Structural Certification of the F-16 Block 52+ Aircraft

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Abstract

This presentation will describe in some detail the process followed by Lockheed Martin Aeronautics – Fort Worth for the structural certification of the new production F-16 Block 52+ aircraft for foreign military sales (FMS).

The F-16 Block 52+ aircraft are structurally upgraded from the USAF Block 50/52 aircraft due to carriage of the fuselage shoulder mounted conformal fuel tanks and due to the addition of numerous advanced systems. The structural requirements and their methods of verification are set forth in the program contract and subsequent program documents such as the weapon system specification and air vehicle specification. Every USAF and FMS F-16 has an Aircraft Structural Integrity Program (ASIP) based upon program contractual requirement and tailored to MIL-STD-1530B Aircraft Structural Integrity Program. An ASIP Master Plan has been written for the Block 52+ aircraft which has been coordinated with and approved by the USAF F-16 System Group. This ASIP Master Plan states in specific terms how all the tasking outlined in the "five pillars" is accomplished. An overall design process will be discussed in depth pointing out how all historical structural analysis, structural test and field information has been used in the structural design of the Block 52+ aircraft. A substantial flight test program was planned and executed for the Block 52+ to establish structural design external loadings and design flutter characteristics. Great emphasis has been placed in the design and certification of the F-16 Block 52+ aircraft in the use of correlated finite element analysis and in the use of detailed fine grid finite element analysis. A complete aircraft strain survey was performed such that the results could be correlated to the aircraft finite element analysis. Efficiencies in schedule and technical correctness have been achieved from the emphasis placed on correlated structural analysis methods and techniques.

A successful path for structural certification of the F-16 Block 52+ aircraft has been obtained through the use of a tailored ASIP Master Plan which rigorously applies the principles stated in MIL-STD-1530B and which meets all contractual requirements. The presentation will conclude with a short film clip of an actual F-16 Block 52+ aircraft in flight.

Acknowledgements

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  - *Archie E. Woods, C-17 ASIP Manager, C-17SG/ENFS*
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Acknowledgements

- **Hellenic Air Force**
  - ***For Challenging LM Aero to Develop an Advanced Version of the F-16 Aircraft; Launch Customer for the new F-16 Block 52+ Aircraft***
  - ***For Allowing LM Aero The Use of Their Movie Clip to Show the Exciting Flight Capabilities of the F-16 Block 52+ Aircraft***
  - ***For Their Continued and Dedicated Support of the F-16 ASIP Process***

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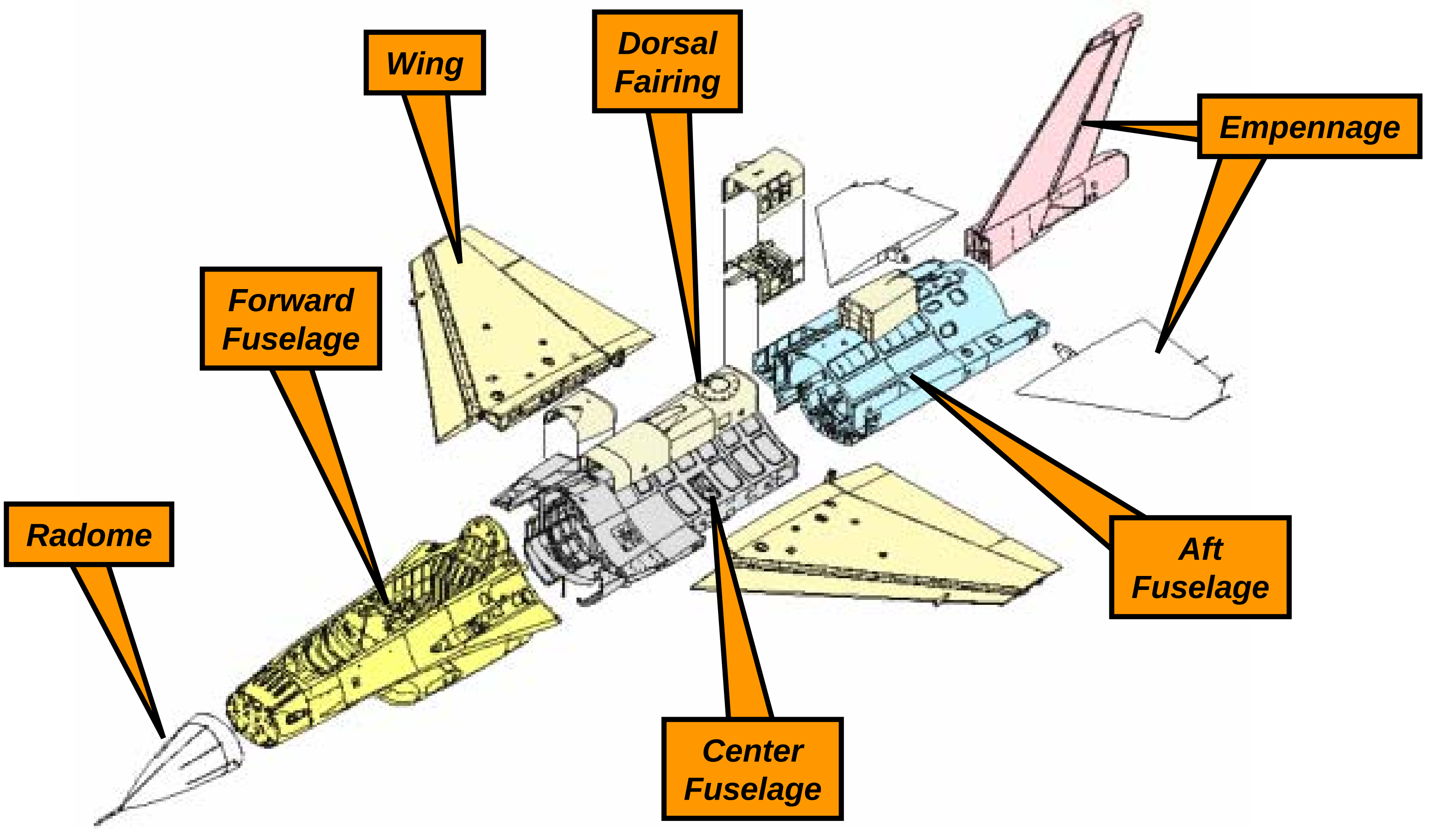
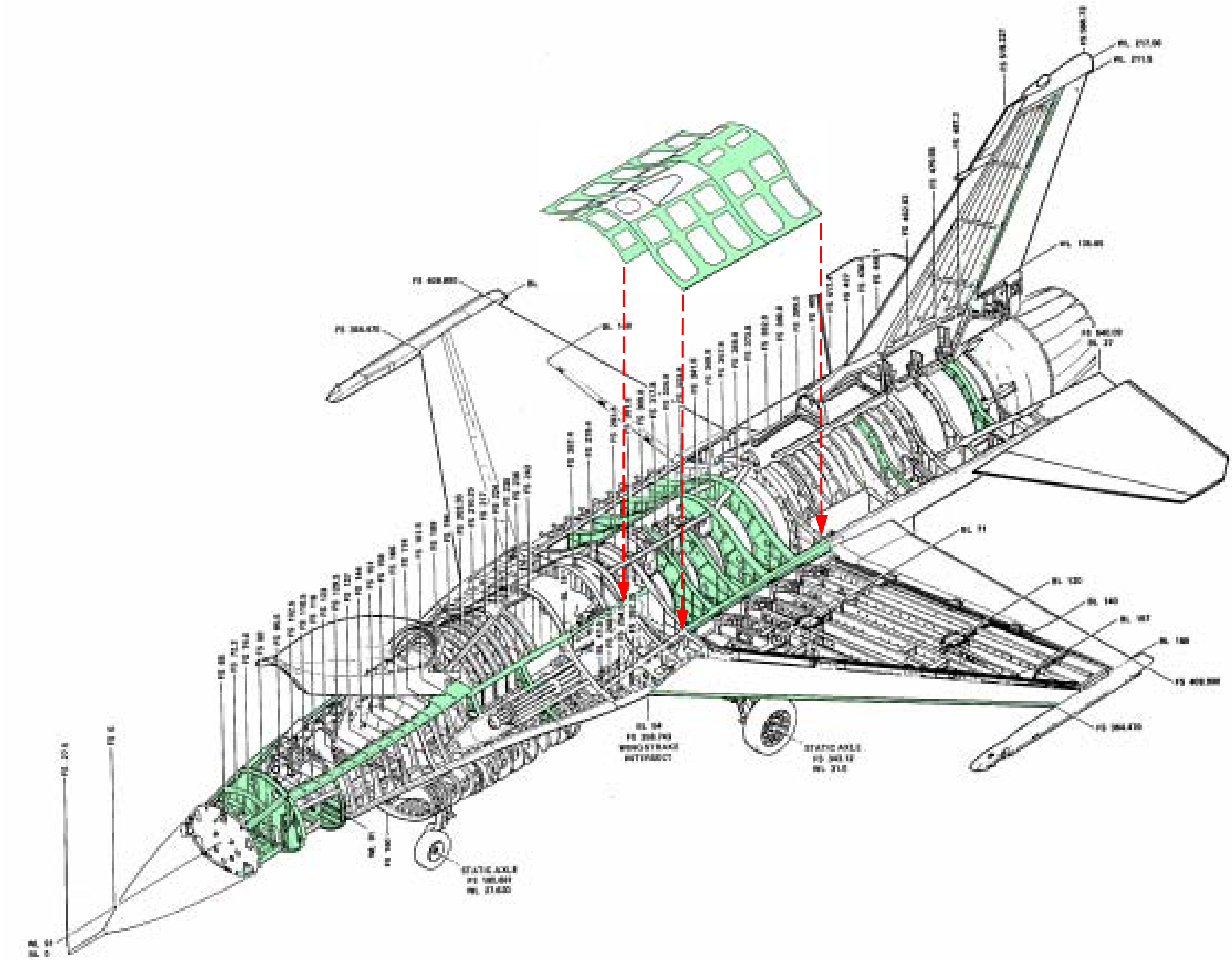
All from Lockheed Martin Aeronautics Company Fort Worth

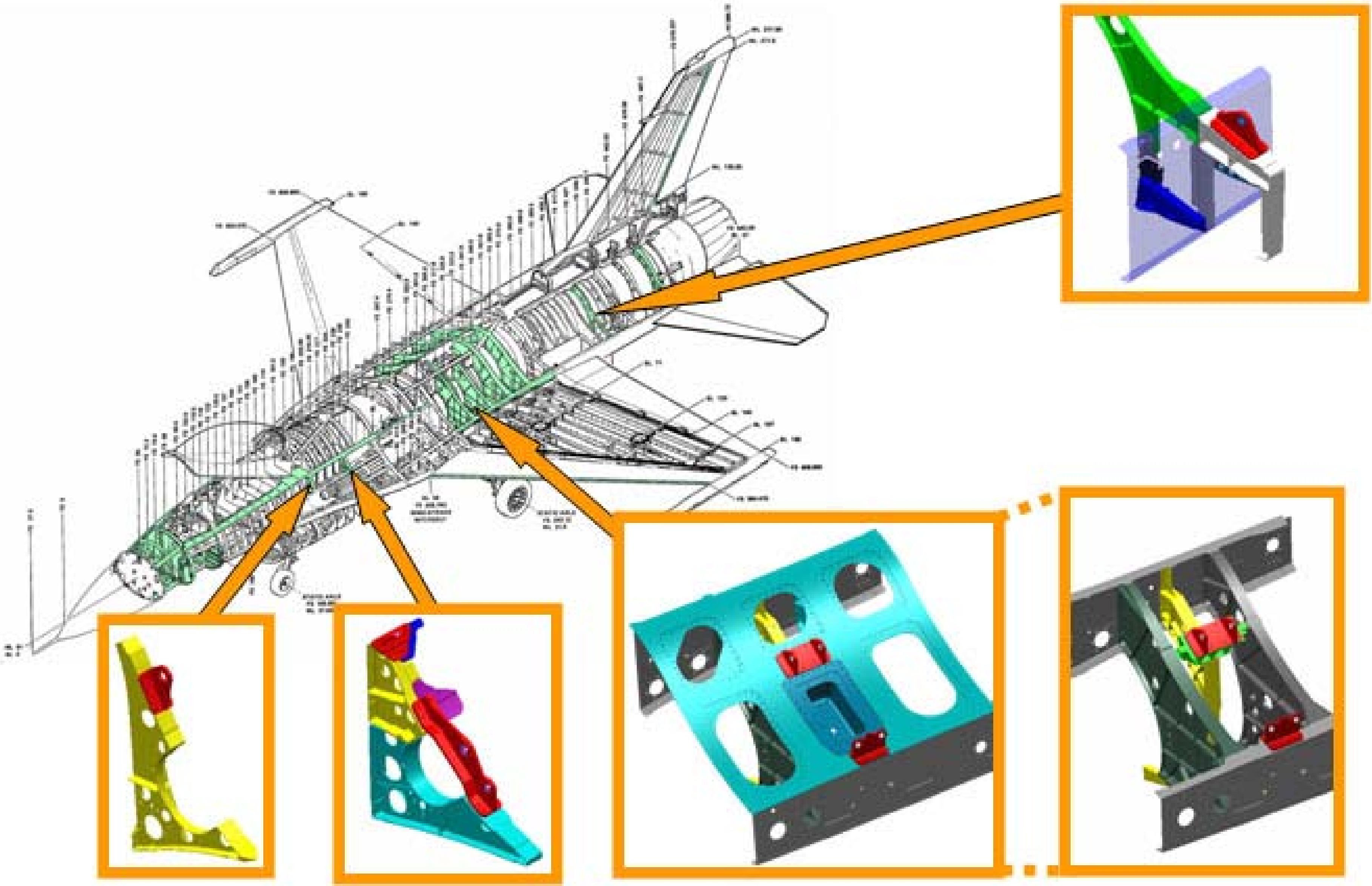
F-16 Block 52+ Modular Design



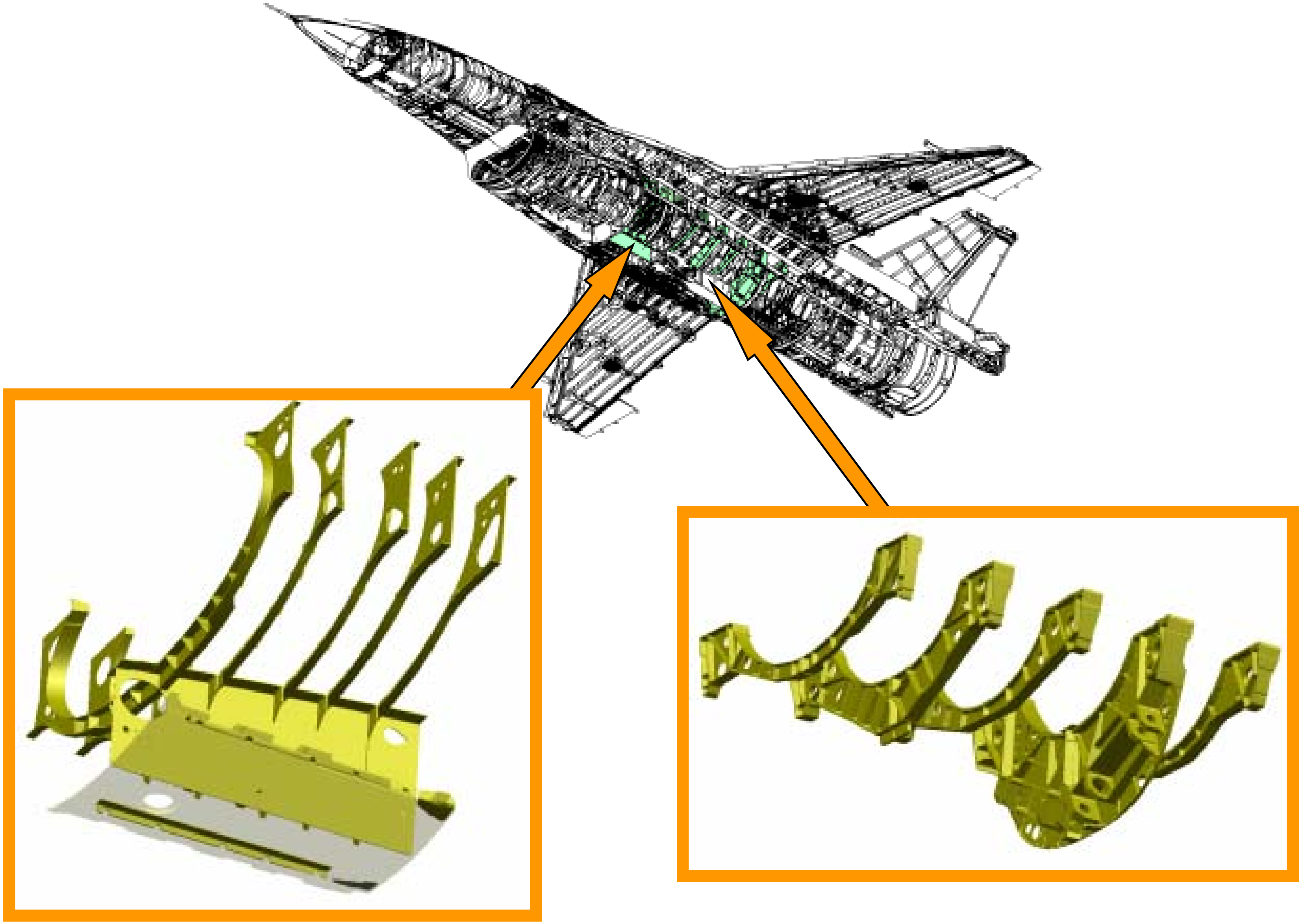
F-16 Block 52+ Structural Changes
Fuselage Upper Surface and Vertical Tail



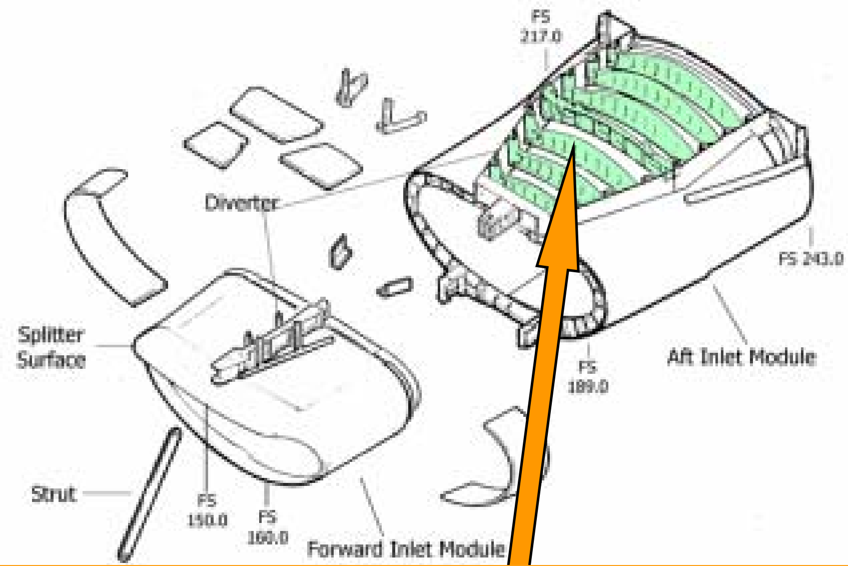
F-16 Block 52+ Structural Changes
Conformal Fuel Tank Back-Up Structure

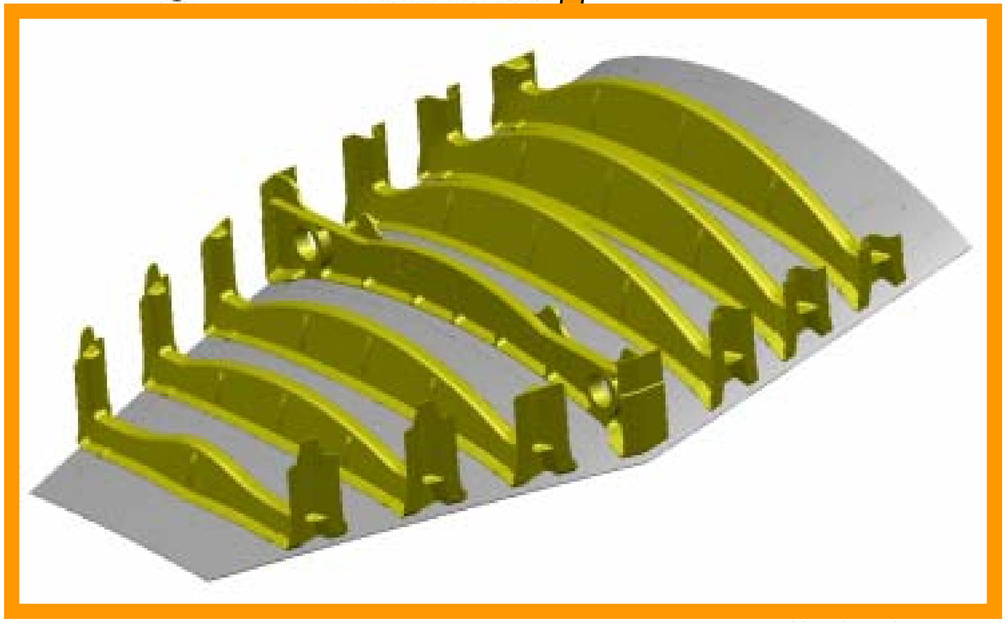


F-16 Block 52+ Structural Changes
Fuselage Lower Surface



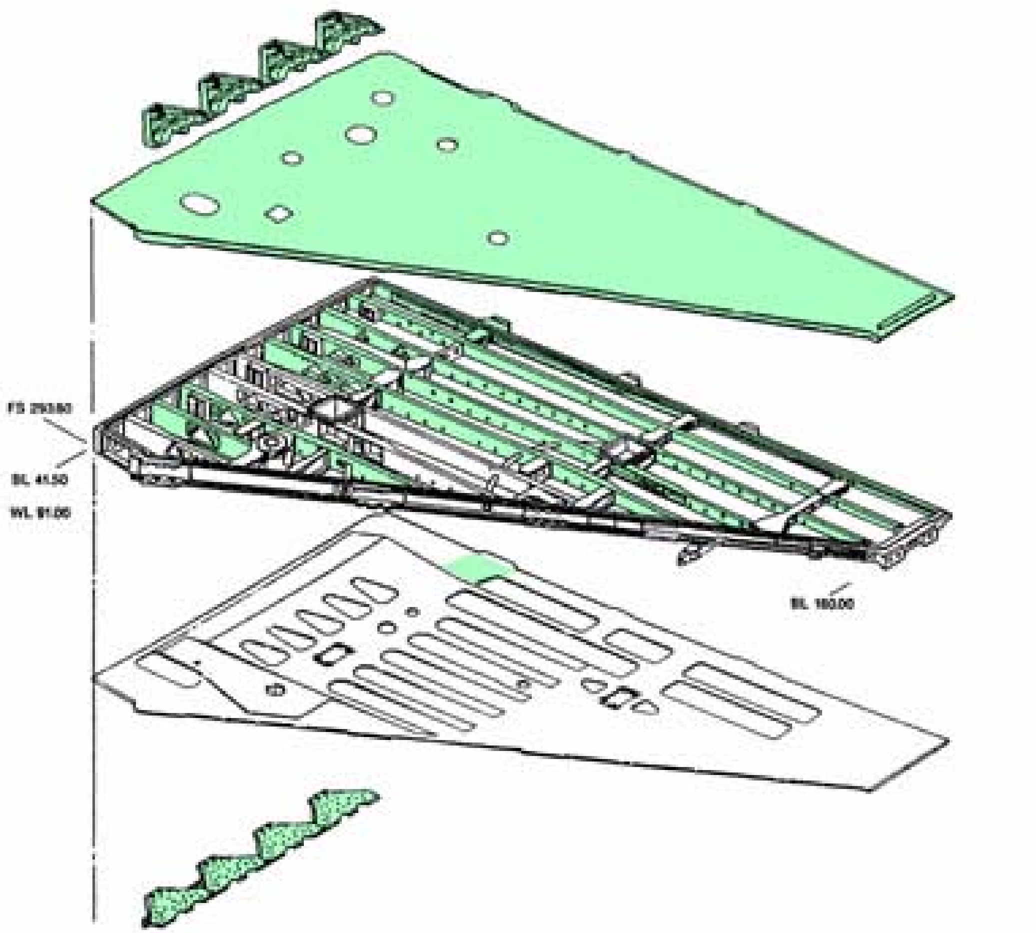
F-16 Block 52+ Structural Changes
Inlet Structure



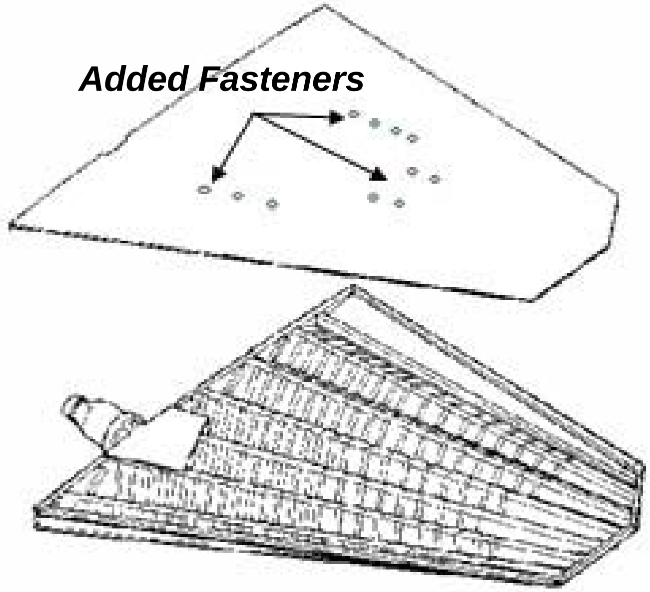


F-16 Block 52+ Structural Changes
Wingbox and Horizontal Tail

Wingbox



Horizontal Tail



The Path Toward Structural Certification

- **Structural Requirements and the Methods of Verification are Defined in the Program Contract, Weapon System Specification, Air Vehicle Specification, etc.**
  - ***Requirements Verification will be Through a Combination of Structural Analysis and Testing***

- **Structural Integrity Plan Developed to Meet Program Structural Requirements**
  - ***MIL-STD-1530B – Tailored and Applied As Required***
  - ***Program ASIP Master Plan is Normally a CDRL***
  - ***Other Structural Integrity CDRLs Dependent on Program Requirements***

- **Structural Certification Occurs When the F-16 Systems Group Approves the CDRLs and Other Supporting Data Provided by LM Aero in Accordance with Contractual Requirements**

F-16 Block 52+ ASIP Master Plan

- **Block 52+ ASIP Master Plan Tailored to MIL-STD-1530B**
  - ***Coordinated and Approved by the Customer in Early Stage of the Design Cycle***
  - ***Exhaustive Roadmap Report Describing Structural Analysis Tasks and Structural Test Performed Throughout the "Five Pillars" to Meet the Program Contractual Requirements***

- **Structural Requirements**
  - ***9g/3g Strength Capability at BFDGW of 28750 lb. with and without Conformal Fuel Tanks***
  - ***Airframe Structure Designed to Meet Durability and Damage Tolerance Inspection Interval Requirements Using Customer Specific Service Loads Definition***
    - Mission Mix, Usage and Store Loadings
  - ***Service Life of Landing Gear and Arresting Hook Evaluated with Unique Block 52+ Service Loads***

- **Customer Unique Structural Design Criteria**

ASIP Plan Development and Execution As Outlined in MIL-STD-1530B is Fundamental to Success!

The ASIP "Five Pillars" as per MIL-STD-1530B

Full-Scale Development			Force (Fleet) Management	
Task I **Design Information**	**Task II** **Design Analysis & Development Tests**	**Task III** **Full-Scale Testing**	**Task IV** **Force Management Data Package**	**Task V (User)** **Force Management**
ASIP Master Plan Structural Design Criteria Damage Tolerance & Durability Control Plan and Critical Parts List Selection of Materials, Processes and Joining Methods Design Usage and Design Service Life Mass Properties	Material and Joint Allowables Static Loads Analysis Service Loads Spectra Chemical/Thermal Environment Spectra Stress Analysis Airframe Damage Tolerance Analysis Airframe Durability Analysis Landing Gear Fatigue Analysis Flutter / Dynamics Analyses Design Development Tests Mass Properties Analysis	Static Tests Durability Tests Damage Tolerance Tests Flight & Ground Operations Loads Tests Flutter / Dynamics Flight Tests Ground Vibration Tests Weight & Balance Testing Interpretation and Evaluation of Test Results	Final Analyses Strength Summary and Operating Restrictions Force Structural Maintenance Plan Loads Environment Spectra Survey Methodology Individual Airplane Tracking (IAT) Program Methodology IAT Models ASIP Data Collection and Processing Software & Platforms Data Package Updates	Loads/ Environment Spectra Survey (L/ESS) Data Individual Airplane Tracking (IAT) Data ASIP Recorder Data Processing Individual Airplane Scheduled Maintenance Actions Structural Maintenance Records Weight & Balance Records

Block 52+ Structural Design Process

Design Requirements

-Strength and Service Life
-Flutter

Input and Historical Data

Service Experience

- Falcon UP
- ECPs 1871/1966
- Falcon STAR
- Fleet Cracking Data

Test Experience

- Blk 30 Static & Durability
- Blk 40 Aft Fus. Durability
- Aircraft Strain Surveys
- Loads & Flutter Flt Tests

Past Analysis Results

- Static Strength
- DaDTA
- FEA
- Loads & Flutter

Recorder/IAT/LESS Data

- Mission Mix
- Stores Configurations
- Operational Usage Data

Structural Analysis Tasks

Loads and Dynamics

- Design Static Loads
- Design Service Loads
- Loads & Flutter Flt Test
- Ground Vibration Test

Finite Element Analysis

- Coarse Grid Results
- Fine Grid Results
- Aircraft Strain Survey

Static Strength

- MS = Positive
- NLG Static test
- SSOR

DaDTA

- Durability Life
- Damage Tolerance Life
- Fracture Crit. Parts List

Block 52 + Airframe: The Most Structurally Capable F-16 Built to Date

F-16 Block 52+ Design Loads Development

- **Analytical Prediction Basis:**
  - ***Heritage Design Loads and Flight Test Data***
  - ***Wind Tunnel Results Developed for Single and Two Place Aircraft with and without Conformal Dorsal and with and without Conformal Fuel Tanks***
  - ***Maneuver Response Data From Analytical Simulations***

- **Loads Flight Testing Conducted for Verification:**
  - ***Five Loadings, Twenty Two Flights to Verify Analytical Predictions***
  - ***Six Loadings, Ten Flights to Establish Control Law Modifications***
  - ***Flight Test Results Compare Favorable to Analytical Predictions***

- **Over 600 Static Load Conditions Defined for Strength Evaluation**

- **Flight-by-Flight Service Loads Developed Using Existing Operational Recorder Data Adjusted to Customer Contracted Mission Mix and Maneuver Content**
  - ***Each 500 Hr Block Contains 200+ Component Loads and 35+ Maneuver Response Parameters For Each of 500,000+ Maneuver Time Hacks***

Design Loads Correlated to Flight Test Results

F-16 Block 52+ Flutter and Dynamics Assessment

- **Flutter Limit Predictions are Based Upon Block 50 Finite Element Analysis Adjusted with the Appropriate Block 52+ Mass and Stiffness Changes**
  - ***Aircraft Ground Vibration Tests Performed for Prediction Correlation***
  - ***Stiffness Testing Performed on New Suspension Equipment***
- **Flutter Flight Testing Performed to Verify Predictions or to Set Limitations**
  - ***Six Configurations Were Tested in Seven Flights***
  - ***Flight Testing Continues for Store Certification and Envelope Expansion***
- ***Equipment and Equipment Installations Designed to Specific Aircraft Vibration Levels per the F-16 Environmental Criteria***
  - **Verification is Achieved Through Vibration Testing**
  - **Limited Flight Testing Verification of Equipment Installations**

Flutter Airspeed Limitations Verified or Set by Flight Test Results

F-16 Block 52+ Finite Element Analysis

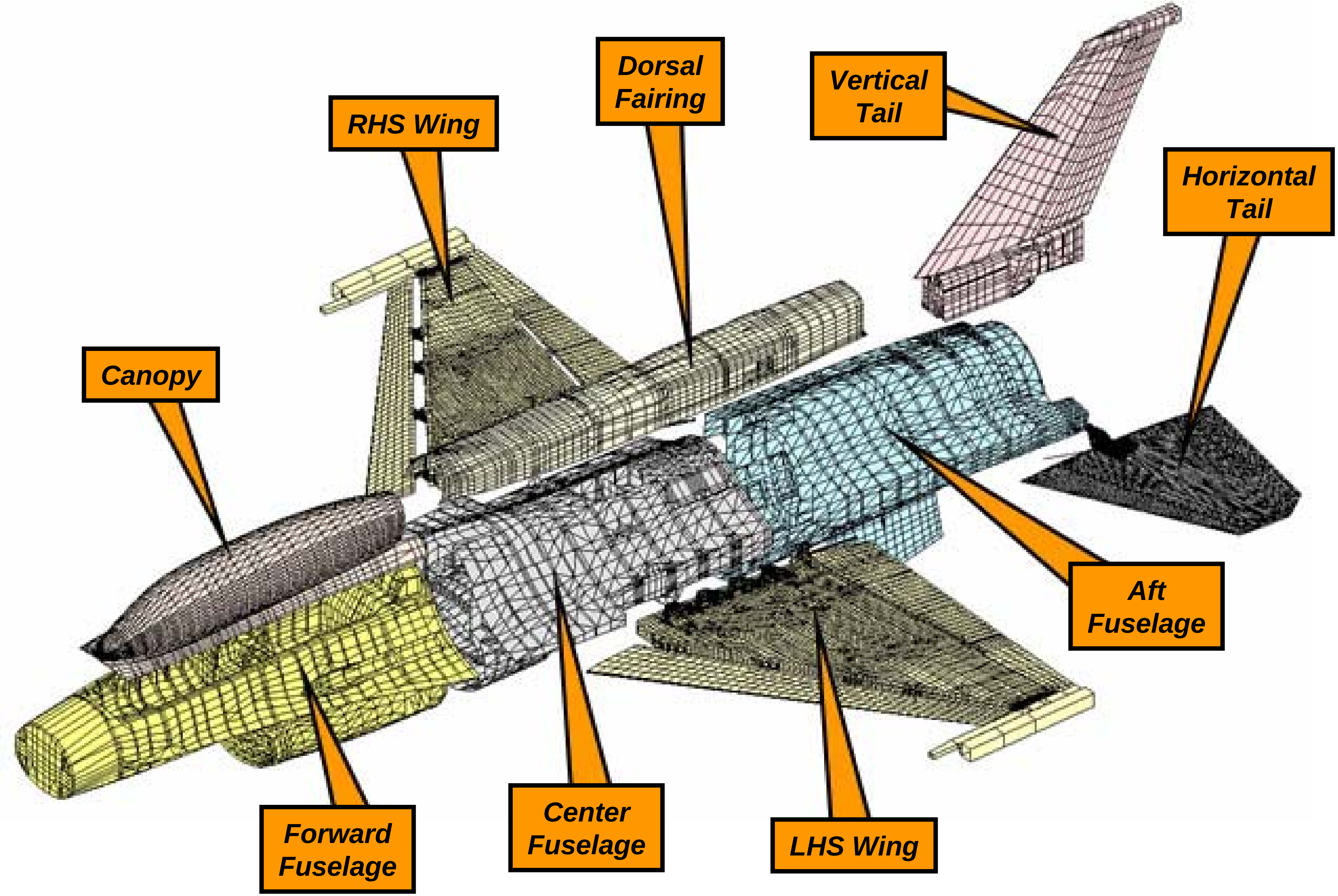
- **Coarse Grid and Fine Grid Finite Element Models Employ Correlated and Proven Methods**
  - ***Aircraft Static Tests***
  - ***Aircraft Strain Surveys***

- **Aircraft Coarse Grid Finite Element Model Updated to Use Methods Developed Through Previous ASIP Sustainment Contracts**
  - ***Refined Mesh and Use of More Robust Shell and Solid Element Formulations to Improve Accuracy***
  - ***A Unique Aircraft Coarse Grid Finite Element Analysis Performed for Each Customer to Reflect Unique Structural Configuration and External Loadings***

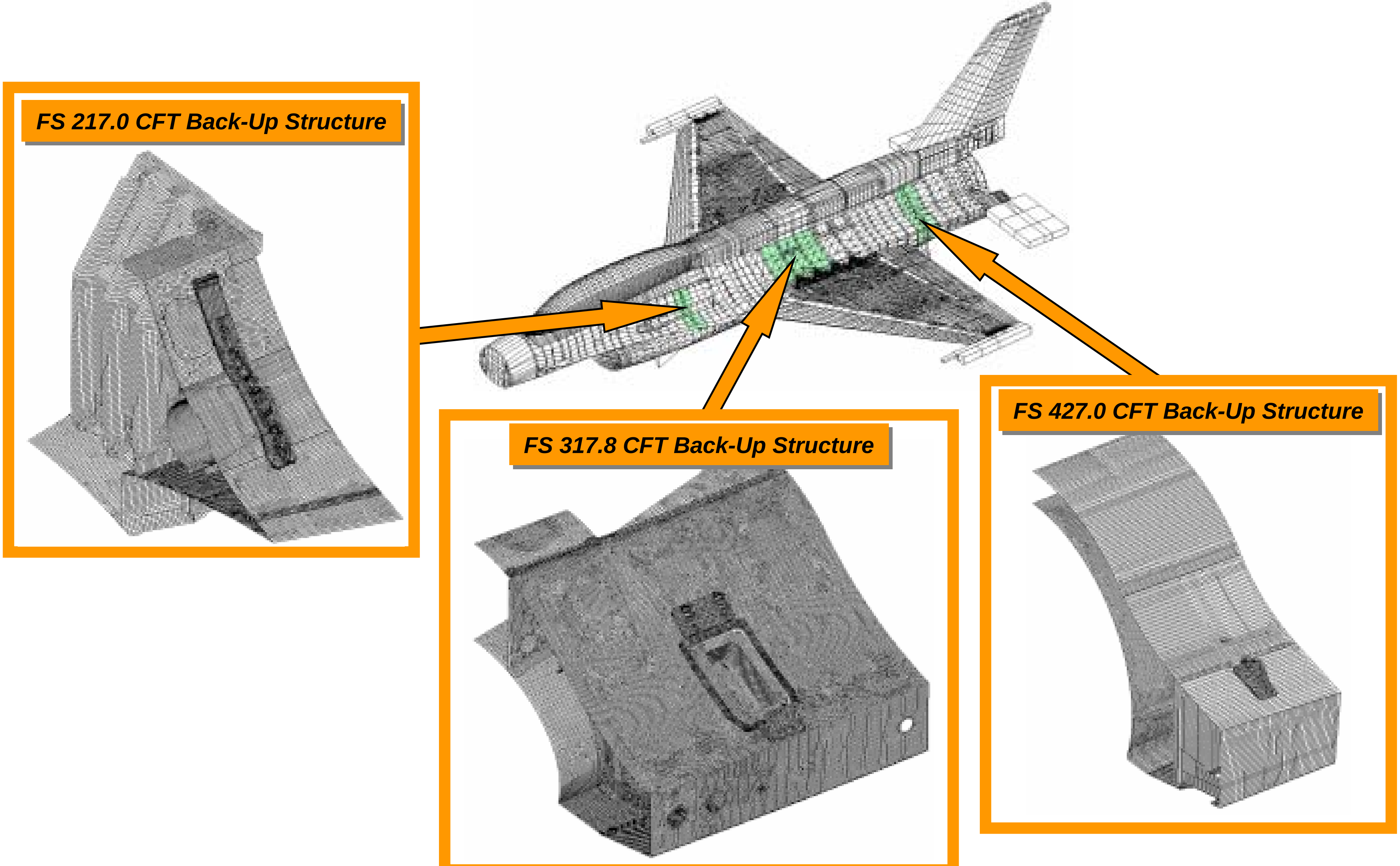
- **Much More Original and Detailed Finite Element Analysis Data was Developed in Support of the Block 52+ Airframe than Ever Before on an F-16 Program**
  - ***CFT Back-Up Structure***
  - ***Wing Carry-Through Bulkheads***
  - ***Center Fuselage Upper Skins***
  - ***Aft Fuselage Vertical Tail Support Structure***
  - ***Centerline Keel Beam Structure***

- **Finite Element Analysis Methods Employed in the Design of the Block 52+ Airframe Validated by Strain Survey of a Production Aircraft**

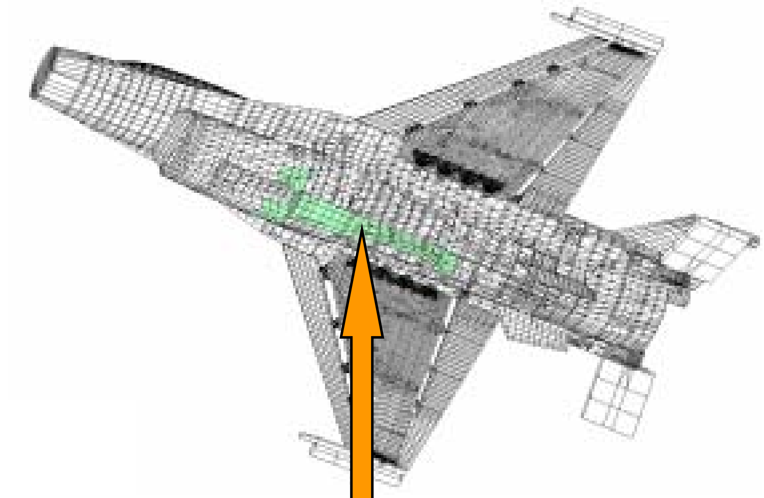
F-16 Block 52+ Aircraft Finite Element Model



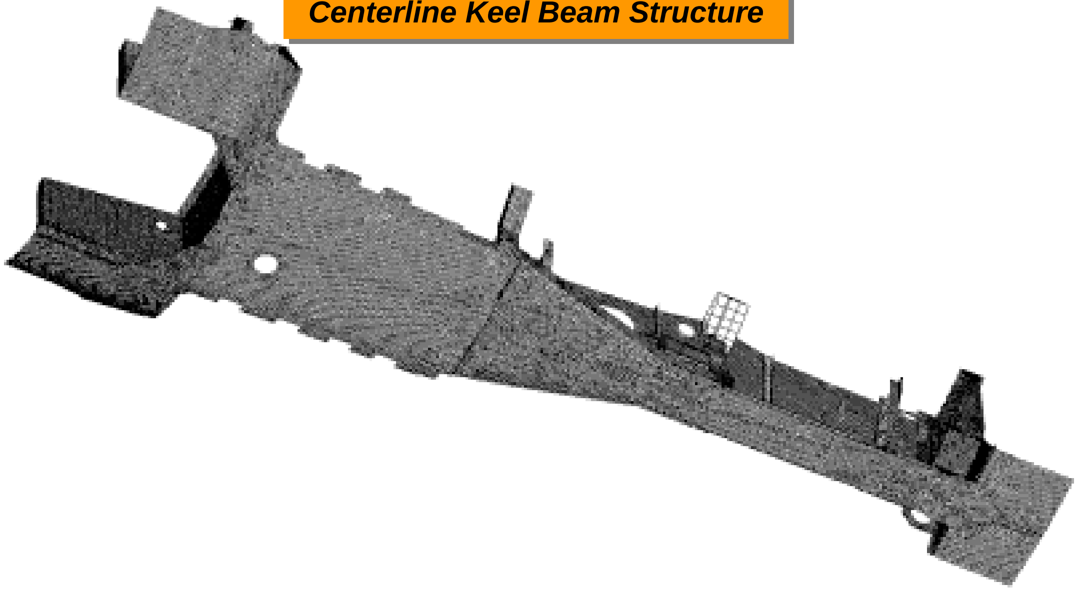
F-16 Block 52+ Aircraft Fine Grid Finite Element Models



F-16 Block 52+ Aircraft Fine Grid Finite Element Models (Continued)



Centerline Keel Beam Structure



F-16 Block 52+ Aircraft Strain Survey

Excellent Correlation Validated Finite Element Analysis Methods Employed in Block 52+ Airframe Structural Analysis

F-16 Block 52+ Stress Analysis

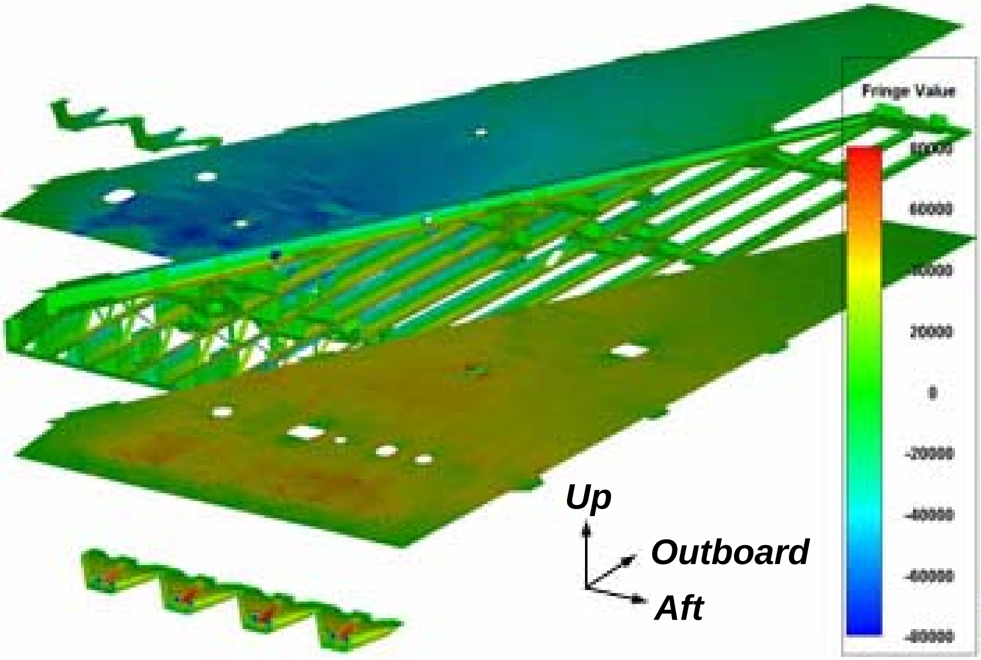
- **Detailed Stress Analysis was Performed on the Complete Airframe for Each Customer to Reflect Unique Structural Configuration and External Loadings**
  - ***Forward Fuselage***
  - ***Center Fuselage***
  - ***Aft Fuselage***
  - ***Wing and Leading and Trailing Edge Flaps***
  - ***Empennage***
  - ***Dorsal Fairing***

- **Efficiencies In Stress Analysis Achieved Through:**
  - ***Use State of the Art Post-Processing Methods in Finite Element Analysis Data Recovery***
  - ***Develop and Apply Uniform and Automated Techniques in Classical Stress Analysis***
  - ***Document and Publish Stress Analysis Results in Advanced Electronic Format***

- **Areas Improved to Meet Static Strength Requirements:**
  - ***Upper Wing Skin***
  - ***Lower Wing Fitting Attach Bolt Diameter and Material***
  - ***Primary Fuselage Structure for CFT Carriage***
  - ***And Others***

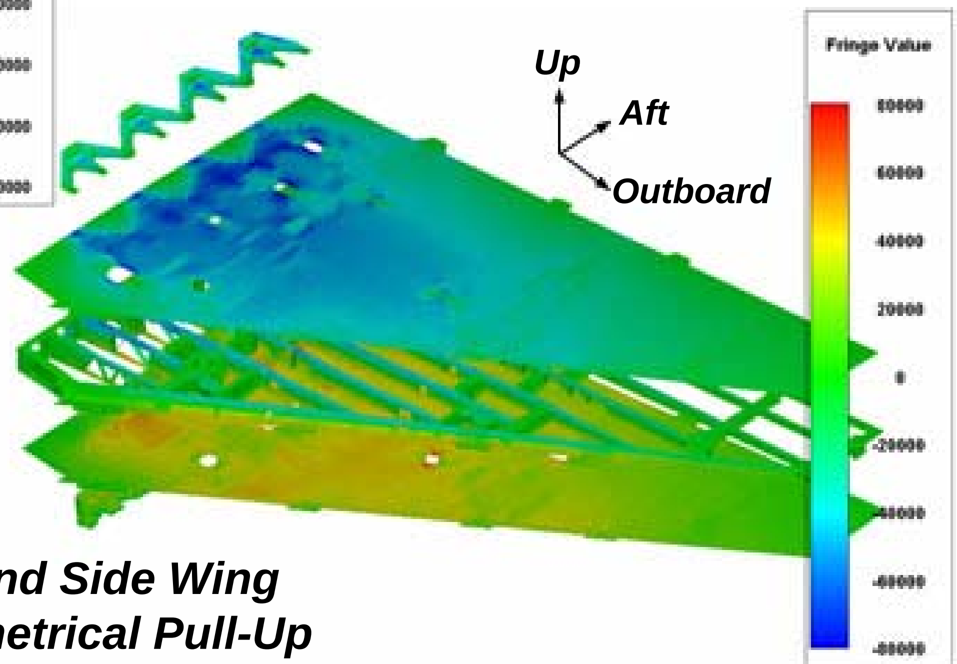
- **Ultimate Margins of Safety Provided to Define Strength Summary and Operating Restrictions for Each Customer**

F-16 Block 52+ Stress Analysis (Continued)



Isometric View; Looking Up and Aft

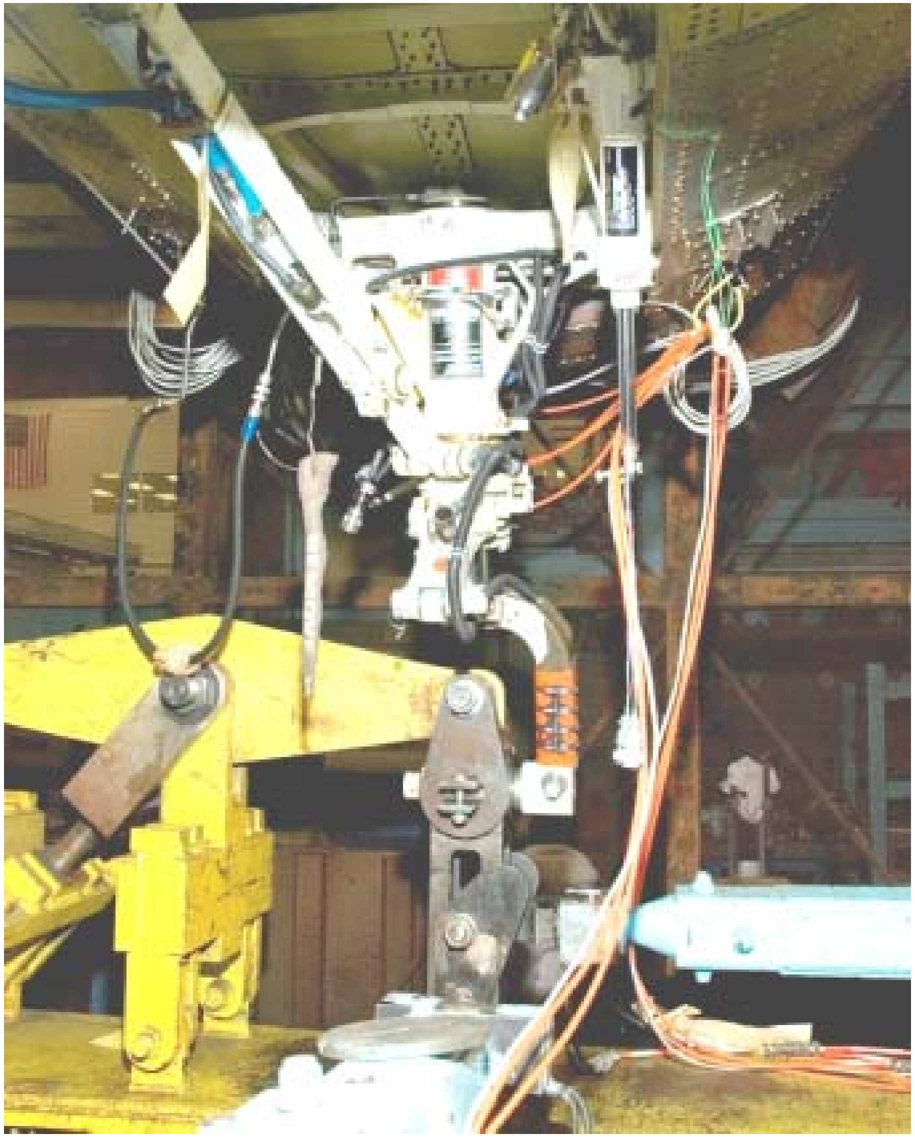
Isometric View; Looking Down and Aft



Left Hand Side Wing
9g Symmetrical Pull-Up
Ultimate Directional Stresses

F-16 Block 52+ Nose Landing Gear Static Test

- **Nose Landing Gear Improvement Made to Meet Block 52+ Weight and Center of Gravity Requirements**
  - ***Wider Tire and Wheel***
  - ***Axle***
  - ***Piston and Fork Assembly***
- **Strength Analysis Performed by the Supplier and Reviewed by LM Aero**
- **Successfully Static Tested at LM Aero Engineering Test Laboratory**
  - ***14 Ultimate Test Conditions***
  - ***16 Limit Test Conditions***
  - ***35 Strain Survey Load Conditions***
  - ***189 Strain Gage Channels***
  - ***9 Deflection Gages***



F-16 Block 52+ Service Life Analysis

- **Detailed Durability and Damage Tolerance Analyses were Completed for All Block 52+ Customers in order to Validate Contractual Service Life Requirements.**
  - ***Cycle-by-cycle Crack Growth Analysis Completed for Critical Structural Locations***

- **Detailed Durability and Damage Tolerance Analyses Accounted for:**
  - ***Unique Structural Configurations***
  - ***Unique Usage including:***
    - CFT carriage
    - 600 gallon tank carriage
    - Customer specific mission mix (%A-A, %A-G, etc.)
  - ***Utilized High Level of Detailed Fine Grid FEM Results***
  - ***Improved Material Selections (Al-Li skins, bulkheads)***

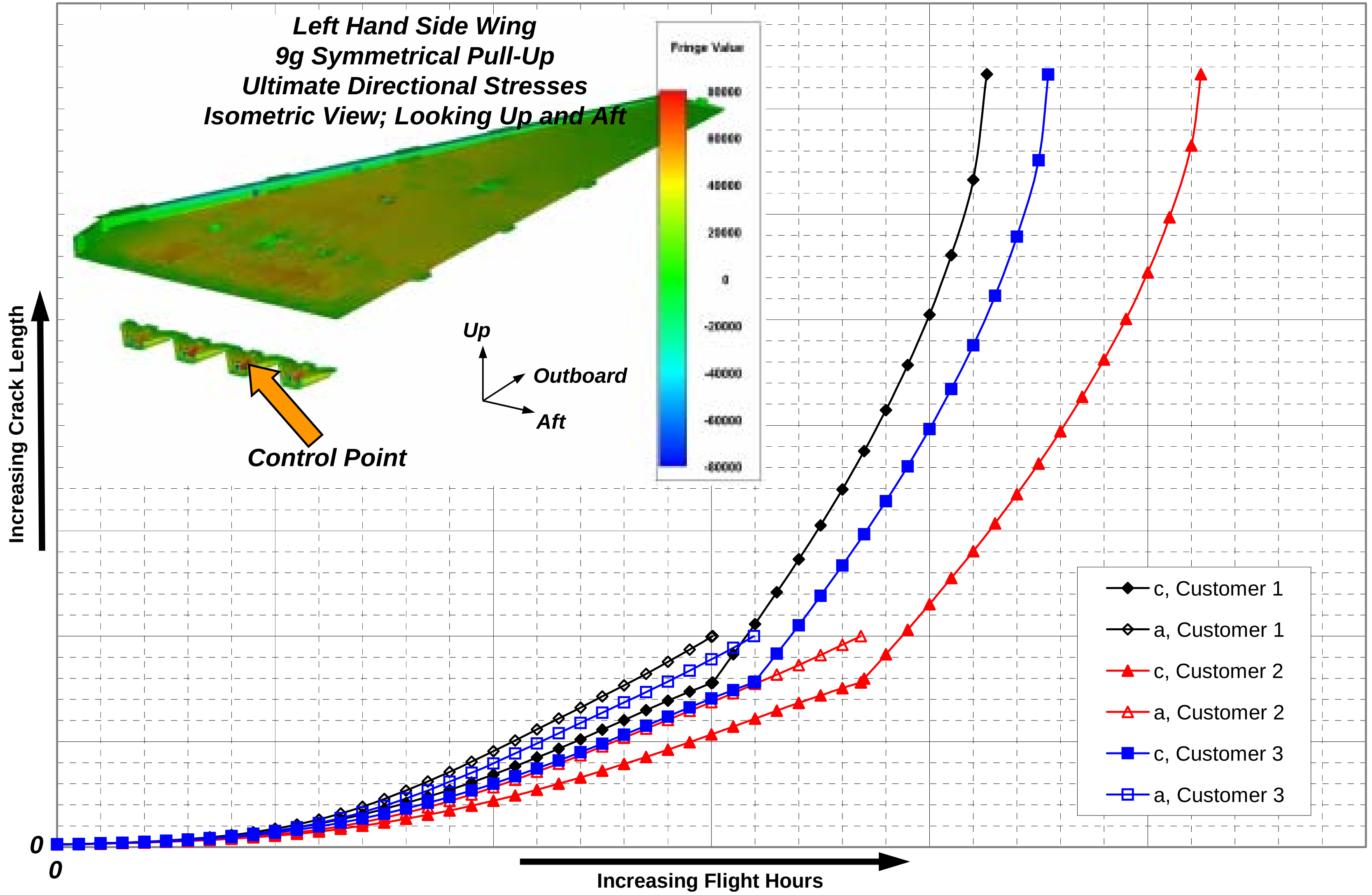
- **Use of Correlated/Validated Analytical Methodology and Models Leveraging Historical Knowledge Base:**
  - ***Fleet Cracking Database Results***
  - ***Full Scale and Component Test History***
  - ***Past Analytical Predictions***

F-16 Block 52+ Service Life Analysis (Continued)

- **Areas Improved to Meet Service Life Requirements**
  - ***BL 19 Longeron Material Change***
  - ***Canopy Support Frame Flange Thicknesses Increased***
  - ***Use of ForceTec Fastening System In Center Fuselage Upper Skins – Eliminates Nut Plate Rivet Holes***
  - ***Wing Carry Through Bulkhead Inspection Improvements and Application of Cold Expansion Process***
  - ***Wing Carry Through Bulkhead Web and Flange Thicknesses Increased***
  - ***FS 479 Upper Bulkhead Material Change***
  - ***Wing Spar Thicknesses Increased***
  - ***Lower Wing Attach Fitting Inspection Improvements***
  - ***Vertical Tail Spar Web Thickness Increased***
  - ***And Others***

F-16 Block 52+ Service Life Analysis (Continued)

Durability and Damage Tolerance Analysis Summary
FS 341.80 Lower Wing Attach Fitting Bolt Hole – Cold Expanded



Summary and Conclusions

- **Structural Certification Achieved for the F-16 Block 52+ Through a Disciplined and Rigorous Application of MIL-STD-1530B to Satisfy the Program Contractual Requirements**
  - ***Detailed ASIP Master Plan Developed, Coordinated, and Approved by USAF F-16 Systems Group***
  - ***ASIP tasks Delineated in Master Plan Successfully Completed***
- **F-16 Block 52+ Benefited from Structural Design Process that Incorporates Lessons Learned from:**
  - ***Operational Fleet History of 20+ years***
  - ***Full Scale and Component Test History***
  - ***Structural Analysis Experience of Previous F-16 type versions***
- **Unprecedented Use of Correlated Structural Analysis Methods Resulted in Realized Efficiencies in Cost, Scheduling and Technical Correctness**
  - ***Leveraging Results of Previous F-16 ASIP Sustaining Tasks to Develop/Improve/Validate Industry Best Practices***
  - ***Active Participation and Direction from USAF in Developing Efficient Methods Applied to the F-16 ASIP – New Production and Sustainment***

Block 52+ Airframe is the Most Capable F-16 to Date – A Product of a Disciplined and Rigorous Application of the ASIP Principles.

F-16 Block 52+ Inaugural Flight

Implementation and Certification of Integral Structures on the C-17 Aircraft

Kenneth Chan*, Hugo Guzman, Ko-Wei Liu, Tsair-Jyh (George) Tzong

Boeing Company

29 November 2005

C-17 Monolithic Structures - Case Studies

Three major areas :

- Cargo Door Bulkheads
- Forward Fuselage Pressure Bulkheads
- Aft Fuselage Frames

Outline

Introduction to Integral Structures

- Definition
- Benefits
- Design guidelines

C-17 Major Monolithic Structures

- Cargo Door Bulkheads
- Forward Fuselage Pressure Bulkheads
- Aft Fuselage Frames

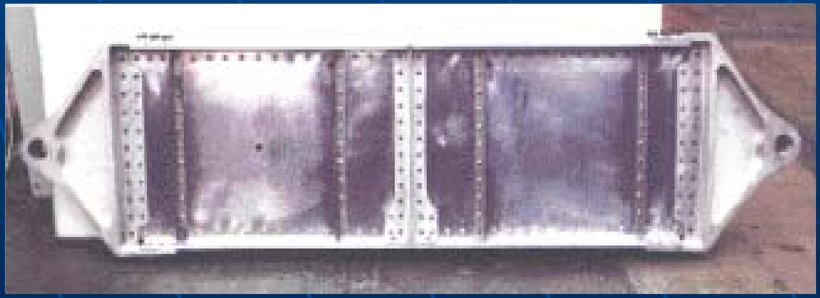
Repair

AFRL Sponsored R&D

Conclusions

What is Integral Structure?

- aka Unitized structures and Monolithic structures
- Consolidation of several structural parts into one unit, mechanically or chemically
- Fabrication with machining, castings, millings, welding, or other forming processes



Built-up

Integral

Benefits of Integral Structures

- Reduce part count, manufacturing cycle time, and fabrication cost
- Add design flexibility, strength, inspectability
- Prevent structural fatigue and corrosion
- Enhance automation, improve ergonomics and reduce work fatigue
- Increase Determinant Assembly (DA) opportunities, improve fit and reduce rework

General Design Guidelines

- Maintain load path, distribution and stiffness as built-up
- Tolerate large damage with readily detectable flaw size
- Sustain minimum of 3 lifetimes for crack initiation, plus 3 lifetime of durability from a 0.01” flaw to functional impairment.
- Meet discrete source damage and survivability requirements
- No or minimum weight increase

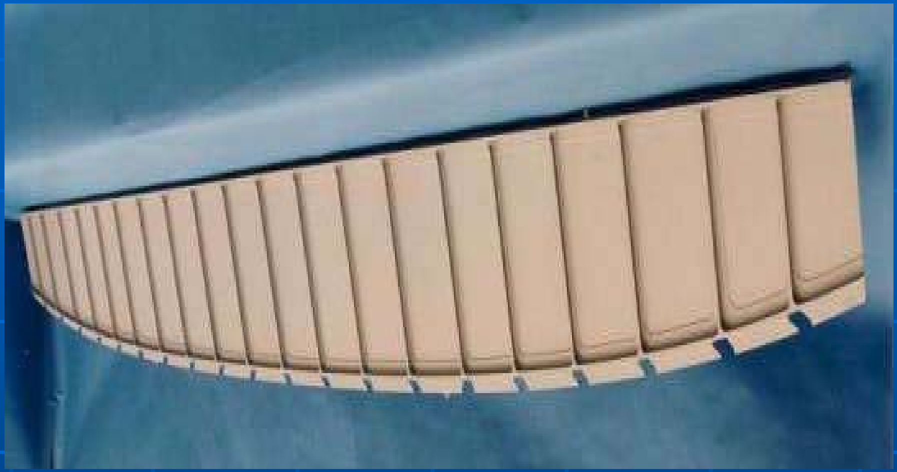
However, each design has its particular concerns which will be addressed in the following

Cargo Door Bulkheads

- Monolithic redesign – integrated caps, webs, stiffeners and shear clips into one part

Integral Cargo Door Bulkheads

Specific Concerns:

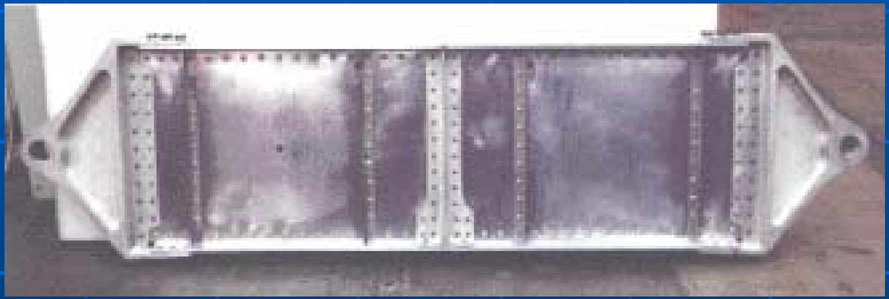


- Web buckles at 20% of full cabin pressure (1P)
- Impacts of the fatigue and fracture on web are unknown
- Structure needs demonstration of 40,000 full pressure cycles without cracking

C-17 Cargo Door Investigation

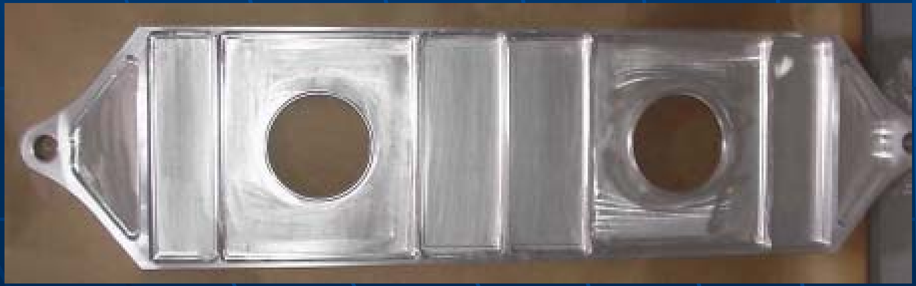
Various beam design studies were conducted at Boeing since 1998

Built-up Beam



Monolithic Beam

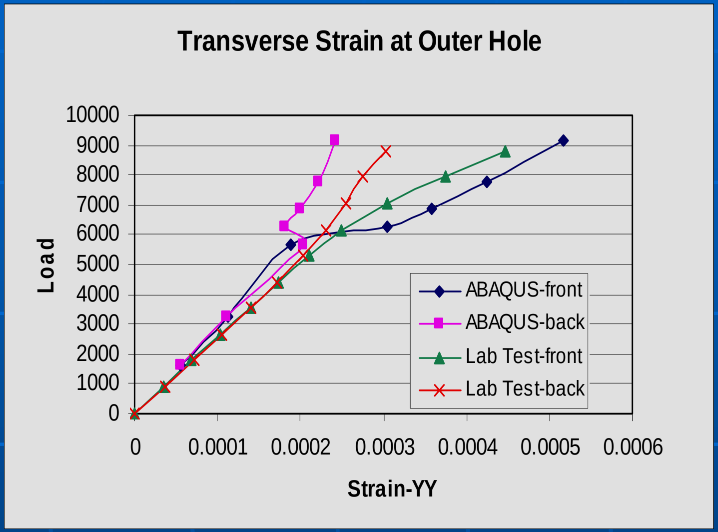
Monolithic Beam with Holes



Anodized Monolithic

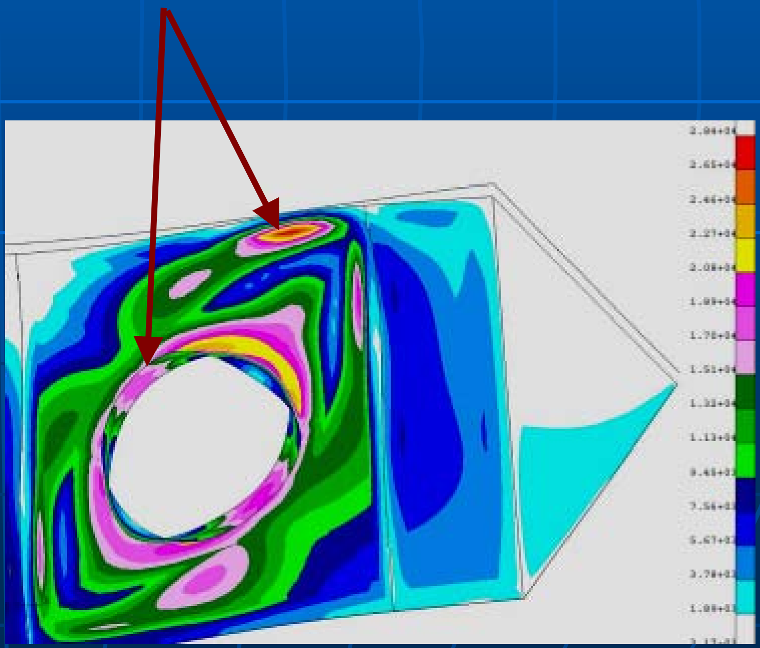
Testing of Simply Supported Beam

Test and Analysis Correlation



Non-Linear FEM Analyses in ABAQUS were performed

Critical Locations



Point Design Testing

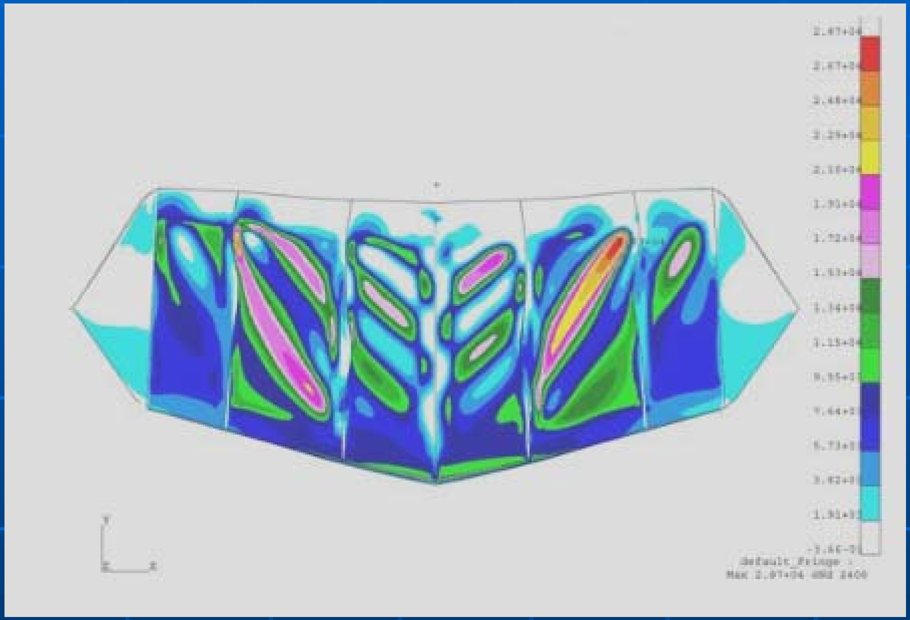
Cargo Door Bulkhead configuration was tested and analyzed in 2004

Point Design Testing - Results

Cycles	Load	Observation
20	6,000 lbs	No Crack
40,000	1 P	No Crack
50,000	1.2 P	No Crack
54,000	1.4 P	No Crack
60,000	1.4 P	1" Crack L.S., .5" Crack R.S.
70,000	1 P	1" Crack L.S., .5" Crack R.S.
80,000	1.4 P	1.5" Crack L.S., 1.35" Crack R.S.
84,000	1.4 P	2.3" Crack L.S., 1.5" Crack R.S.
87,502	1.4 P	Broke

Analytical Results

Maximum Principal Stress at web

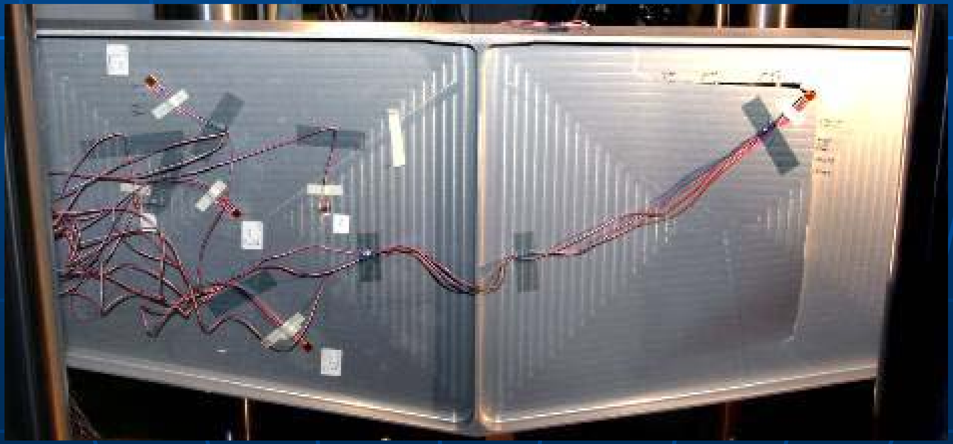


28.7 KSI @ 1.0 P
35.6 KSI @ 1.2 P
42.3 KSI @ 1.4 P

Finding: Peak stress less than **38 KSI** for **1P** condition will meet C-17 Durability Life Design Requirement

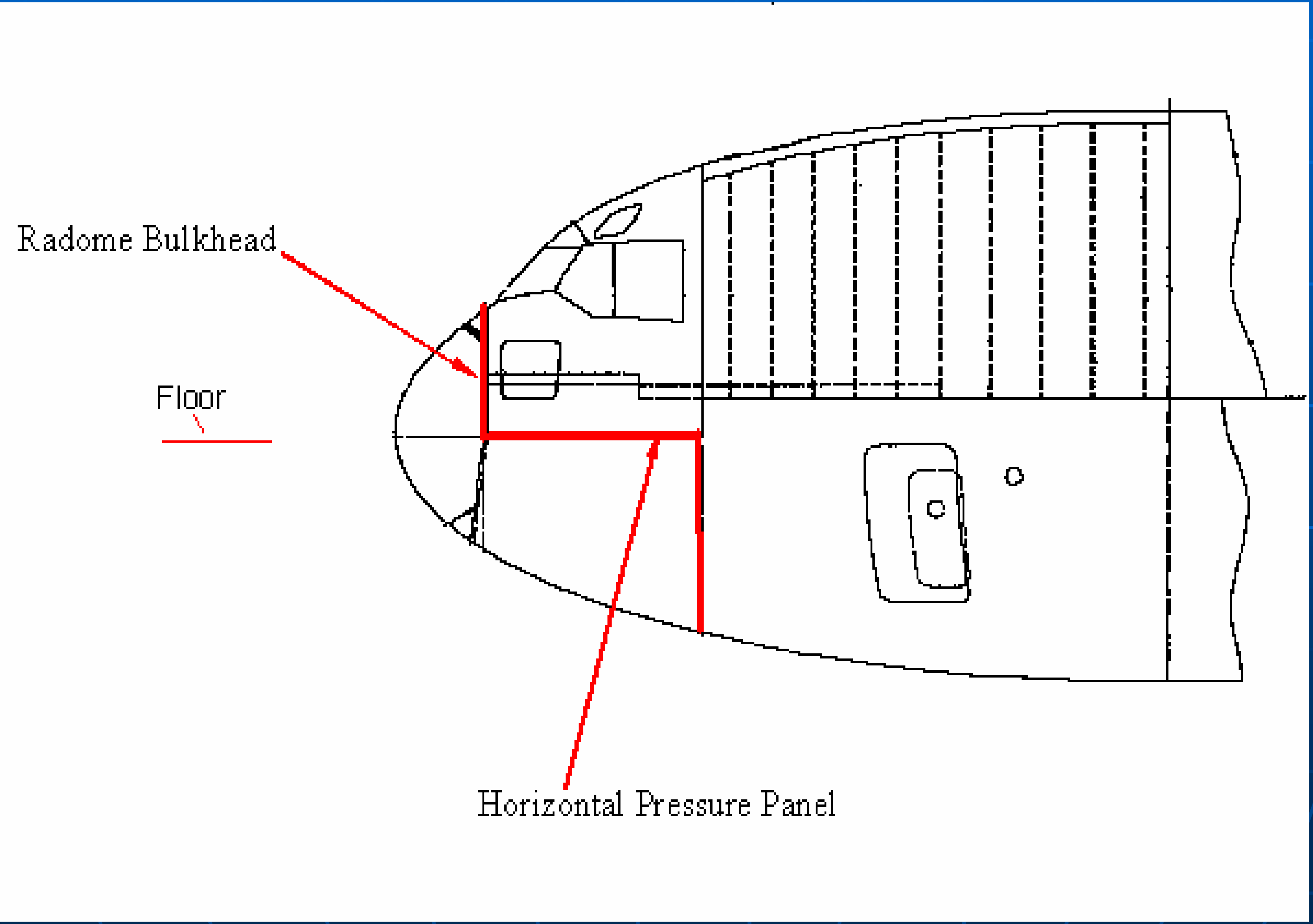
Cargo Door Bulkhead - Conclusions

- Exceeded the design requirement of 40,000 full pressure cycles (1P)
- Cracks at 1" did not grow at repeated 1P loading
- Final failed after 80,000 cycles at 40% higher than operating full pressure load



Forward Pressure Bulkheads

Radome and Horizontal Bulkheads

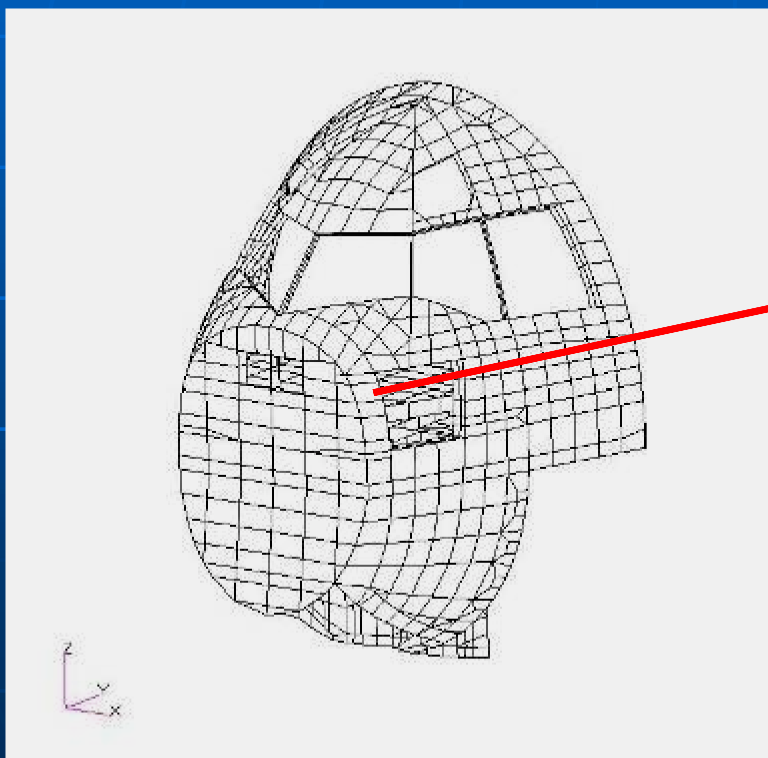


Forward Fuselage Specific Concern

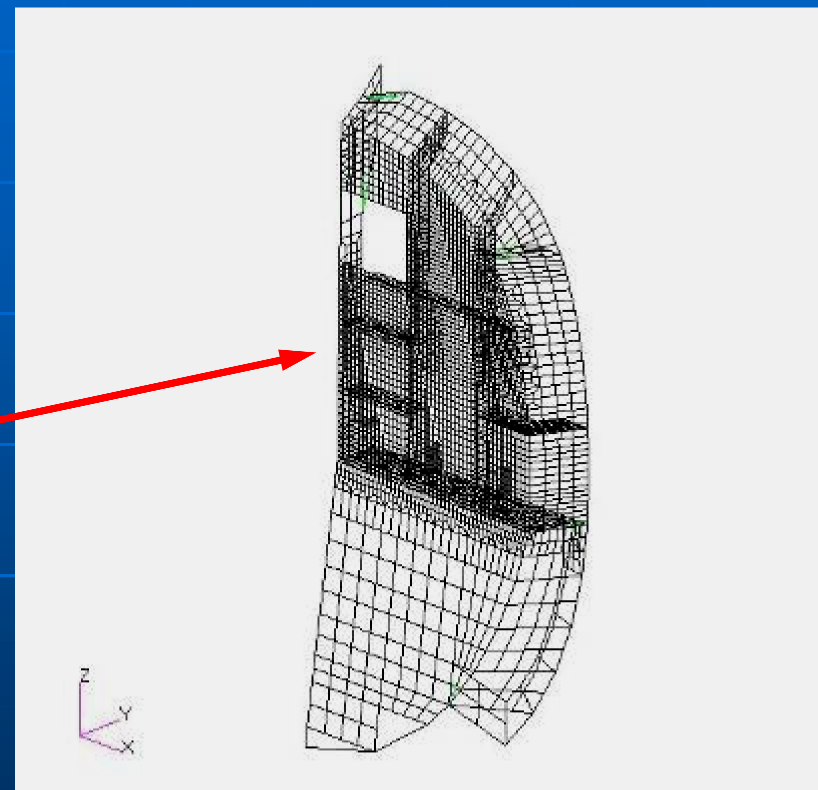
Pressure Bulkheads

Shall have residual strength capability to sustain an 18 inch crack (readily detectable) at full internal cabin pressure

Radome Model



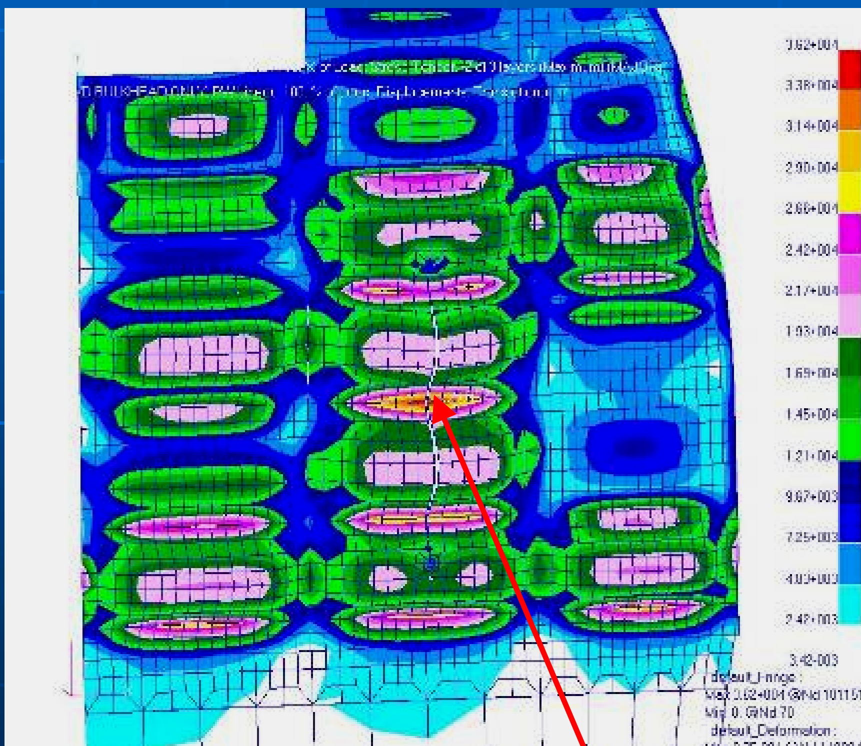
Coarse Mesh Model

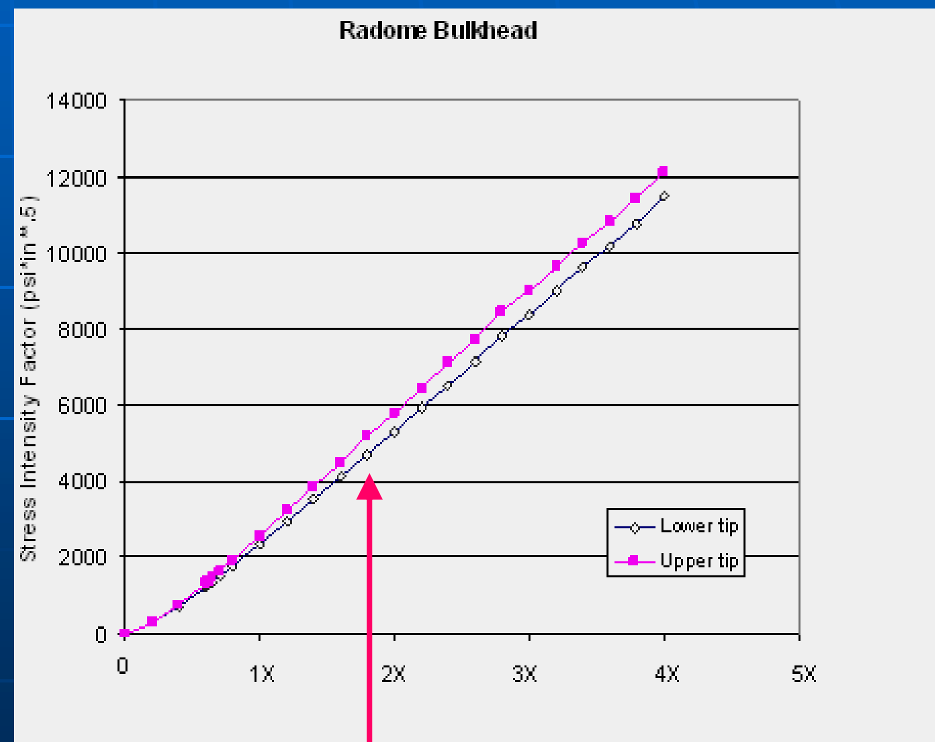


Fine Mesh Model

Radome Stress Intensity Solution

NASTRAN Large Displacement Analysis

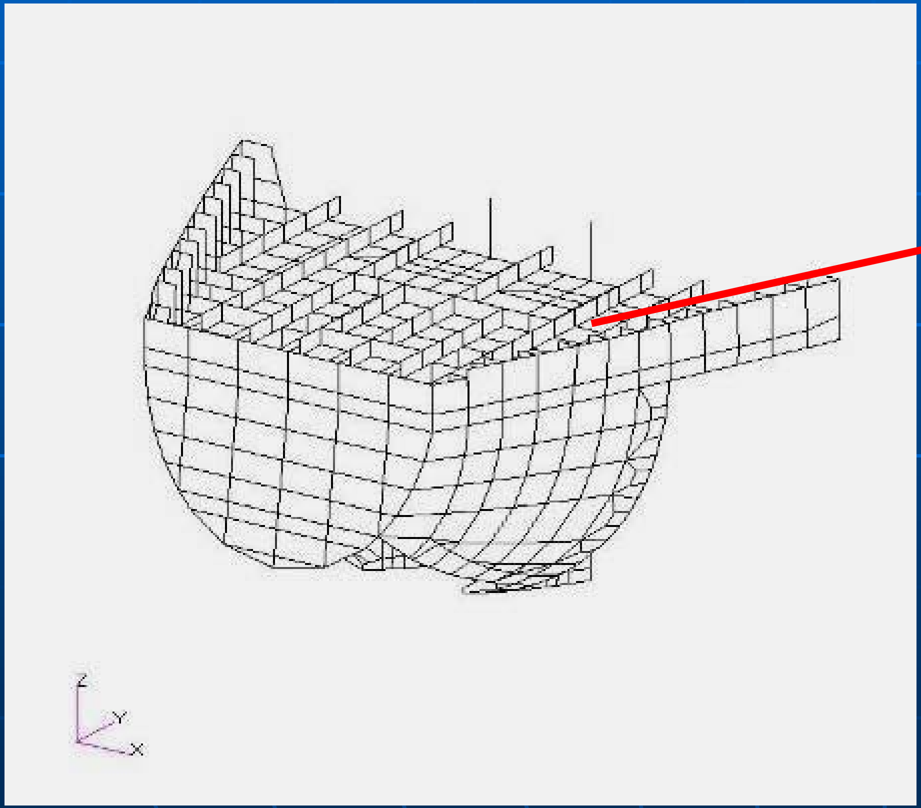




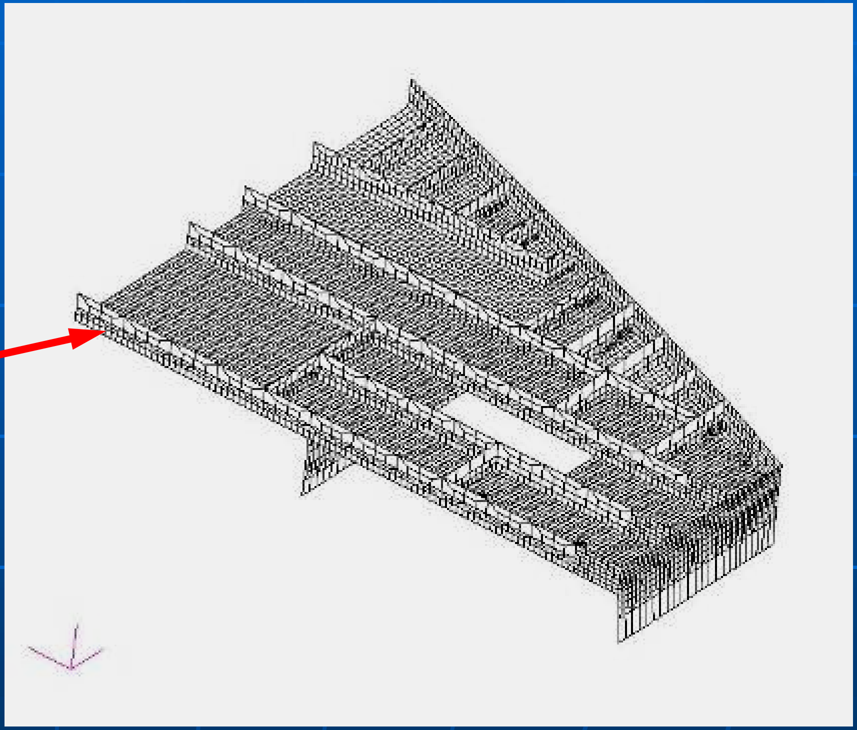
18" Crack at highest stress region

1P cabin pressure

Floor Pressure Panel Model



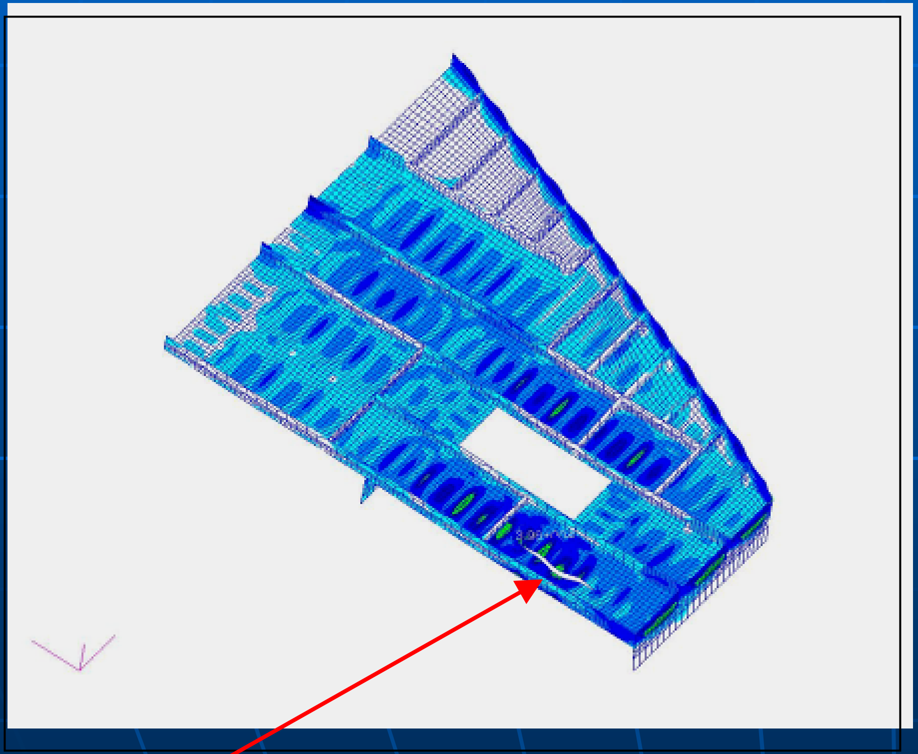
Coarse Mesh Model



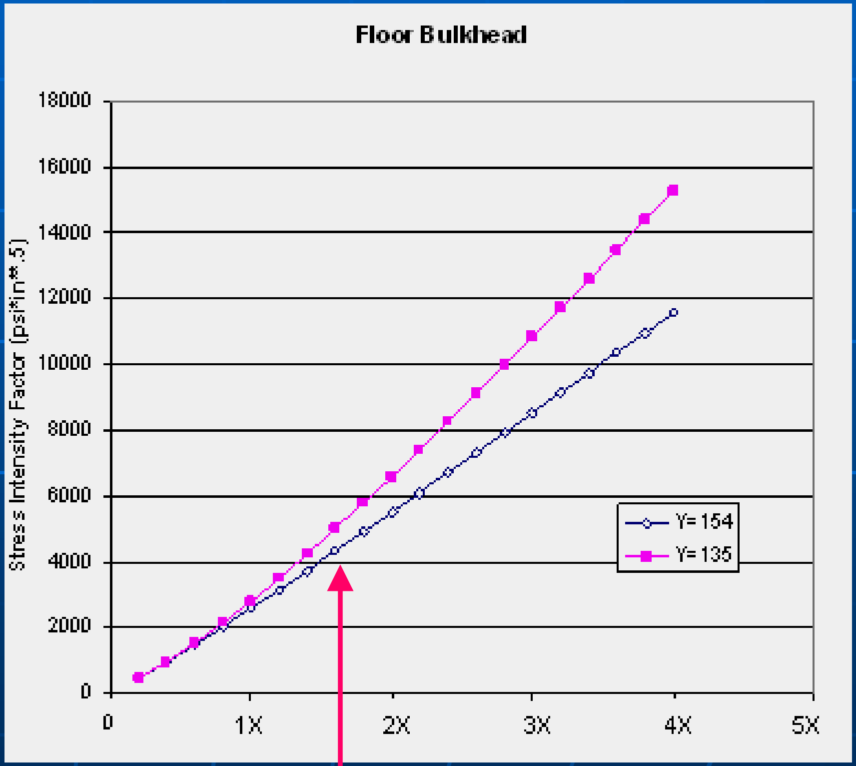
Fine Mesh Model

Horizontal Panel - Stress Intensity Solution

NASTRAN Large Displacement Analysis

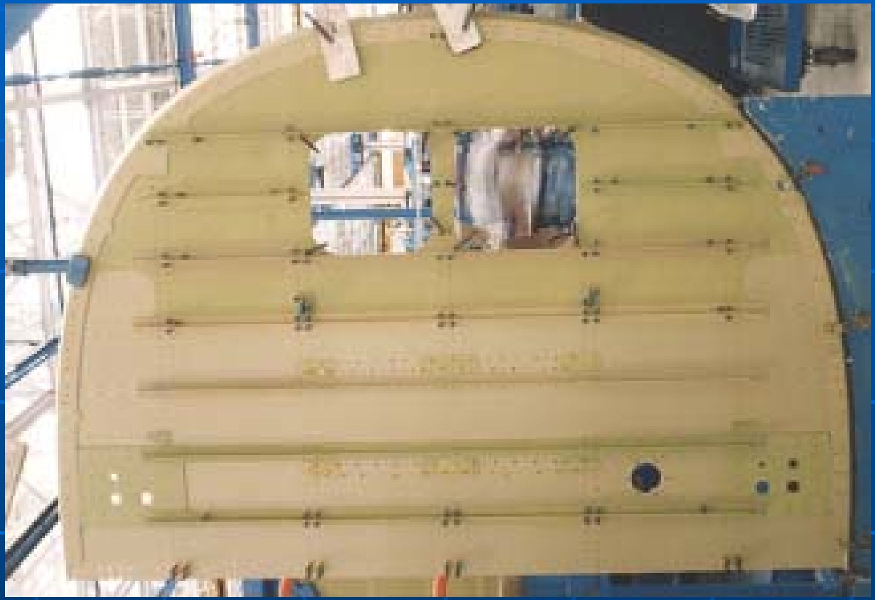


18" Crack at highest stress region



Full cabin pressure

The Upper Bulkhead Redesign



Before

After

Eliminated 33 detail parts and 820 fasteners

The Horizontal Pressure Panel Redesign

Before

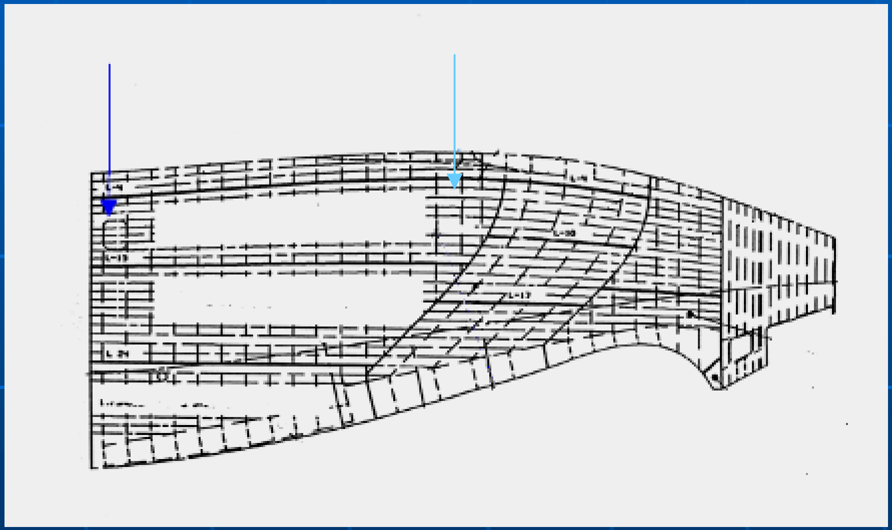
After

Eliminated 64 detail parts and 2240 fasteners

AFT Fuselage Frame Conversion

C-17 AFT Fuselage Frames

Total of 15 Frames in the Aft Fuselage



Two frames had been implemented to date, 3rd is on-going

AFT Fuselage Frame - Specific Concern:

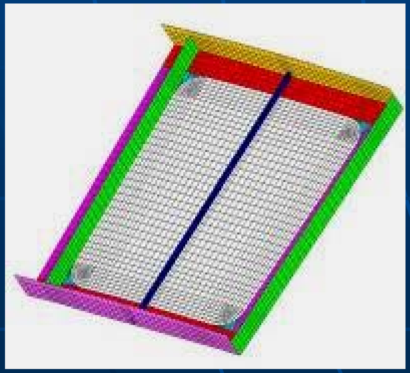
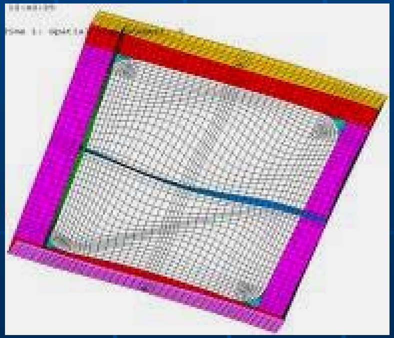
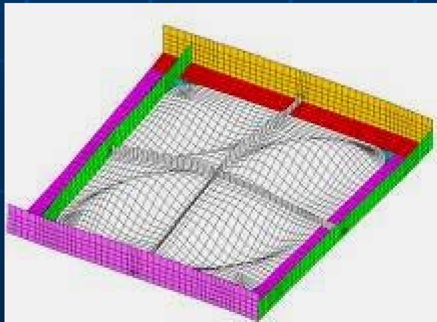
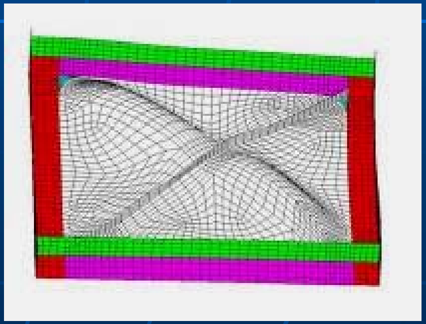
- Peak frame web stress to be below 38 ksi for 1P cabin pressure load

- All web design details to be identical to tested configuration

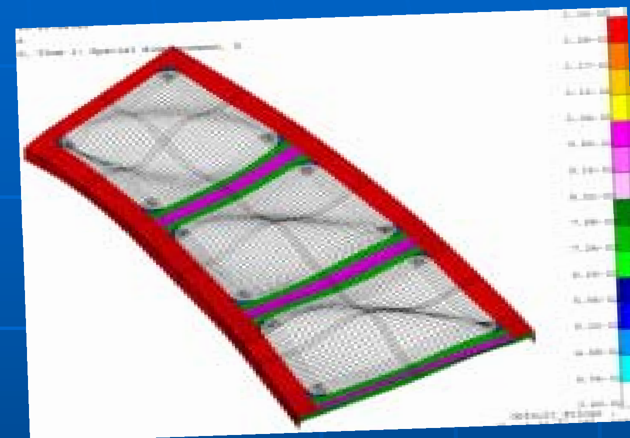
Frame-Web Design Study

Configuration Options:

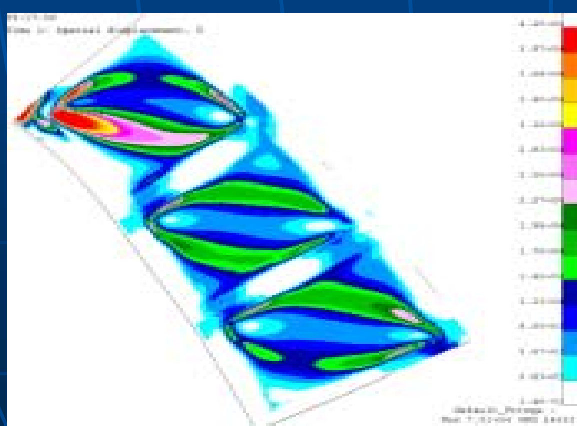
- Various Web thickness
- Various vertical and horizontal center strips
- Various cross and diagonal strips
- Various stiffener sizes and pad-ups
- Combinations of above

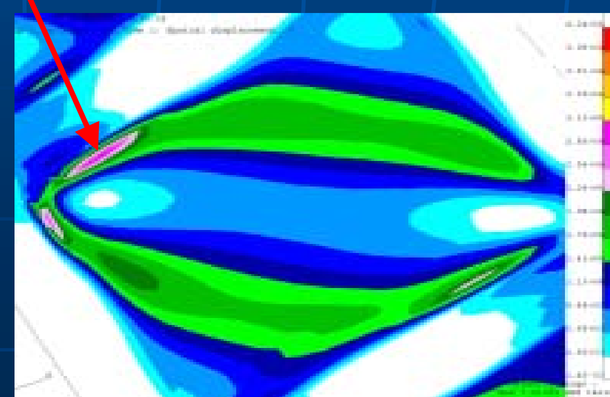





Nonlinear FE structural analysis



Highest Max Principal Stress area





Reparability of Monolithic Structures Design

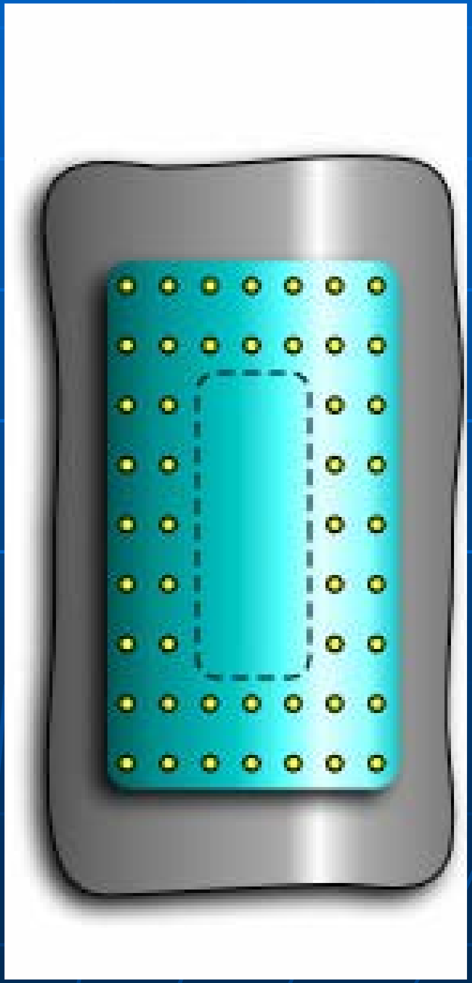
Design Previsions

Stiffener & Cap Repair:

Heights and local lands have sufficient areas for splice repair

Web Repair:

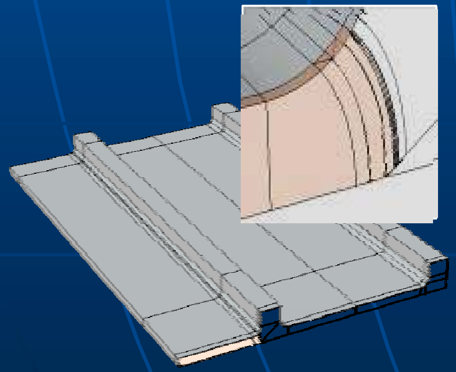
Would allow installation of fastened doubler repair



USAF Sponsored R&D on Monolithic Structures

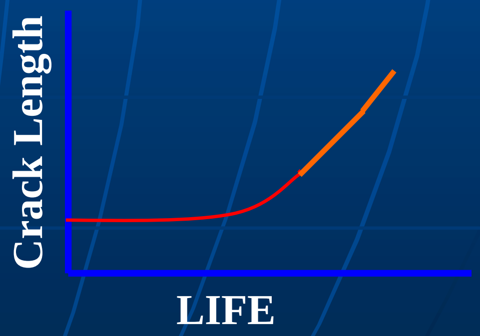
“External K-Solver” - links a Finite Element Code interactively to a Crack Growth Life computational program.

FEM StressCheck



External K-Solver

AFGROW



C-17 Monolithic Structure Implementations

Conclusions:

- Successfully implemented on the C-17
- Specific concerns for each individual part were addressed
- Same practices and benefits can be applied to other large transport aircraft

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DEFINING THE FUTURE

Airworthiness Certification Strategy for Global Hawk HALE

ASIP Conference 2005
Memphis, TN

November 29, 2005

Mo Pourmand
Global Hawk ASIP Manager
HALE Systems Enterprise
Unmanned Systems, Northrop Grumman Corporation

Agenda

- **Introduction to Global Hawk High Altitude Long Endurance (HALE) Platform**
  - Mission requirements and system overview
  - Flight operations summary
- **HALE Structural Design Overview**
  - Design drivers
  - Integrated structural test program
- **ASIP and Airworthiness Certification**
  - Tailored ASIP for HALE UAV's
  - Tailored ASIP for Global Hawk
- **Summary**

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DEFINING THE FUTURE

Introduction to Global Hawk HALE

System Designed To Meet Challenging Mission Requirements

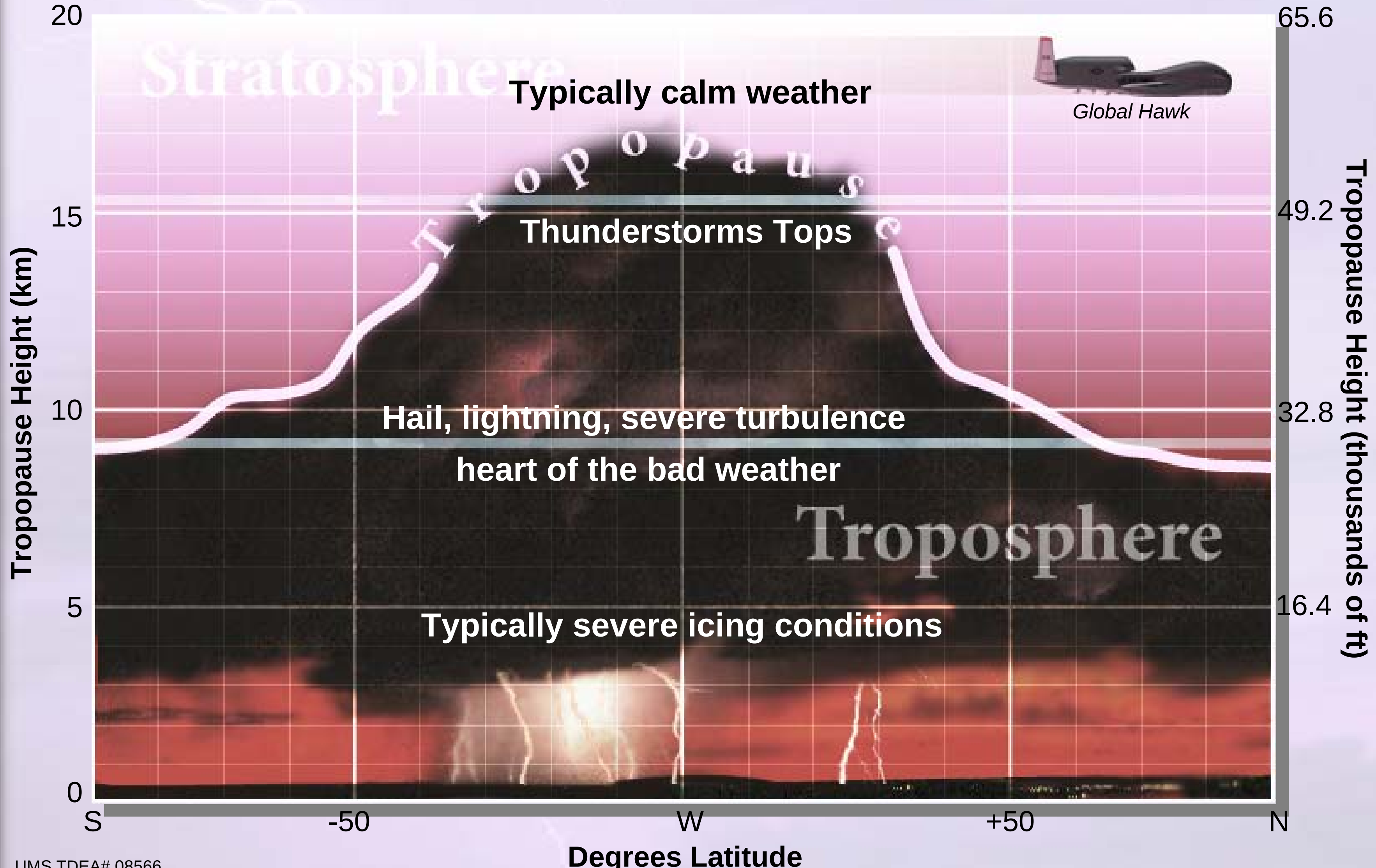
- Unmanned autonomous operation
- Automated in-flight contingencies
- Long endurance (30+ Hours)
- High altitude (60,000+ feet)
- 3,000 lbs Multi-Int payload capability
- Real-time mission control, override & re-tasking
- Airspace integration for worldwide operations
- Multi service interoperability
- Cost effective redundancy for autonomous flight operation

High Altitude, High Speed, Long Endurance

1. High altitude is critical for turbulent weather avoidance
2. True airspeed & therefore ground speed are maximum at high altitude
3. Winds are light & variable at high altitude
4. High altitude operations do not conflict with other air traffic
5. High altitude provides longer sensor range
6. Long endurance at high altitude provides maximum area surveillance capability

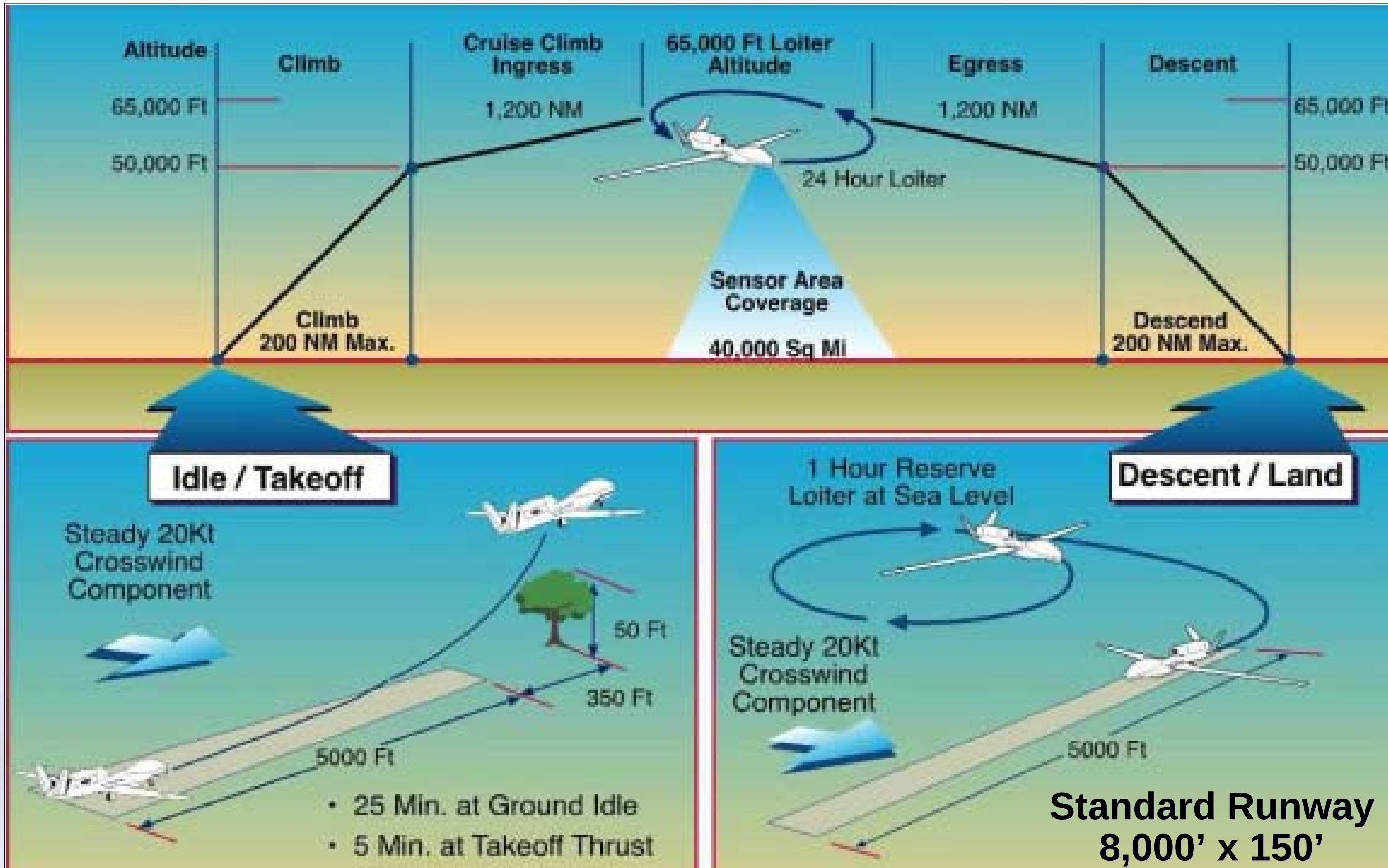
Generally, conditions become exponentially better at altitudes above 55K ft

High Altitude is Critical for Weather Avoidance



UMS TDEA# 08566

Typical Global Hawk Mission Profile



Historical Flight Operation

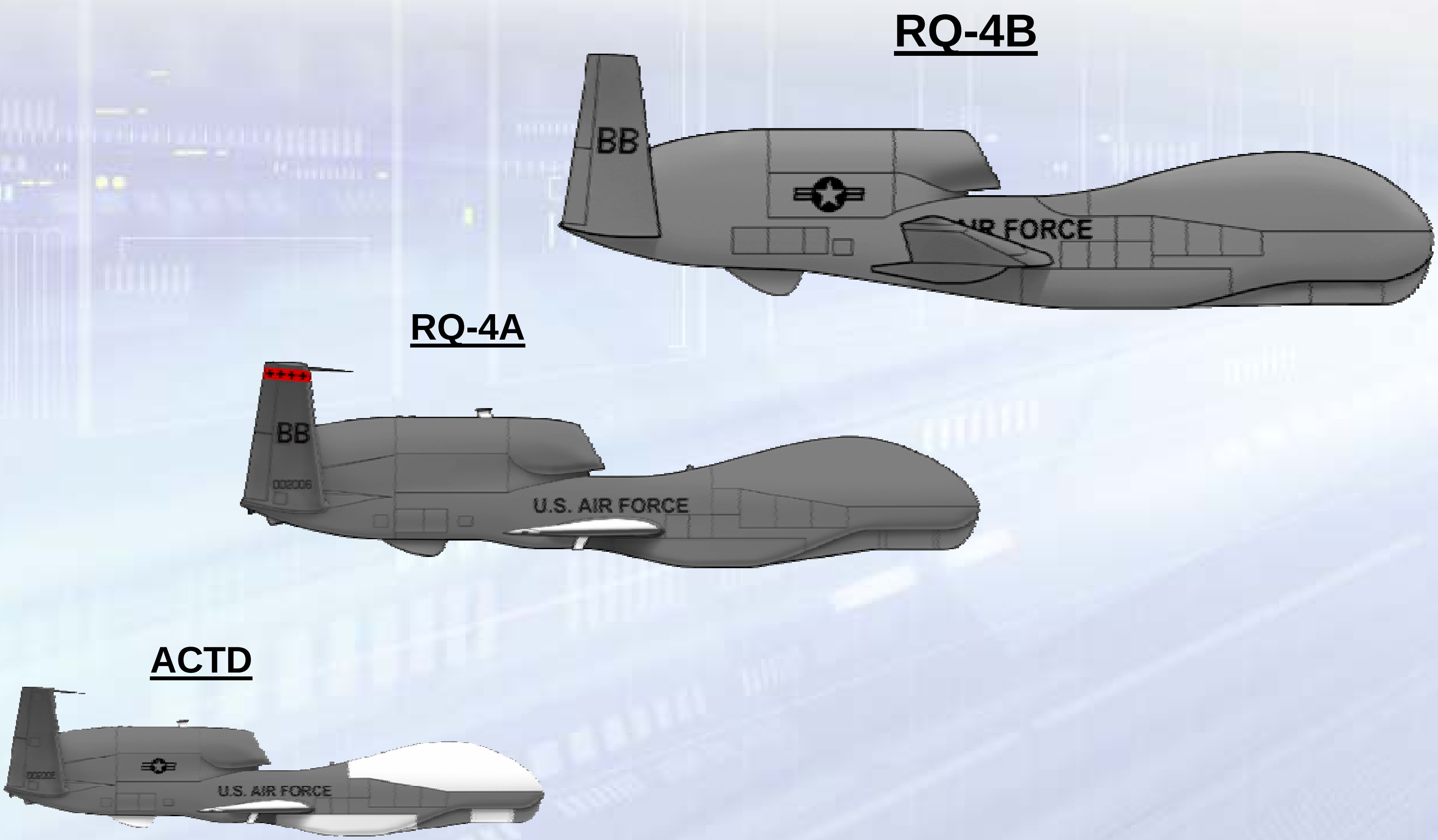
Flight Summary

- Program Totals: 500+ flights / 8,000+ hours
  - Over 50% of the total hrs and flights are all on one vehicle
  - No major anomalies during the first four phase inspections
- 300+ Hours In FAA Controlled Air Space

Flight History

- Contract award May 1995
- First flight Feb 28,1998
- Altitude – 60,000+ feet
- Duration – 30+ hours
- Operated In Jurisdiction of 14 Foreign Airspaces

Global Hawk HALE Solution

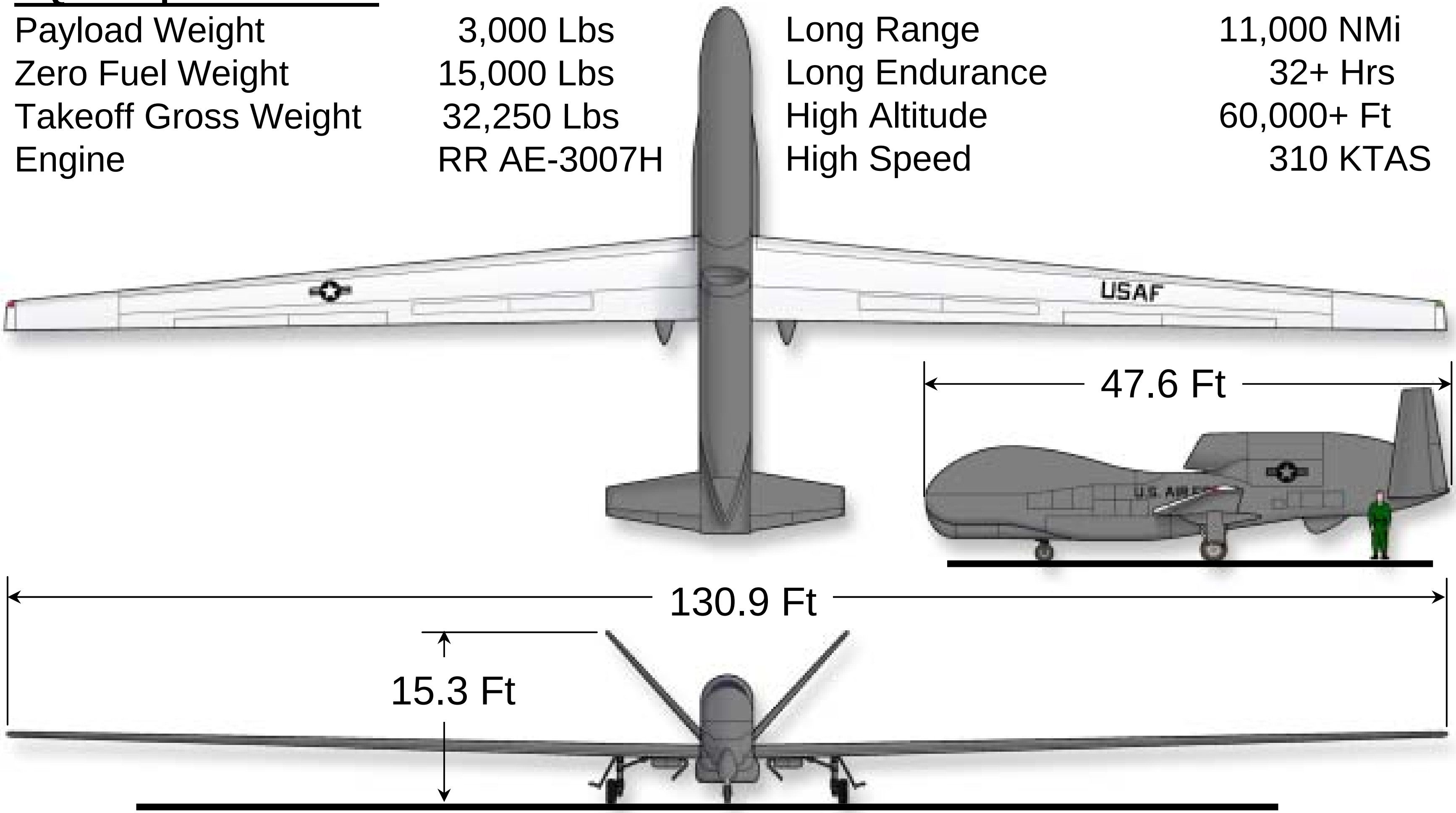


UMS TDEA # 06128 & 08566

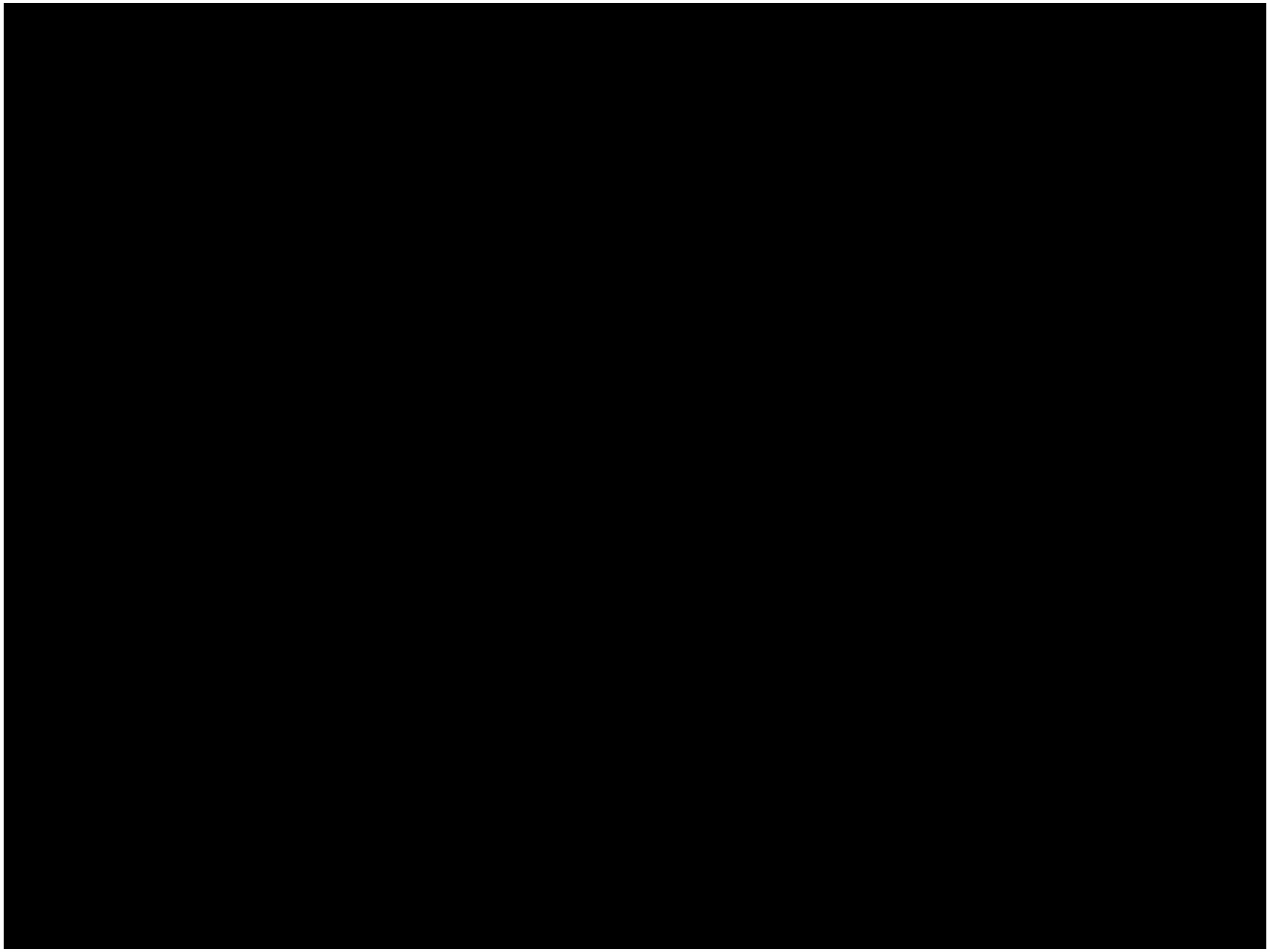
RQ-4B Configuration Specifications

RQ-4B Specifications

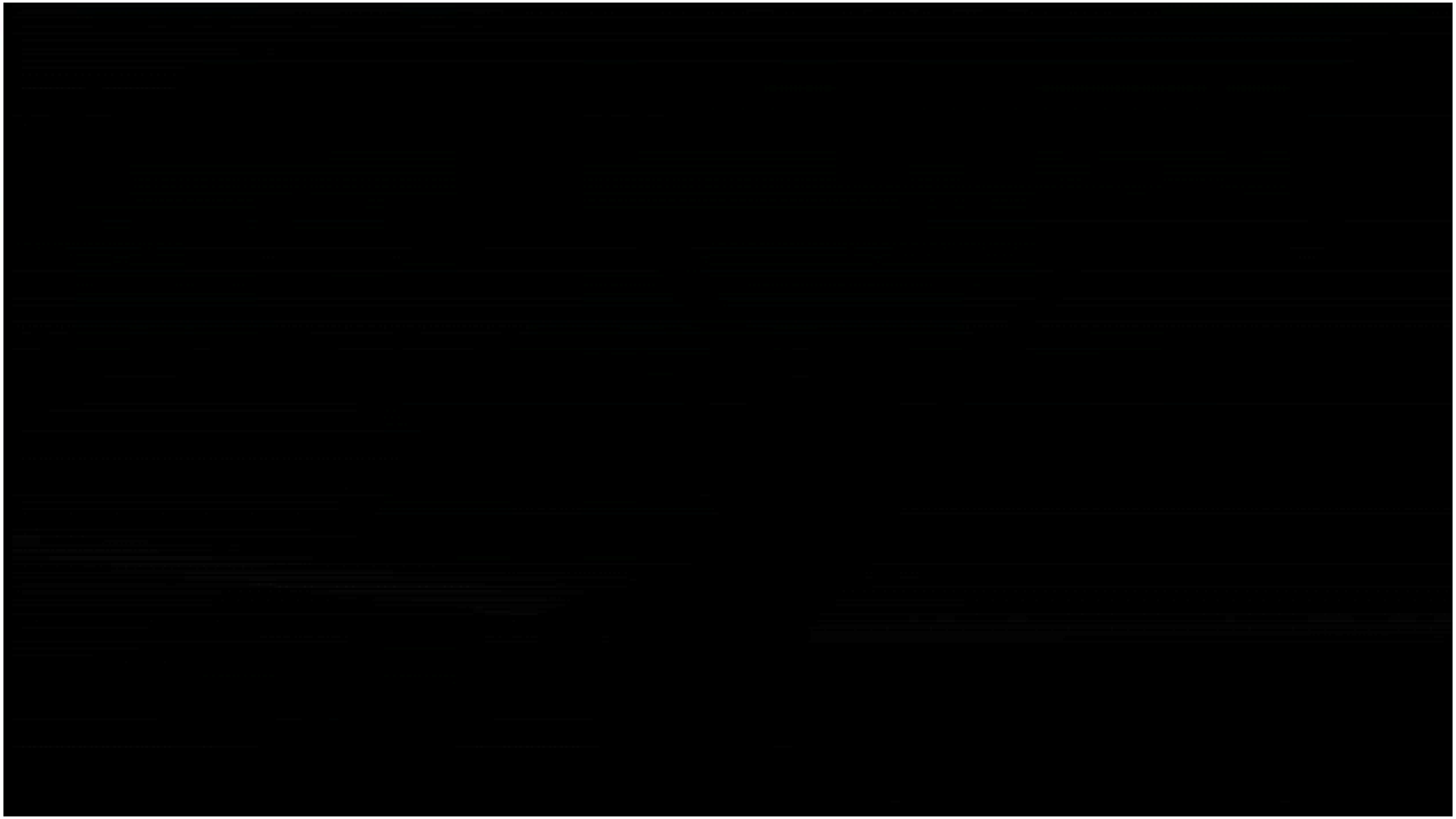
Payload Weight	3,000 Lbs	Long Range	11,000 NMi
Zero Fuel Weight	15,000 Lbs	Long Endurance	32+ Hrs
Takeoff Gross Weight	32,250 Lbs	High Altitude	60,000+ Ft
Engine	RR AE-3007H	High Speed	310 KTAS



Global Hawk Take off and Landing



Global Hawk Cruising



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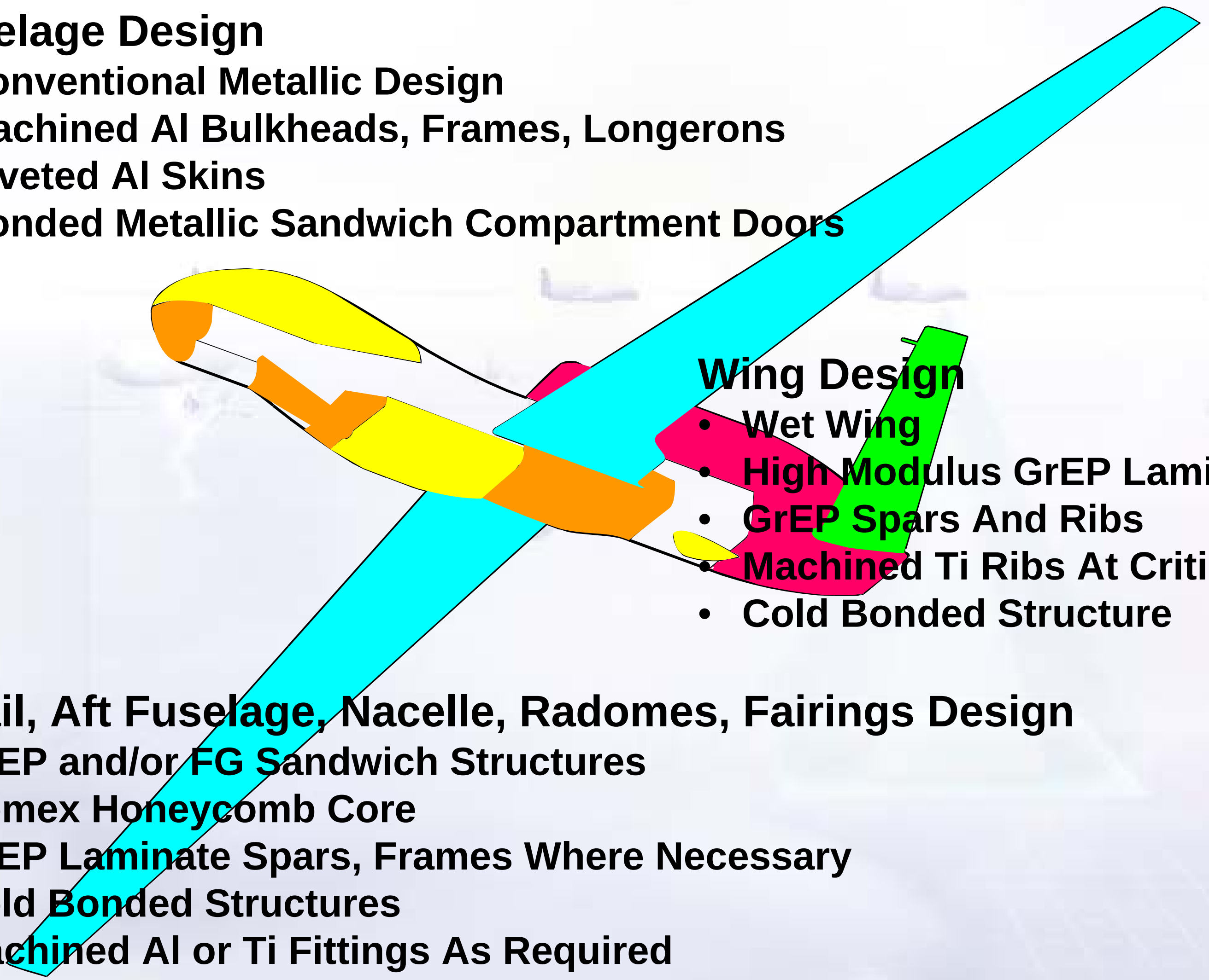
HALE Structural Design Review

Structural Design Overview

Fuselage Design
- Conventional Metallic Design
- Machined Al Bulkheads, Frames, Longerons
- Riveted Al Skins
- Bonded Metallic Sandwich Compartment Doors



Wing Design
- Wet Wing
- High Modulus GrEP Laminate skins
- GrEP Spars And Ribs
- Machined Ti Ribs At Critical Joints
- Cold Bonded Structure

V-Tail, Aft Fuselage, Nacelle, Radomes, Fairings Design
- GrEP and/or FG Sandwich Structures
- Nomex Honeycomb Core
- GrEP Laminate Spars, Frames Where Necessary
- Cold Bonded Structures
- Machined Al or Ti Fittings As Required

Bonded Structures Adhesive Selection

- EA9394 epoxy adhesive
- Best system at reasonable cost, much lower in cost than film adhesive
- Good combination of pot life, handling time, and full cure capability at room temperature
- Qualified for exposure and use with water and JP fuels
- Evaluated for different bondline thickness
- Extensive use in industry and readily available
- Application on the international Space Station
- Extensive evaluation by AFRL

Bond Adhesive Requirements

- **Moisture and Temperature Exposure**
  - Require excellent hot/wet glass transition temperature
  - Cryogenic temperatures at high altitude
- **Chemical Exposure**
  - Need excellent adhesive solvent exposure properties
    - JP-8, JP-5 and hydraulic fluids
- **Typical Strength Properties Evaluated**
  - Design operating strains
  - Joints strain-to-failure
  - Lap shear and peel strength
  - Durability and damage tolerance

Primary Structural Design Drivers

- **Maneuver Loads**
  - 1.5g typical cruise maneuver controlled by software
  - Worst pull-up maneuver < 3g max
- **Gust Loads (90% of mission spent above 50K = less probability of encountering high gust speeds)**
  - 3.2g gust load factor based on mission cycle analysis
- **Ground Operation Loads**
  - Controlled by software for low sink rate, and moderate taxi and braking
- **Airspeeds**
  - V_{cruise} = Mach 0.6 at altitude
  - V_{nte} = 165 KEAS
- **Bottom Line – Benign and Predictable Loads Envelope**

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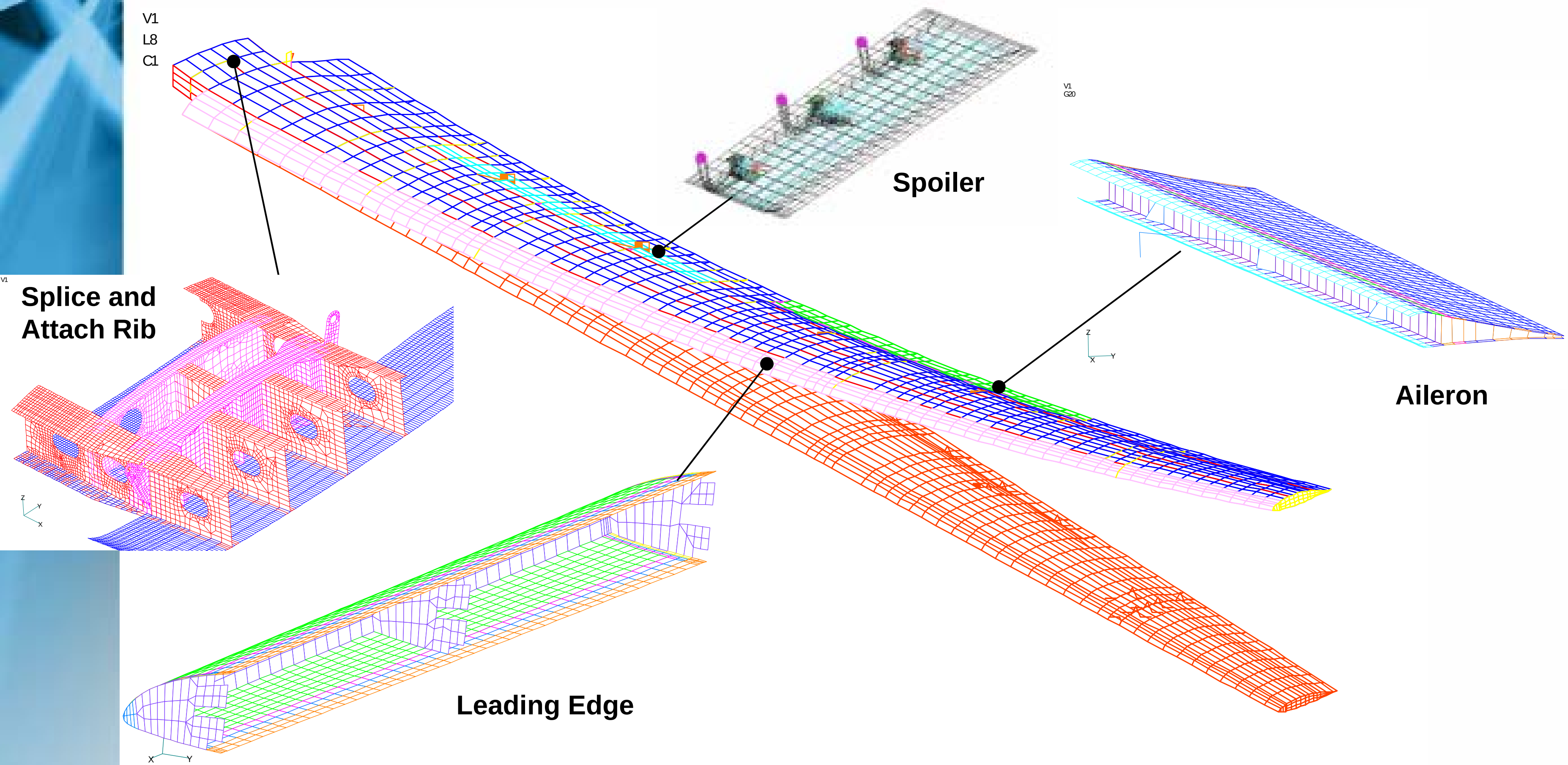
Finite Element Models

- **Validated wing FE model with excellent correlation to test results**
  - Manufacturing article test, proof test, GVT, and ultimate testing



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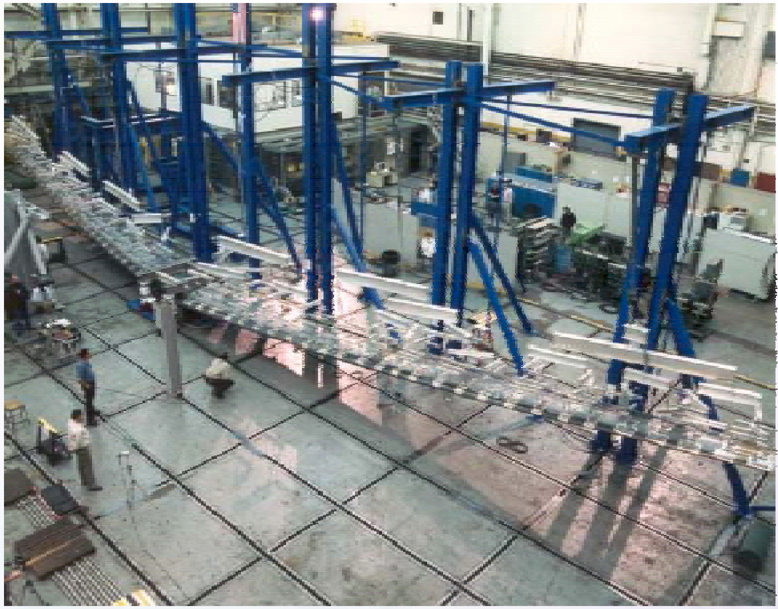
Global Hawk ASIP Integrated Structural Test Program

- **Implement tailored ASIP requirements with an integrated structural test program towards airworthiness certification of Global Hawk HALE**
  - Demonstrate extended life capability
  - Lower overall mission risk
  - Adequate for tailored ASIP program



- **Building block approach**
  - Coupon test
  - Joint allowables
  - Element test
  - Component level tests
  - Proof tests
  - Full-scale static tests
  - Full-scale component level durability tests

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DEFINING THE FUTURE

HALE ASIP and Airworthiness Certification

Tailored ASIP for HALE UAV's

- **Global Hawk is Trial Case for HALE ASIP Tailoring**
  - Use JSSG 2006 and MIL-STD-1530 guidelines
  - Rapid pace spiral development requires alternative approaches
    - Building block approach reduces acceptable risk
    - Evaluate delay of full-scale testing when acceptable alternate methods are employed

- **ASIP tailoring decisions for HALE UAV's must consider acquisition and life cycle costs along with the quantification of increased risk**

Tailored ASIP for Global Hawk HALE

- **Mission Specific Tailoring**
  - HALE vs Combat = speed and maneuver loads requirements
  - High altitude vs low altitude = gust loads exposure
  - Short mission vs long endurance = GAG cycles
- **Global Hawk Approach**
  - HALE mission minimizes maneuver requirements
  - Pre-programmed autonomous maneuvers within flight envelope
  - High altitude operations minimize exposure to gusts
  - Long endurance flights minimize structural cycling

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Tailored Testing

- **Mission requirements allow consideration of slight risk increase due to delay of full-scale testing**
- **Benefits**
  - Supports fast paced spiral development strategy
  - Minimizes initial acquisition costs
  - Provides Warfighter with needed capability sooner
- **Implications on EMD**
  - Added costs on production due to proof testing
- **Implications on Life Cycle**
  - System support increased due to additional inspections

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Tailored ASIP for HALE UAV's - Examples

- **Tailoring Examples – Potential Safety Impact**
  - Truncated EMD stage – Early LRIP go-ahead
  - Reduced Factor of Safety for gust events
  - Typical gust load criteria based on high altitude consistent mission usage, and time at altitude
  - Reduced impact damage resistance for light-weight composite structure design

Summary

- **Typical ASIP requirements and elements of airworthiness certification can be tailored for HALE UAV's**
  - Low mission GAG cycles
  - Repeatable and controlled missions
- **Global Hawk has successfully demonstrated operational airworthiness within acceptable risk**
  - 500+ missions and 8,000+ flight hours
- **Tailored HALE ASIP tasks may increase life cycle cost**
  - Technical risk must be balanced with economical impact

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Questions?