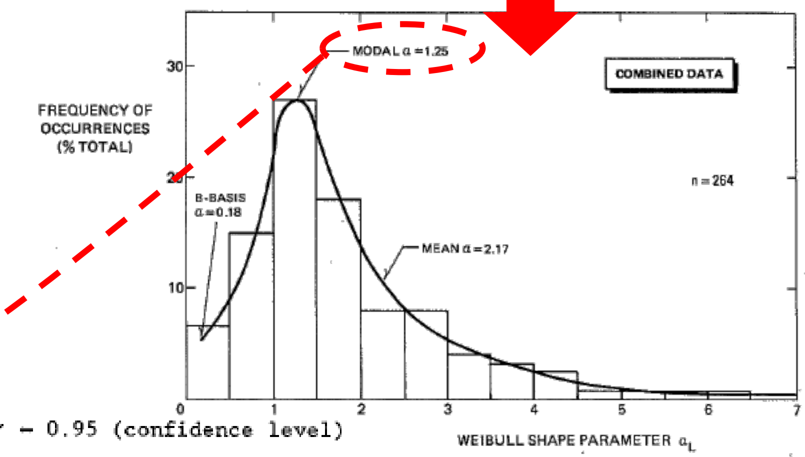
Load Enhancement Factor Approach





Fatigue Data Fitting Models

Equivalent static strength values for fatigue data



$\alpha_L = 1.25$ n = 1 (one test article)

$\alpha_R = 20.0$ p = 0.9 (B-Basis) $\gamma = 0.95$ (confidence level)

$$LEF = \frac{\left[\Gamma\left(\frac{\alpha_L + 1}{\alpha_L}\right)\right]^{\frac{\alpha_L}{\alpha_R}}}{\left[\frac{-\ln(p) \cdot N^{\alpha_L}}{\chi^2_\gamma(2n)/2n}\right]^{1/\alpha_R}}$$

test duration	load enhancement factor
1.0	1.177
1.5	1.148
2.0	1.127
3.0	1.099
13.3	1.0

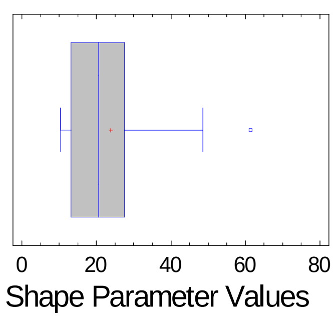
Load Enhancement Factor Approach

Comparisons of NAVY/FAA data and EADS CASA data

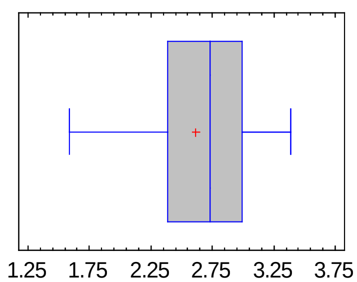
1986 study conservatively estimated static shape parameter at 20

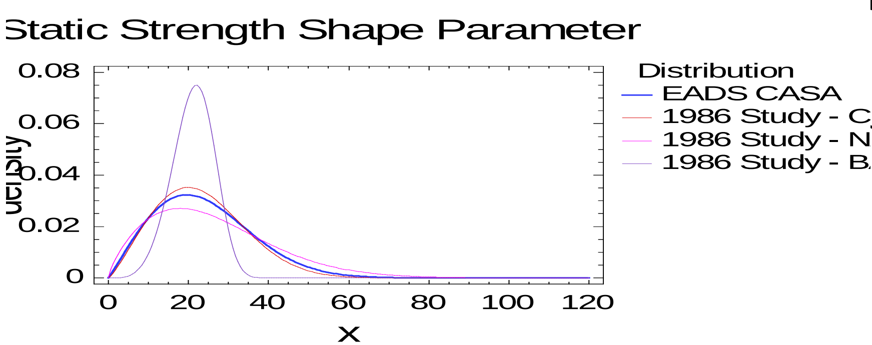
1986 study conservatively estimated fatigue shape parameter at 1.25

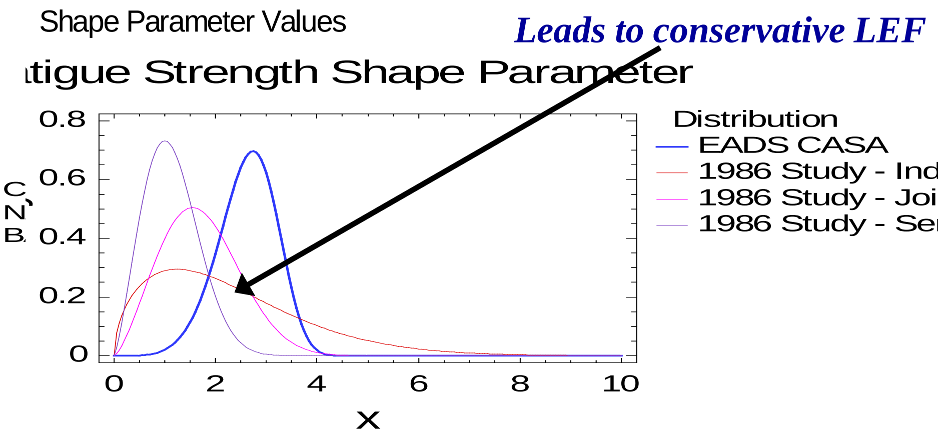
EADS CASA Static Strength tests



EADS CASA Fatigue Strength Tests

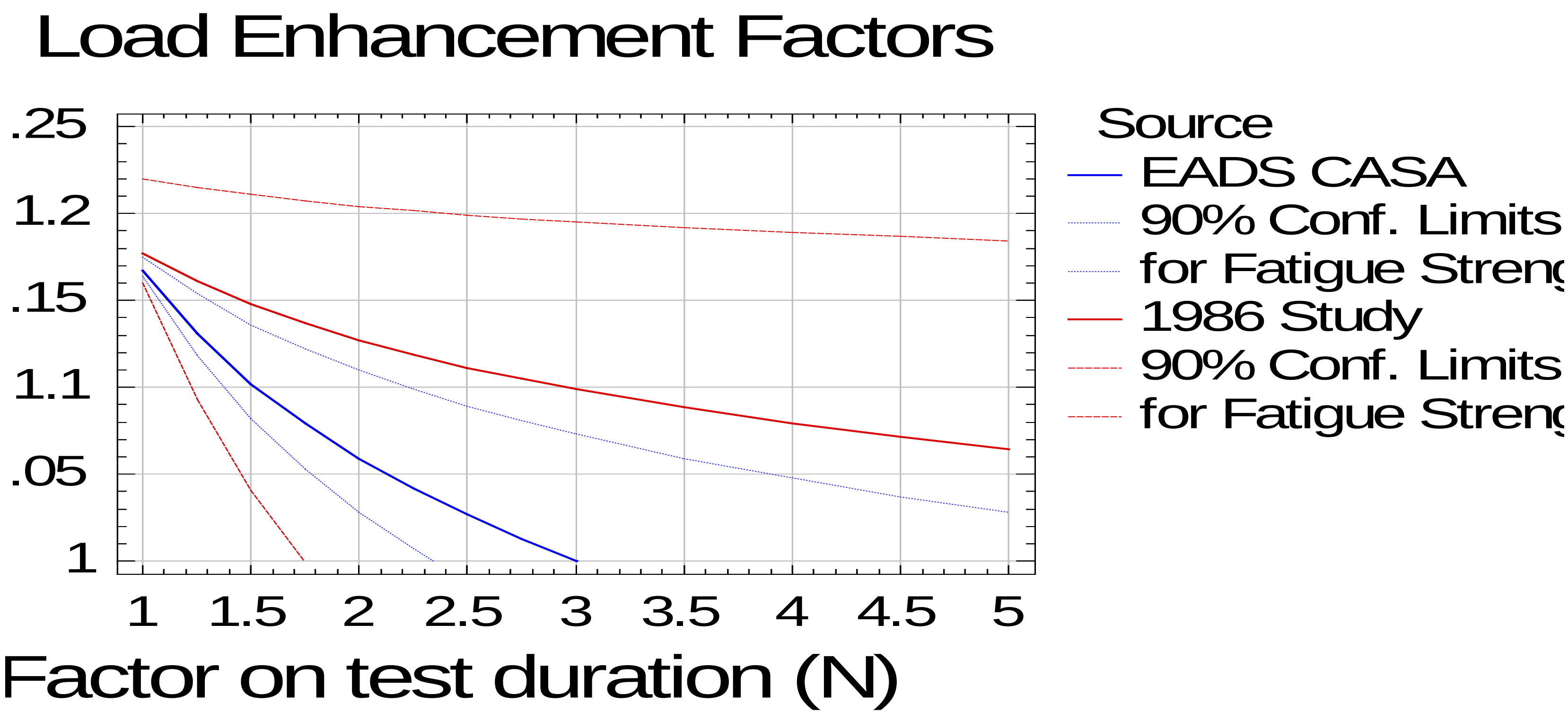






Load Enhancement Factor

Comparisons of NAVY/FAA data and EADS CASA data



Confidence limits set based on fatigue strength only since the mean and mode static strength values seem stable

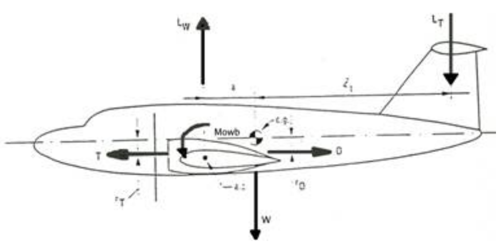
Task Research Objectives

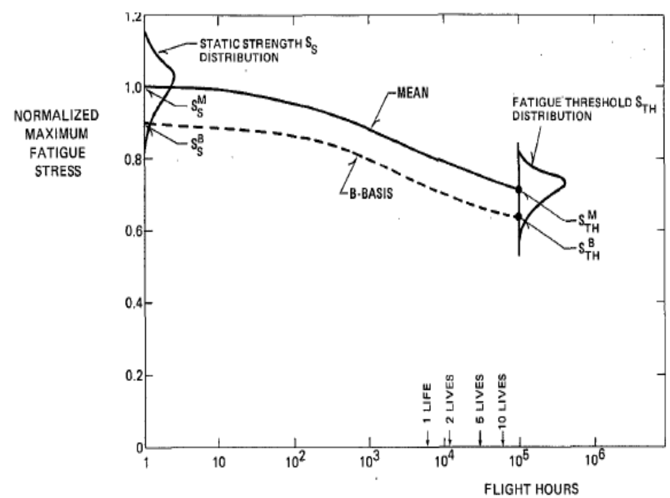
- Generate data and guidelines for the generation of Weibull shape parameters for
  - Different material systems
  - Loading modes and geometries
  - Environments
  - Bonded joints (2 thicknesses)
  - Sandwich construction
  - Multiple R-ratios

Develop shape parameters for different geometries, environments, layups, and loading modes

Data Development

- Use existing lamina and laminate data for static strength
- Static / Fatigue Loading
  - Notched Tension
  - Notched Compression
  - Bonded joints
  - Interlaminar shear
  - Sandwich construction
  - RTD and ETW
- Fatigue
  - Const. amplitude (5 H*z*)
  - R-ratios
    - 0 (Fuselage)
    - -0.2, 5 (Wing)
    - -1 (Control Surface)



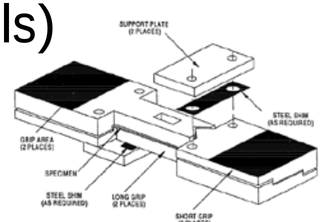


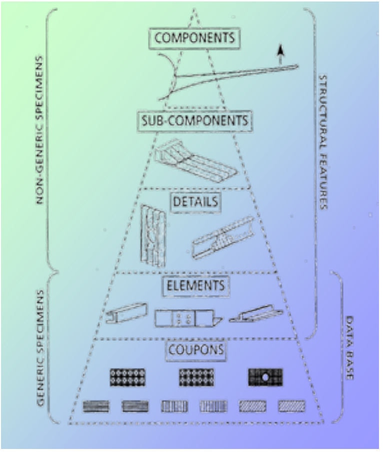
Load Enhancement Factor (LEF)

Based upon detailed design configurations with and without flaws (notched, bonded, interlaminar shear, sandwich construction)

Material	Test Method	Loading Condition	Standard	Static Test Environment		Cyclic Test R ratio (3 Stress Levels)			
				RTD	ETW	-0.2	0	5	-1
40/20/40 Laminate	Open-Hole	Tension	ASTM D5766	6	6	18	18		18
		Compression	ASTM D6484	6	6			18	
	Bonded Joint (t=0.01-inch)	Tension	Modified ASTM D5766	6	6	18		18	
	Bonded Joint (t=0.06-inch)			6	6	18		18	
	Double Notch Compression	Interlaminar Shear	ASTM D3864	6	6	18		18	
Sandwich	3-Ply Facesheet w/ 0.5-inch Core	4-Point Bend	ASTM C393	6	6		18		

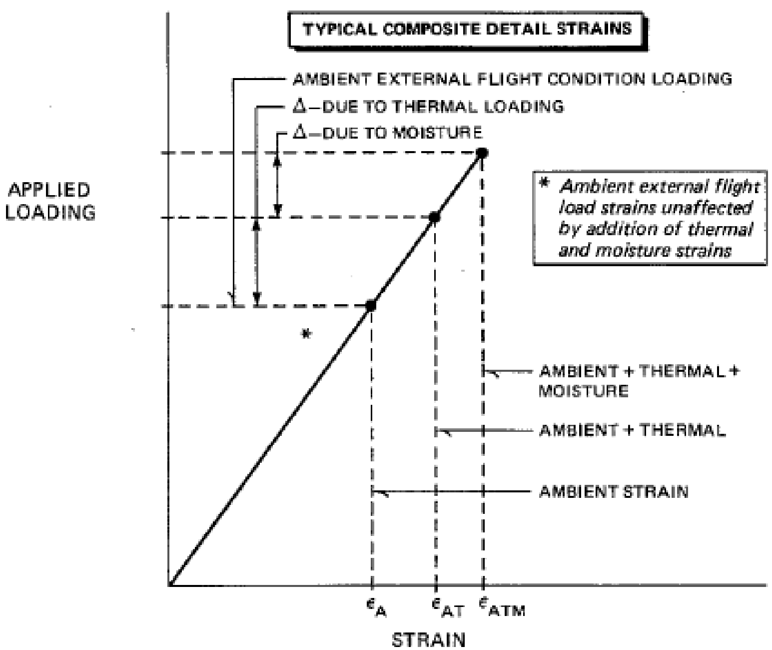
- For each material system
- Combine with existing lamina and laminate data
- 72 Static specimens
- 198 cyclic specimens (3 stress levels)
  - Constant amplitude
  - Frequency: 5 Hz

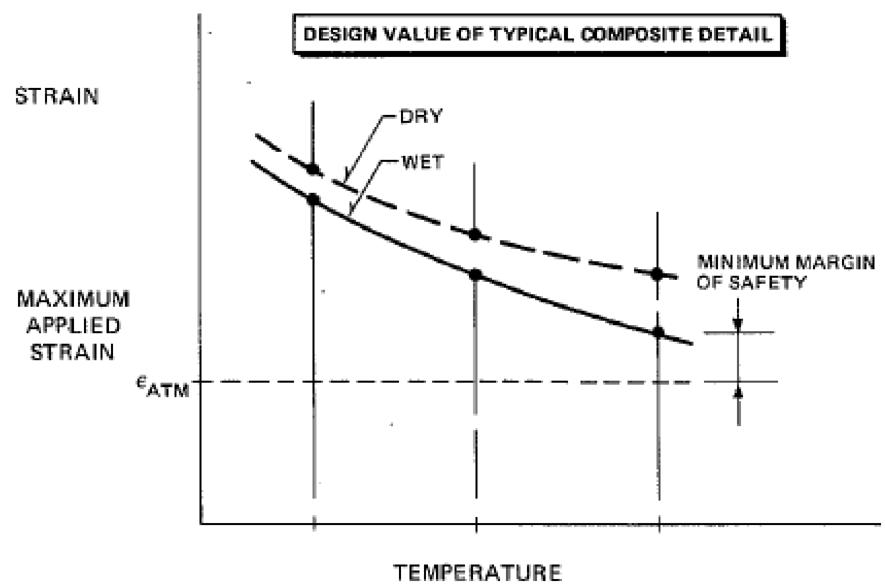




Environmental Enhancement Factor

- Develop guidelines for the development of environmental enhancement factors for static strength loading
- Use data developed at lamina, laminate, element and subcomponent to demonstrate application





Categories of Damage & Defect Considerations for Primary Composite Aircraft Structures

Category	Examples	Safety Considerations (Substantiation, Management)
Category 1: Damage that may go undetected by field inspection methods (or allowable defects)	BVID, minor environmental degradation, scratches, gouges, allowable mfg. defects	Demonstrate reliable service life Retain Ultimate Load capability Design-driven safety
Category 2: Damage detected by field inspection methods @ specified intervals (repair scenario)	VID (ranging small to large), mfg. defects/mistakes, major environmental degradation	Demonstrate reliable inspection Retain Limit Load capability Design, maintenance, mfg.
Category 3: Obvious damage detected within a few flights by operations focal (repair scenario)	Damage obvious to operations in a "walk-around" inspection or due to loss of form/fit/function	Demonstrate quick detection Retain Limit Load capability Design, maintenance, operations
Category 4: Discrete source damage known by pilot to limit flight maneuvers (repair scenario)	Damage in flight from events that are obvious to pilot (rotor burst, bird-strike, lightning)	Defined discrete-source events Retain "Get Home" capability Design, operations, maintenance
Category 5: Severe damage created by anomalous ground or flight events (repair scenario)	Damage occurring due to rare service events or to an extent beyond that considered in design	Requires new substantiation Requires operations awareness for safety (immediate reporting)

Damage Tolerance Substantiation

PROGRAM OBJECTIVES

- Provide guidance documentation as to industry "best practices" to damage tolerance substantiation in full-scale test protocols
  - Address different damage categories
  - Address Allowable Damage Limit (ADL)
  - Address damage growth threshold and definition of Critical Damage Threshold (CDT)
  - Assess repairs and repair's repeated load capability and address Repairable Damage Limit (RDL)

Candidate Work Tasks

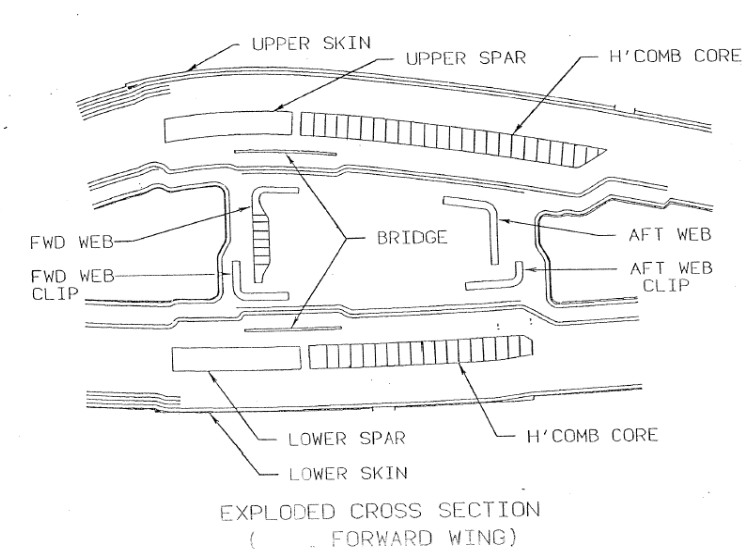
- Fatigue & damage tolerance substantiation after static strength substantiation on a separate test article
- Fatigue, static strength and damage tolerance substantiation using the same test article
- One of the above but with variations in the loading, and/or severity of damage to demonstrate an ability to measure early warnings of failure in the test (and predict a failure)
- Supporting data needs
  - Static load cases and repeated loading envelops
  - Test fixture design, fabrication & setup and test article instrumentation
  - Building block testing to support analysis groups
  - LEF & truncation limits for repeated load testing (shared databases)
  - Environmental factors for residual strength testing

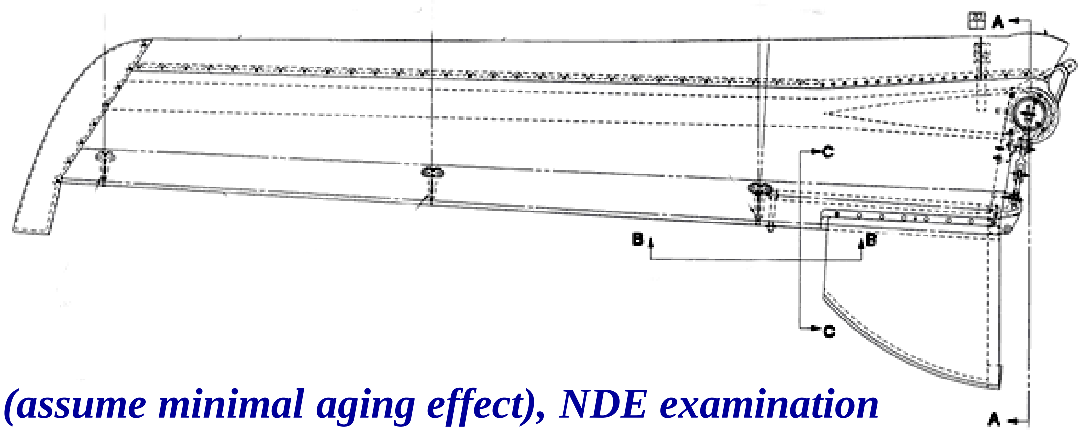
Note: Test plans consider damages ranging from allowable damage limit (ADL) to critical damage threshold (CDT) and repairs up to the repairable damage limit (RDL)

Validation and Test Examples on Full-Scale Structures

- Need multiple, representative full-scale structures for testing
  - Demonstrate effects in multiple full-scale tests
  - Characterize load versus life effect on multiple full-scale articles
  - Damage Tolerance substantiation articles for various categories of damage
  - Multiple repair substantiation articles
- Problem ??? - cost of multiple structures for tests

Full-Scale Specimens





14 articles

Approx. average of 1000 flight hours (assume minimal aging effect), NDE examination

Full-Scale Specimens

FAA programs (assessing any age effects as well as DT), NDE examination

Currently 1 article is planned (documentation example)

Full-Scale Specimens

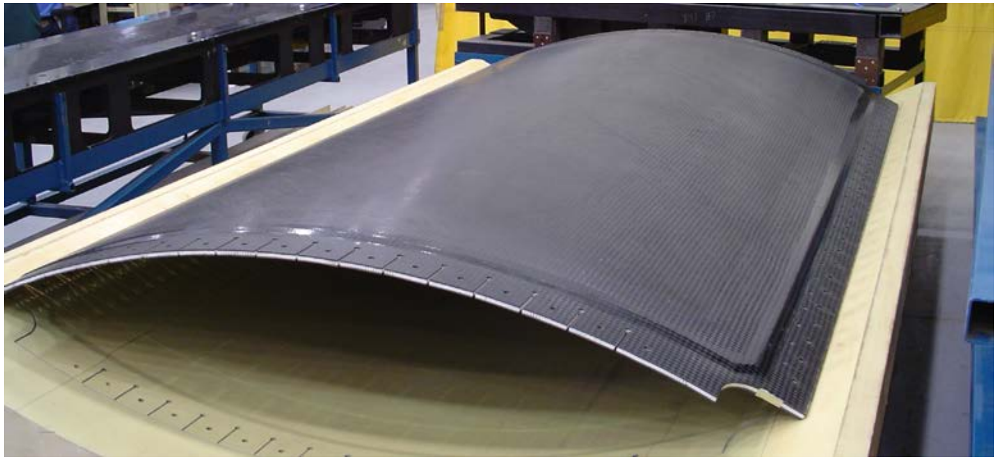
Liberty XL2

Liberty
AEROSPACE

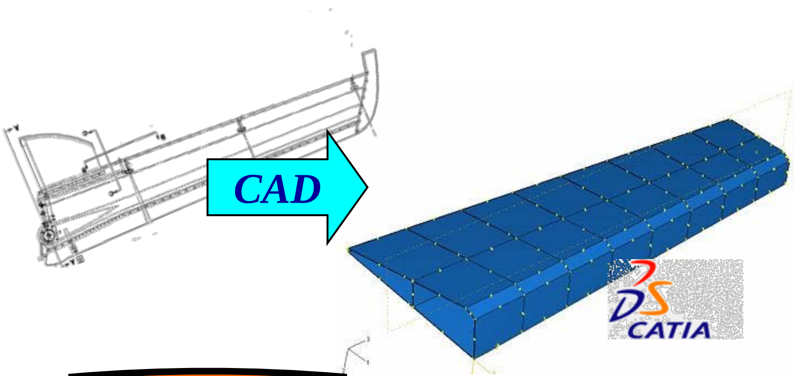
- Two fuselage tests are planned
- Structure is sandwich construction / minimum gage

Additional Full-Scale Tests

- Using the FASTER facility at the FAA Technical Center (Atlantic City, NJ)
- Fuselage loading – tension loading including pressure
- Test articles are representative of general aviation fuselage (sandwich construction)

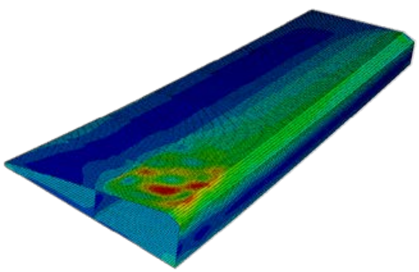


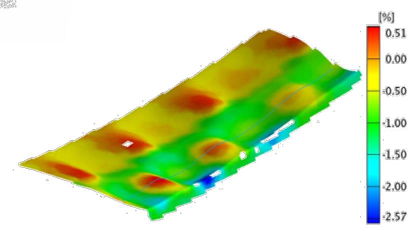
Verification for Full-Scale Structure



CAD

Stress Analysis





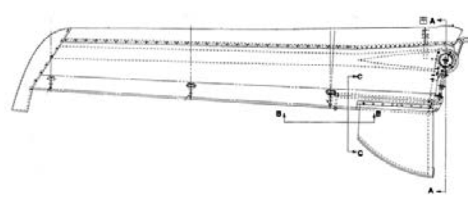
Define Baselines

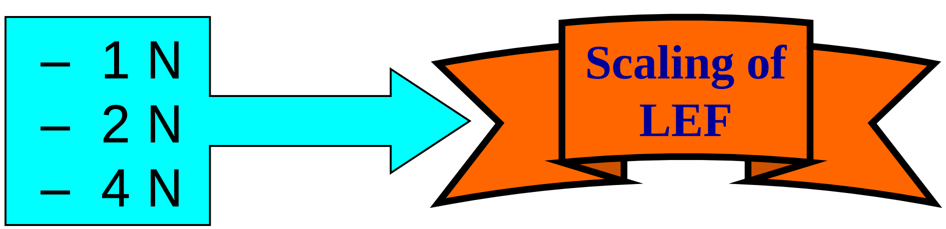
BREAK!

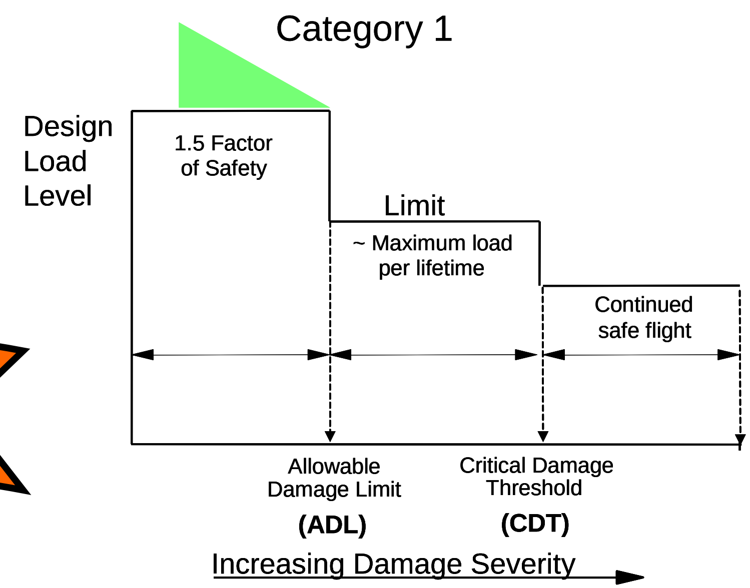
- Static Baselines (front wings)
  - Reflective of *Category 1 Damage State* along with NDI
  - Compression dominant test
  - Strain survey / FEM check
  - Establish ultimate and limit load
  - Structure Reflects: bonded joints, sandwich structure, shear

Scaling of LEF

- ***Category 1 damage state*** – BVID, minor environmental degradation, manufacturing defects, minor service damage
- *Retain ultimate load and reliable service life*
- *Constant amplitude* repeated loading (N)
- N and load levels selected to produce fatigue failures
- Compression dominant
- NDI & Compliance check

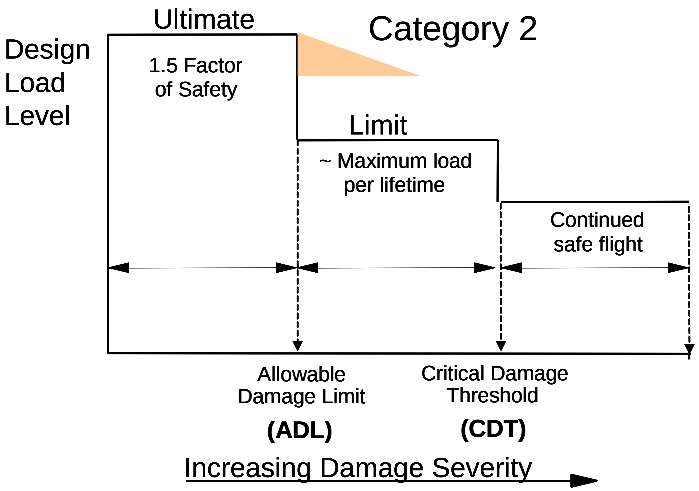




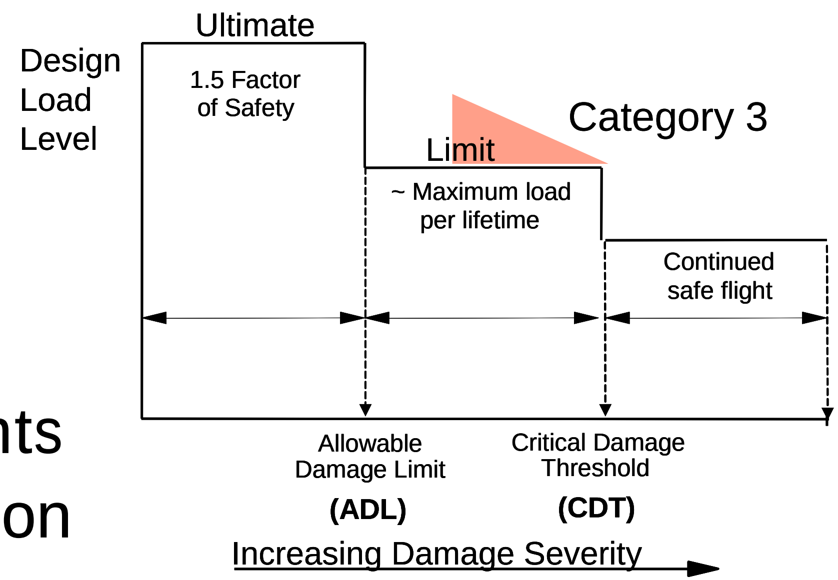


Damage Tolerance Testing

- Category 2 Damage – VID, major environmental degradation
- Demonstrate reliable inspection and define intervals
- Compression
- Impact Damage
- Spectrum Loading
- Retain Limit Load capability
- Demonstrate no or minor growth under repeated loading (inspection interval)



Damage Tolerance Testing



- Category 3 Damage – damage obvious to operator – should be detected within a few flights
- Demonstrate quick detection
- Define damage threshold
- Compression Loading / Impact Damage
- Spectrum Loading (LIMITED CYCLES)
- Retain Limit Load capability

Repair Substantiation

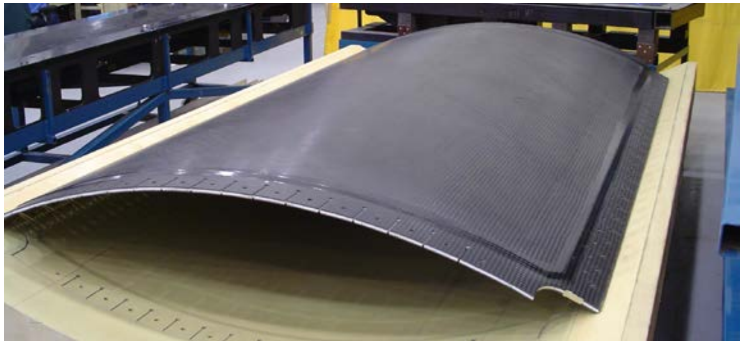
- Demonstrate repair for category 2 and 3 damage states
- Work with OEM to develop guidelines for Repairable Damage Limit (RDL)
- Demonstrate restoration of full service life under spectrum loading
- Demonstrate restoration of ultimate load

Other Test Articles

Initial Test Article Planning

LEF / Damage Tolerance verification article – 2 fuselage repeated load tests – one using traditional philosophy (NAVY/FAA report), one using updated philosophy (defined earlier)

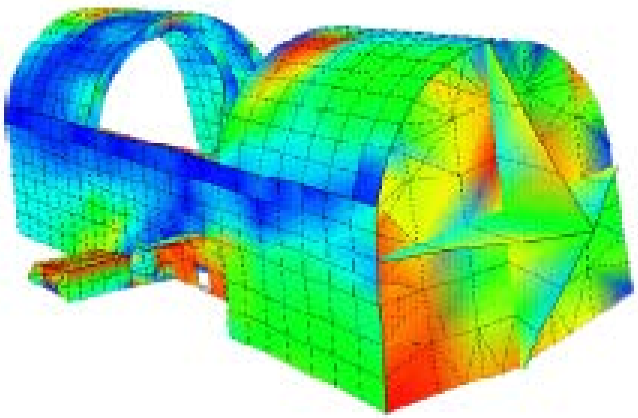
Damage Tolerance verification article – focused on repair and category 3 and/or 4 damage - approx. 6 fuselage repeated load tests – tension loading and puncture damage



Analysis Support

PROGRAM OBJECTIVES

- Identify procedures necessary to maximize analysis support for certification
- Define some options using analysis and demonstrate how it can be used in conjunction with the building block process
- Perform "calibration" tests for model as a subset of the building block process
  - Static and Fatigue
  - Damage Tolerance
  - Repair



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