F-35 Aircraft Structural Integrity Program Overview

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F-35 – Many Programs in One

Interoperability

CTOL

CV

STOVL

P&W F135
GE/RR F136

3 Services

8 International Partners

2 Security Cooperation Participants

Global Sustainment

Domestic / International Suppliers

Autonomic Logistics

3 Flight Test Facilities

Training

Introduction

- **The F-35 Program Offers An Unprecedented Opportunity To Leverage The Fundamental Concepts Of ASIP To Supply Each Of Our Government's Service Branches An Airframe That Meets Their Unique Structural Integrity Requirements At An Affordable Price.**
- **Meeting These Varied Requirements In The Concurrent Development Of The Three Aircraft Variants Presents A Unique Challenge Of Identifying Opportunities For Commonality, Reaching Consensus With Multiple Customers, And Execution Of The Variant Tasks Within The Reduced Cost And Schedule Goals That Form The Vision Of The Joint Strike Fighter Concept.**
- **The 5 Pillars Of ASIP Provide The Roadmap To Both Identify These Opportunities And Meet These Challenges**

Outline

- Program Overview
- Pillar 1 - Design Information & Development Planning
- Pillar 2 - Design Analysis and Development Test
- Pillar 3 - Full Scale Testing
- Pillar 4 - Certification and Force Management Development
- Pillar 5 - Force Management
- Summary
- Q&A

F-35 Background

- **The F-35 Program Consists of 3 Air Vehicle Configurations or Variants and the Autonomic Logistic System that Will Support Them**
  - ***F-35A is a Conventional Take-Off and Landing (CTOL) Variant***
  - ***F-35B is a Short Take-off and Vertical Landing (STOVL) Variant***
  - ***F-35C is a Carrier Variant (CV)***

Unique Opportunities

- **"Commonality Benefit"**
- **Structural Similarity**
  - ***Building Blocks***
  - ***Full Scale Tests***
- **Three Variant Certification**
  - ***Shared Flight Test Pts***

Unique Challenges

- **Performance Based Specification Versus Certification Authority**
- **"Joint" Requirements**
- **Multiple Customers**
  - ***Life Management***
  - ***Certification Approaches***

F-35 Variant Comparison

STOVL

240B-4.3

Span (ft)	35
Length (ft)	51.2
Wing Area (ft²)	460

CTOL

240A-4.4

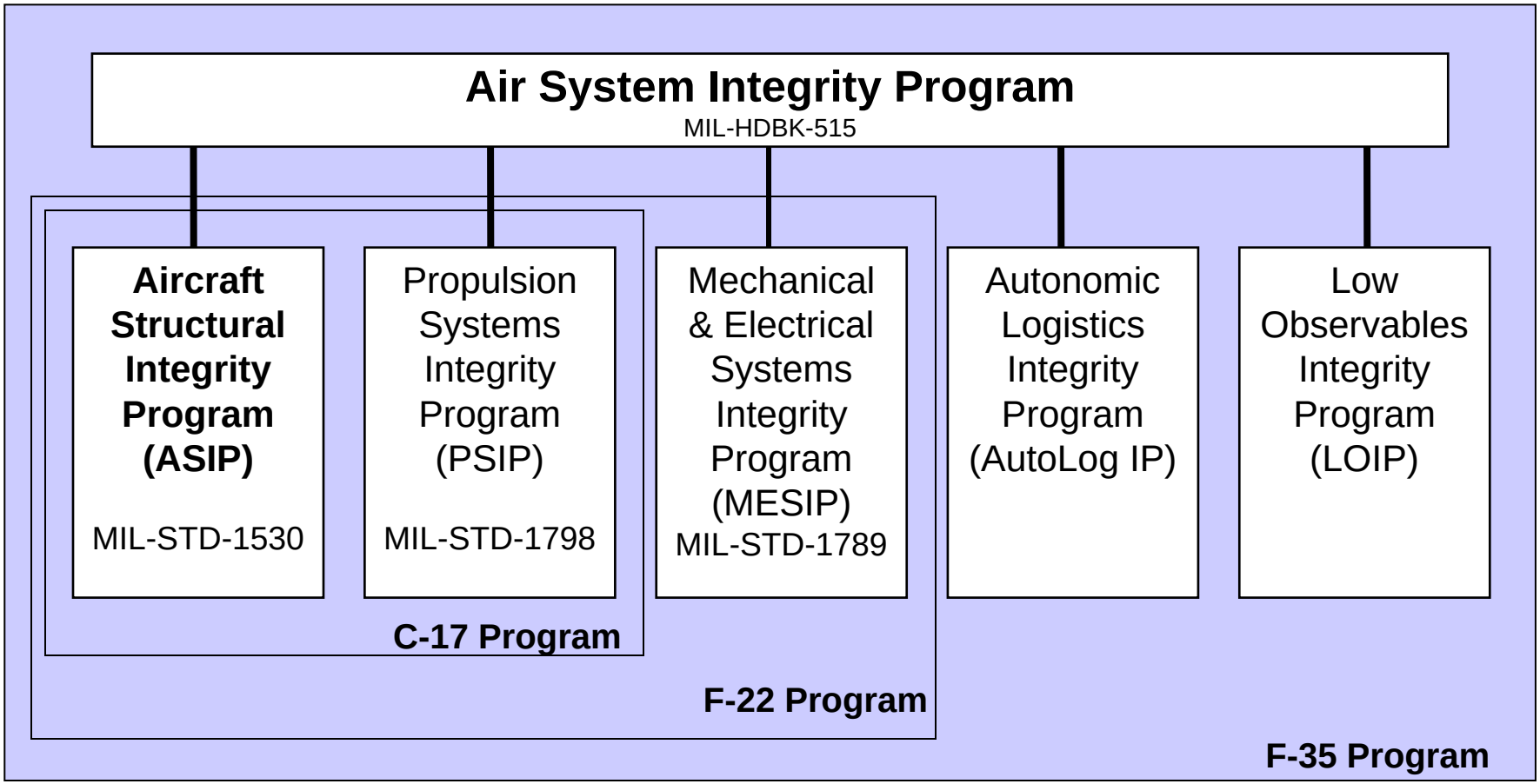
Span (ft)	35
Length (ft)	51.4
Wing Area (ft²)	460

CV

240C-4.5

Span (ft)	43
Length (ft)	51.5
Wing Area (ft²)	667

F-35 Integrity Program



F-35 ASIP Is Structured Conventionally per MIL-STD-1530

ASIP Task Overview

ATP PDR CDR LRIP LL LRIP FF IOC

	Task I Design Info & Development Planning	Task II Design Analyses & Development Tests	Task III Full Scale Testing and Certification	Task IV Force Management Data Package	Task V Force Mgmt, Production and Sustainment
Timeframe	**ATP to PDR**	**PDR to CDR**	CDR to Production Go-Ahead	Production Go-Ahead to Operational Life Management	On-going
Planning & Coordination	**Initial**	**Update**	Update	Update	
Design & Analysis Criteria	**Initial**	**Update**	Update	Update	
Characterize Environment	**Initial**	**Update**	Update	Update	
Characterize Materials	**Initial**	**Update**	Update	Update	
Characterize Production & Quality		**Initial**	Validate	Execute	
Critical Items	**Initial**	**Update**	Update	Update	
Structural Analysis		**Initial**	Update	Validate	
Test	**Coupons & Elements**	**Element to Sub-Component**	Component to Full Scale		
Life Management	**Initial**	**Update**	Update	Validate	Execute

Performance Based Specification

- **Few Direct Structural Specification Requirements Are Included In Joint Contract Specification**
  - ***Structural Requirements Are Derived From Performance Requirements***
  - ***Principal Structural Requirements:***
    - 90% Of The Aircraft Delivered Must Meet The Service Life Requirement
    - The Air System Must Be Durable, Damage Tolerant, Fault Tolerant, Fatigue Resistant, Corrosion Resistant…
- **With Few Direct Specification Requirements, A Rigorous ASIP Plan Is The Principal Means Of Certification And Contractual Verification.**

Pillar 1 – Design Information & Development Planning

- **Many Of The Challenges Of The PBS Environment Are Associated With The First Pillar Of ASIP**
  - ***Ambiguous Performance Based Requirements Rather Than Detailed Specifications***
  - ***Multiple Customers With Varying Traditional Approaches to Development Process & Certification***
  - ***Disconnect Between PBS Approach And Customer Certification***
  - ***JPO Customers As IPT "Partners"***
- **As a Result, Significantly Greater Effort Was Required During the Planning Stage to Establish Common Expectations Between the Customer and Contractor Teams**

Structural Materials Selection

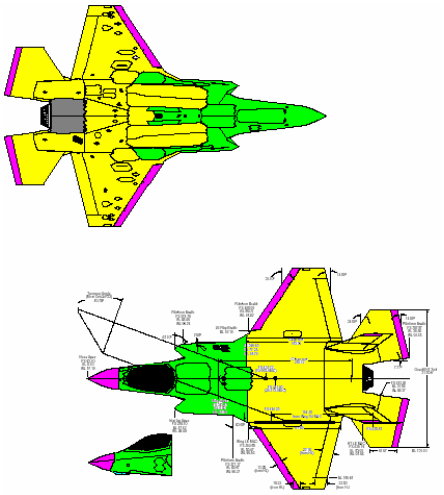
- **F-35 Selected Mature Materials For Structural Applications**
  - ***Composite Materials IM7/977-3 and IM7/5250-4 Characterized on other Lockheed Programs***
  - ***2124 and 7050 Plate Products Well Established In Military Applications***
  - ***7085 Forgings New, But Supplier had Complete MMPDS Database***
  - ***Ti 6-4 BA Plate and Forgings Well Characterized on Other Military Programs***

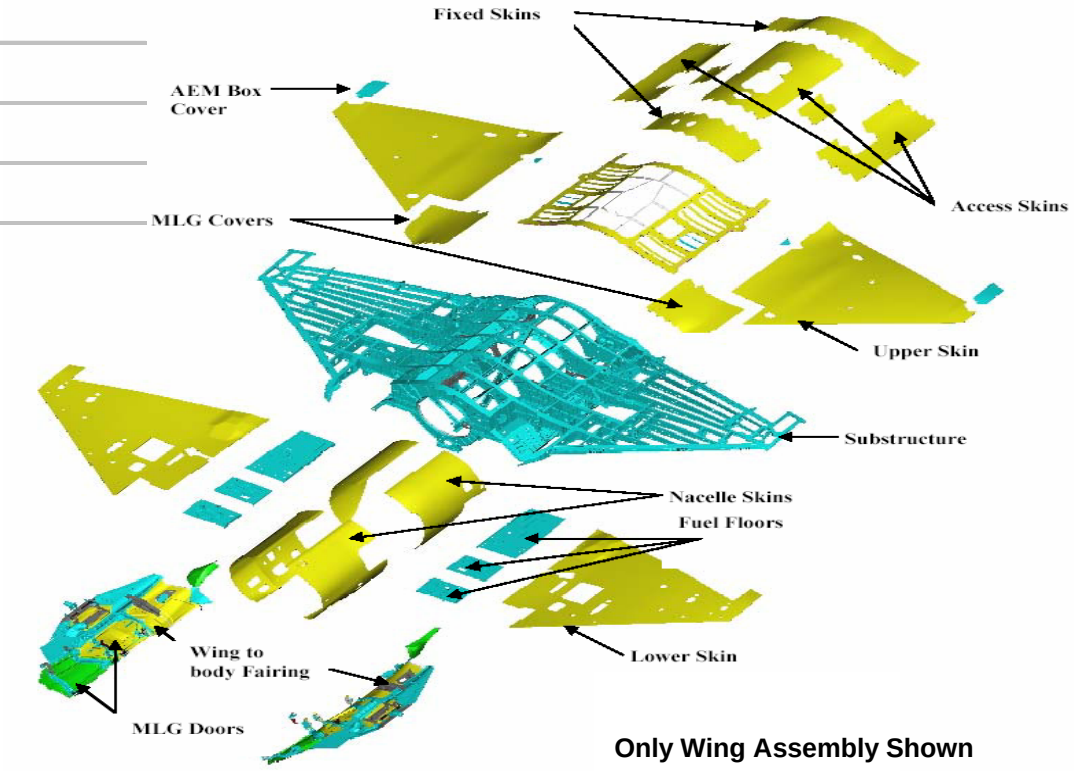
Approach Minimized Static Coupon Level Tests and Specification Development and Enabled Focus on Fracture/Fatigue Properties and Corrosion Behavior

Structural Material Distribution

Airframe Structure Only

		CTOL	STOVL	CV
	Material	Percent	Percent	Percent
	ALUMINUM	43.4%	45.7%	33.4%
	GRAPHITE/EPOXY	13.7%	12.1%	15.1%
	GRAPHITE/BMI	21.4%	21.3%	20.0%
	TITANIUM	15.4%	13.6%	25.4%





Only Wing Assembly Shown

Pillar 1 – Design Information & Development Planning

- **The Overall Status Of This Pillar Of The ASIP Plan Is Very Mature.**
  - ***The Planning, Coordination And Establishment Of Design And Analysis Criteria Are Now Maturing In Step With The Program Needs.***
  - ***The Characterizations Of The Materials, Joints, Environment Are Nearing Completion.***
  - ***The Identification And Control Of Critical Items Is Proceeding In Concert With The Development Of Each Variant And Is Complete For CTOL & STOVL.***
  - ***The Test Program To Establish The Material & Joint Allowables, Corrosion Prevention Methods And To Evaluate New Construction Techniques Is Nearing Completion. The Remaining Test Are For Confirmation Of Limited Data Sets Or Validation Or Full Scale Test Truncation Levels.***
  - ***The Life Management Concept Of Operations Was Developed Early In The Program And Is Being Matured As Part Of The Following Tasks Of ASIP.***

Pillar 2 – Design Analysis and Development Test

- **The Overall Status Of This Pillar Of The ASIP Plan Depends On The Variant Under Consideration.**
  - ***The Updates To The Certification Plans Are Maturing As The Details Regarding Critical Loadings And Failure Modes Are Revealed By The Structural Analysis***
  - ***The Structural Analysis Of The CTOL And STOVL Variants Are Nearly Complete.***
  - ***Sizing Of CV Variant Structure Is Well Under Way With CDR Scheduled For Late Spring '07.***
  - ***The Element And Sub-component Tests To Reduce Risk Or Validate Design Details And Structural Analysis Methods Are Nearing Completion.***
  - ***The Life Management Plans Are Maturing With Development of the Infrastructure for Data Collection Under Way and Locations of the SPHM Strain Gages Defined for STOVL & CV Variants***

Structural Analysis

- **Structural Analysis Methods and Tools Established and Validated**
  - ***Common Methods Used Throughout Multi-Company, Multi-National Team***
- **Internal Loads and Spectra Developed and Deployed Simultaneously to All Sites**
  - ***Rigorous Go/No Go Process Incorporated To Review And Concur With All Air Vehicle FEMs Prior To Release***
- **Structural Analyses Performed In a Detailed and Methodical Manner and Vaulted in Common Databases**
  - ***Stress Analysis***
  - ***Durability and Damage Tolerance Analysis***
  - ***Acoustic Analysis***
  - ***Flutter Analysis***
  - ***Vibration Analysis***
  - ***Buffet Analysis***
  - ***Thermal Analysis***

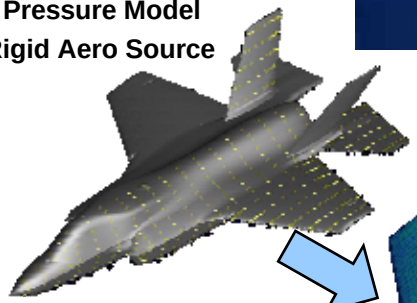
Detailed and Rigorous Structural Analysis Performed

External Loads Development

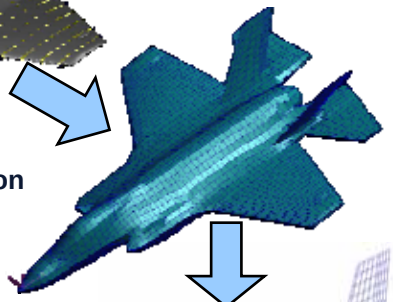
F-35 Loads Wind Tunnel Tests

Model	Objective
L-2: Full Span; 12% Scale CTOL/STOVL Pressure Model. L-3: New Model (240A/B-4.1)	CTOL/STOVL external aerodynamic pressure distributions.
L-2.1: Full Span; 12% Scale CV Pressure Model. L-3C: New Model (240C-4.5)	CV external aerodynamic pressure distributions.
CFD analysis by AEDC	Store Loads For External Carriage of A-A Missiles.
A-5.1: Full Span; 1/15 Scale External Store Airloads Model	Store Loads For External Carriage of A-A and A-G Weapons.
S-2: Part Span; 1/15 Scale Weapons Bay Model	Store Loads For Internal Carriage of A-A and A-G Weapons. Weapons Bay Door Pressures.

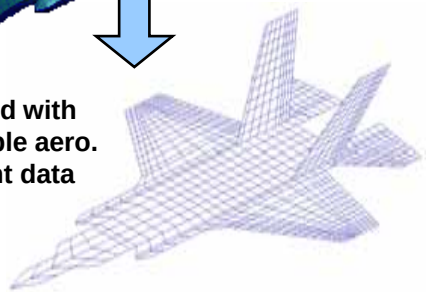
WT Pressure Model
Is Rigid Aero Source



Mapped to
3-D Integration
Model



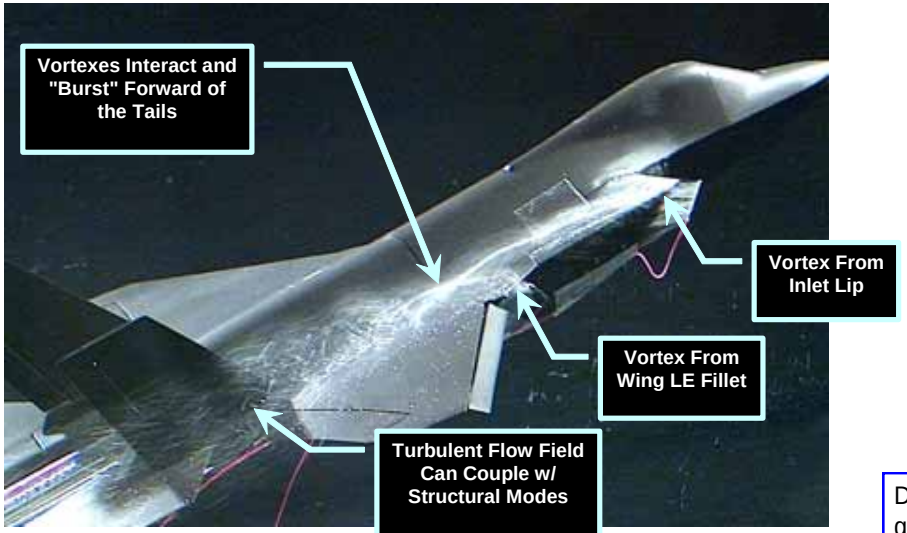
Combined with
2-D flexible aero.
Increment data



- **Balanced Aircraft Load Conditions For Air Vehicle FEM Application**
  - ***Critical Maneuver Loads***
  - ***Critical Dynamic Loads (buffet, store eject, etc)***
  - ***Critical Ground Handling Loads***
  - ***Deflection Critical Load Conditions***
  - ***Pressurization Loads (cockpit, inlet, fuel tanks)***
  - ***"Parent" Conditions For Component Loads***
    - Full aircraft balance for superposition of critical component loads; e.g. weapon bay doors.

Empennage Buffet Loads Development

Water Tunnel Tests Show Vortex Interaction



- **Buffet Environment Defined For Initial Design Of All Variants**
  - ***Maximum Combined Maneuver Plus Buffet Loads***
  - ***Design Load Spectra Include Buffet Load Cycles Consistent With Usage***
  - ***Vibration Environment For Systems And Installations***

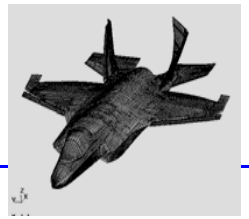
Wind Tunnel Tests:

- 1/40th Scale Water Tunnel Test
- Early HT Tests
- VT Test
- Buffet Fences
- 1st Wing Buffet Test
- STOVL/CTOL Database

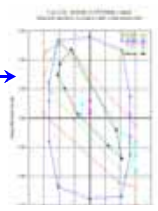
Component Loads From Calculated Buffet Response

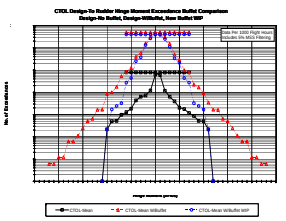
Dynamics Group develops grid point forces to achieve buffet mode shapes

Grid point forces mapped to the Air Vehicle FEM to get internal loads.



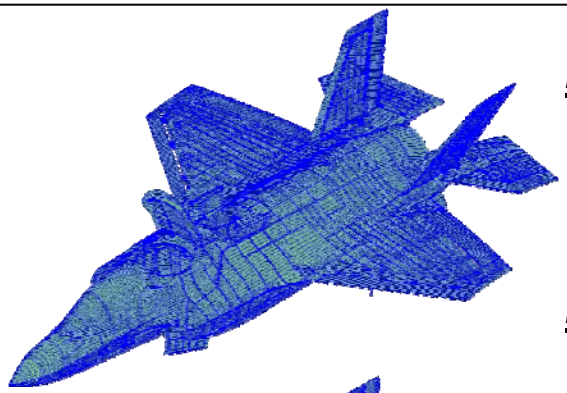
Incremental internal buffet loads added to corresponding static loads yielding strength, service loads.



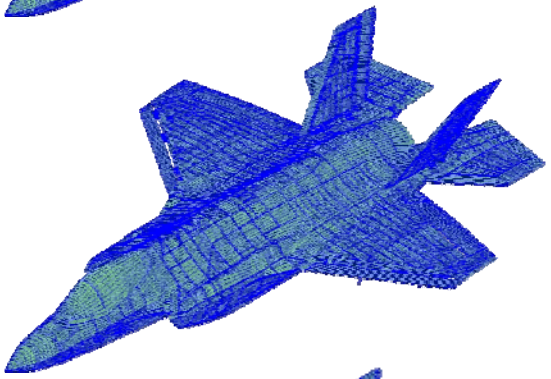


Air Vehicle Finite Element Models For Internal Loads

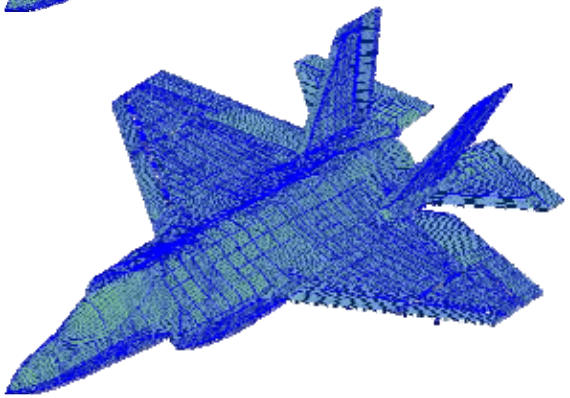
STOVL BTP FEM:
- **162K Nodes**
- **221K Elements**
- **21,329 Load Combinations**



CTOL BTP FEM:
- **158K Nodes**
- **213K Elements**
- **14,555 Load Combinations**

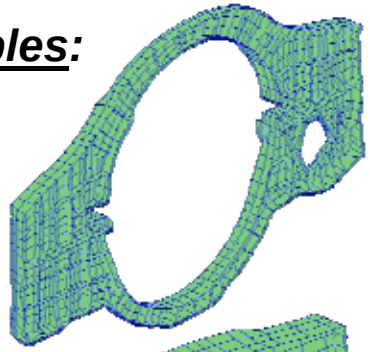


CV BTP FEM:
- **175K Nodes**
- **240K Elements**
- **25363 Load Combinations**



High Fidelity Models Include:
- ***2.5D Mesh In Key Areas***
- ***Mesh Density Established To Facilitate Future Test Correlation***

Examples:



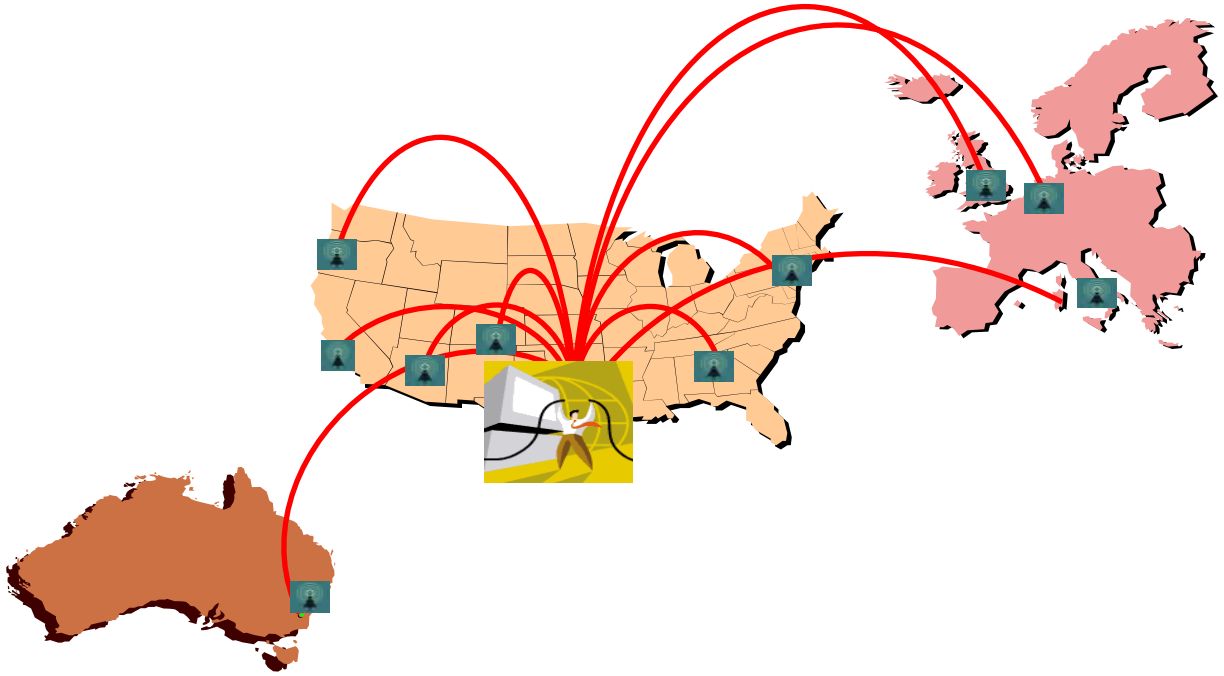
Bulkhead

HT Hinge Spar

- **Complete Air Vehicle Structural Representations**
- **Moveable Control Surfaces and Major In-Flight Opening Doors**
- **Overlapping Assumptions for Removable Panel Effectivity**
- **Structural Sizing Provided By Stress Analysts**

Air Vehicle Finite Element Analysis
Internal Loads Data Storage And Delivery

- **Storage & Distribution Of Internal Loads Datasets**
  - ***Includes Finite Element Models, Applied Loads, And Internal Load Databases***
  - ***Configuration Controlled On Dedicated Loads Data Server***
  - ***Accessed By Structural Analysts Worldwide Through Encrypted Network***
- **Internal Loads Data Released In Fort Worth Is Instantaneously Available To Partners And Suppliers**

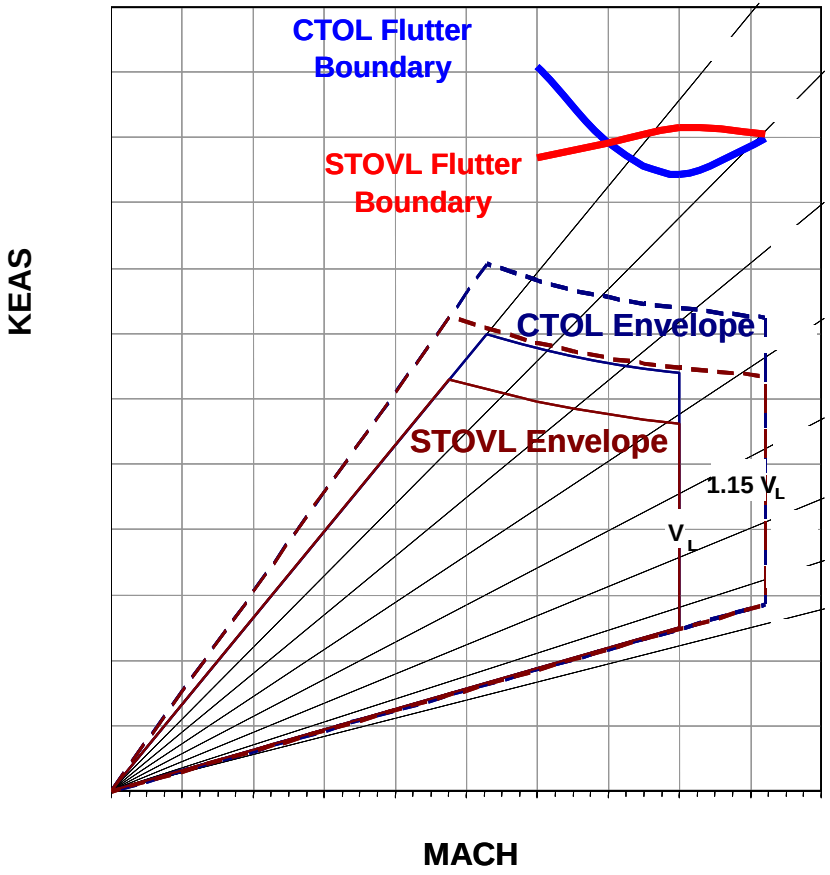


Flutter And Aeroservoelastic Analyses

Aft Fuse/Empennage Wind Tunnel Model Installed In NASA LaRC TDT

- **WT Testing To Verify Transonic Empennage Characteristics And Free Play Requirements**
- **Clean Aircraft Flutter Analyses**
  - ***Set Structure, Systems Stiffness Requirements***
  - ***All Variants Meet Flutter Requirements***
  - ***All Surfaces Free From Divergence***
- **External Store Flutter Analyses**
  - ***Establish Stiffness Requirements***
  - ***Weapon, Pylon, And Hardpoint Geometry***
- **Aeroservoelastic Analysis**
  - ***Structural Filters For Flight Controls***

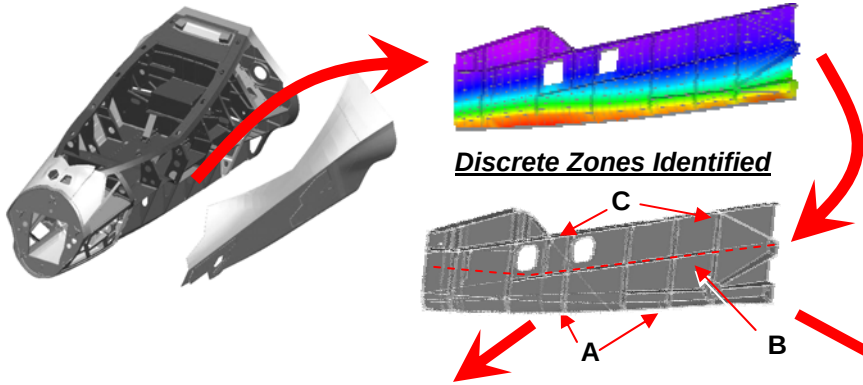
STOVL/CTOL Clean Aircraft Flutter Margins



Durability And Damage Tolerance Analysis

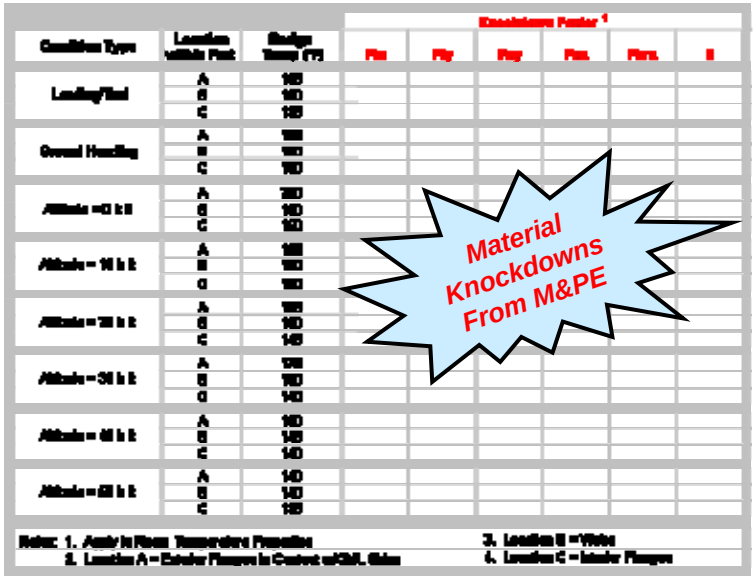
- **Differing AF And Navy DADT Philosophies Require Development Of Service Unique Repeated Load Spectra**
- **CTOL DADT Analyses Are Based On Mission Based Spectra**
  - ***Durability Uses 90th Percentile Spectrum***
    - Based On Crack Growth Analysis
  - ***Damage Tolerance Uses Mean Spectrum***
  - ***Average Crack Growth Rate And Strain Life Curves Used***
  - ***Critical Crack Sizes Based On Guaranteed Minimum Fracture Toughness (Spec Min)***
- **STOVL & CV DADT Analyses Are Based On CPITS Spectra**
  - ***Both Durability And Damage Tolerance Analyses Use The Severe "Critical Point In The Sky" (CPITS) Spectrum***
  - ***Durability Analysis Based On Crack Initiation***
- **DADT Analyses Accomplished Using IMAT Tool At All Sites**

Structural Temperature Definition

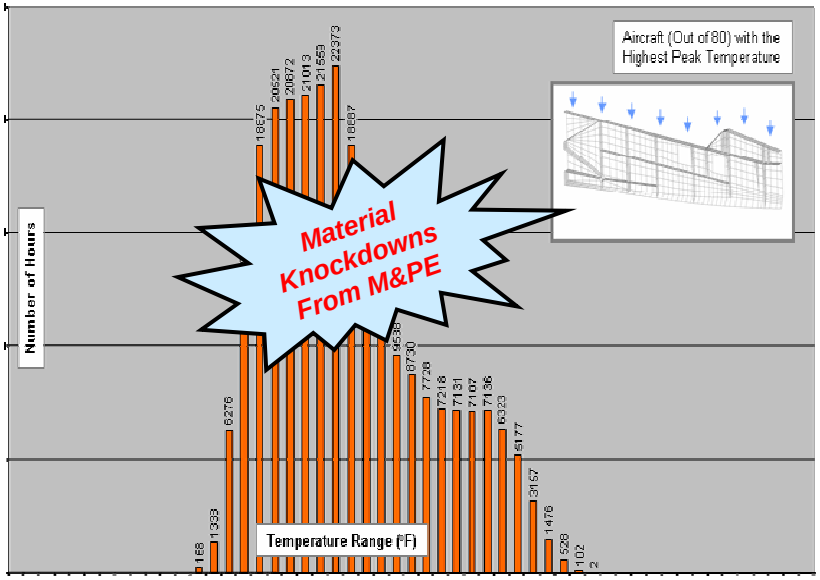


- **Parts Identified By Airframe Stress Analysts and/or Thermal Analysts**
- **74 Parts for AA-1; 239 Parts for STOVL; 430 Parts for CTOL**
- **Detailed Models Of Parts Generated:**
  - ***Results zoned by location; e.g. upr flange, web, etc.***
  - ***Max temps corresponding to structural load conditions***
  - ***Temp spectrum including maintenance for 8000 hrs***
- **Results To M&P For Knockdown Calculations**
- **Temperatures Calculated and Supplied in AV FEM for Overall Airframe Thermal Stress and DADT Evaluations**

Max Temps Within Required Envelope

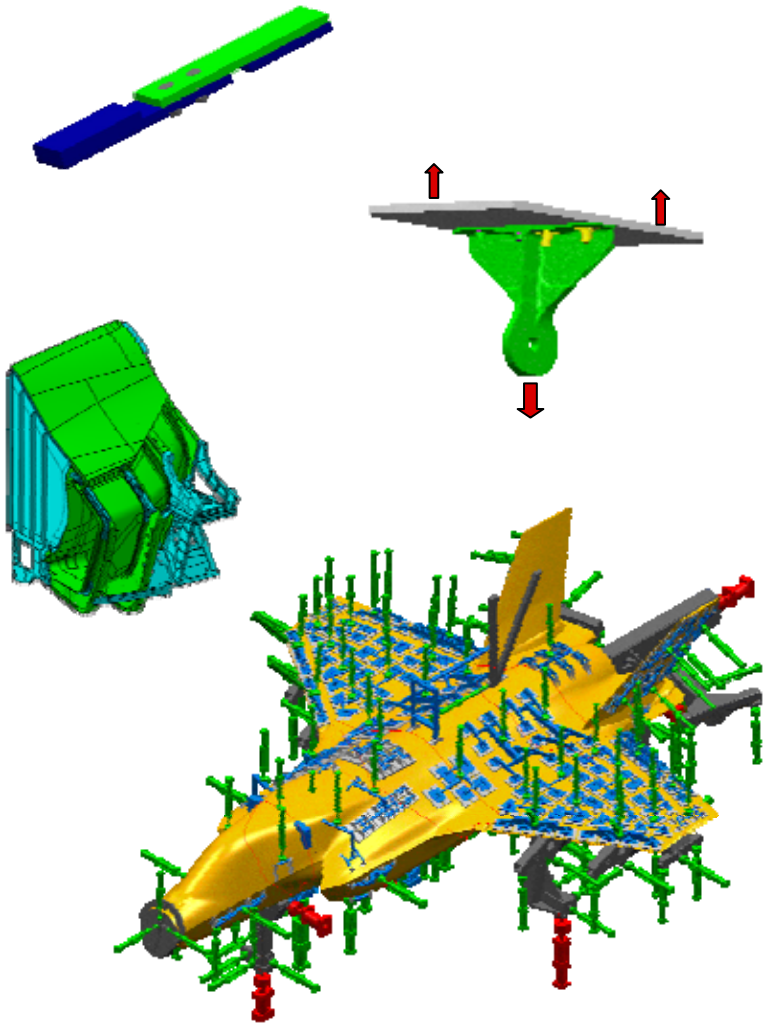


Expected Lifetime Time-At-Temperature



Tests and Demonstrations

- **F-35 Structural Test Program Follows Traditional Building Block Approach**
- **Tests Include**
  - ***Building Block Tests***
  - ***6 Dedicated Static & Durability Articles***
  - ***1 Combined Drop Test/ Barricade/Live Fire Test***
  - ***Ground Tests (SCT/GVT/Etc)***
- **Tests Address:**
  - ***Material Characterization***
  - ***Effects Factors***
  - ***Development/Risk Reduction***
  - ***Structural Analysis Correlation/Calibration***
  - ***Allowables***
  - ***Qualification***
  - ***Certification***



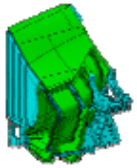
Building Block Test Approach

Structures Development

Allowables
Analysis Calibration
Risk Reduction
Fuel Sealing
Structural Certification
& Verification

Ground & Flight Tests

Components

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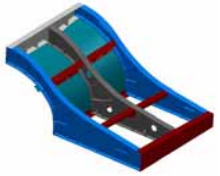
Sub-Components

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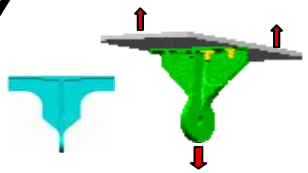
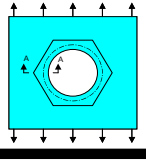
Elements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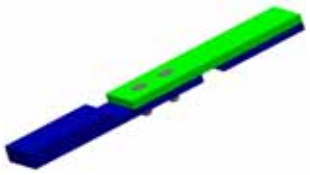
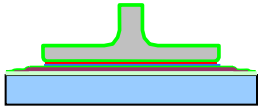
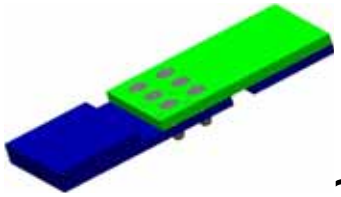
Coupons

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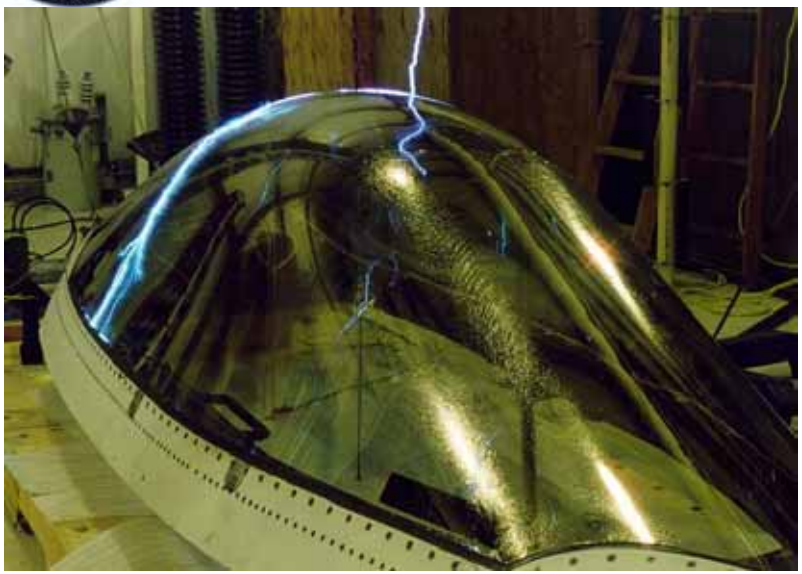
Manufacturing Development

Material Qualification
Process Development
& Verification
Risk Reduction
Fabrication & Assembly Dev

Legacy Metallics
Design Allowables
Aluminum, Titanium,
Steel, Etc.

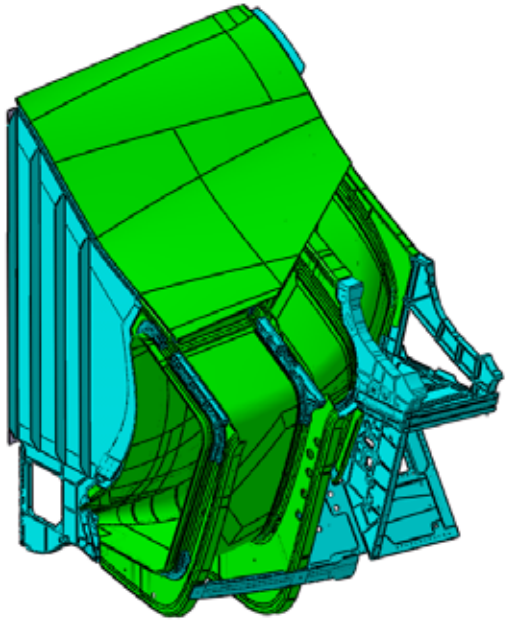
Legacy Non-Metallics
Design Allowables
Epoxy & BMI

Structural Certification Tests



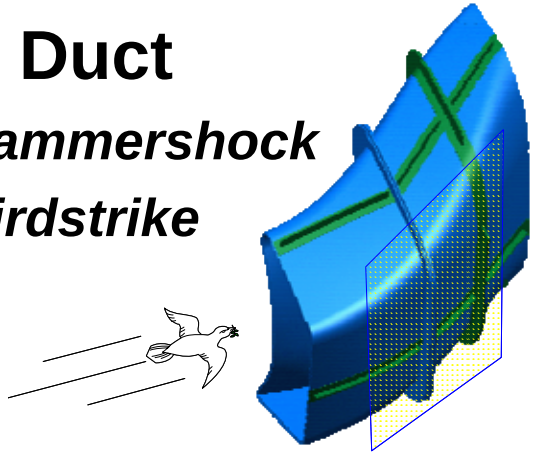
Canopy Verification

- *Electrostatic Discharge*
- *Birdstrike*
- *Latch/Unlatch*
- *Pressurization*
- *Thermal Fatigue*
- *Lightning Strike*



Inlet Duct

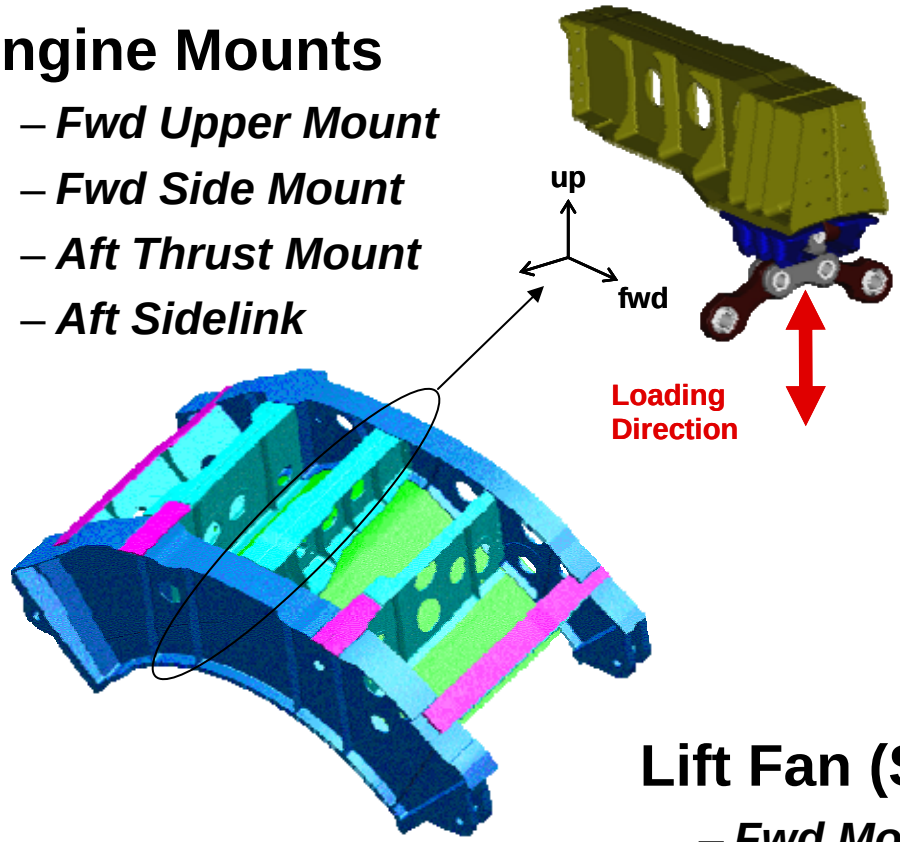
- *Hammershock*
- *Birdstrike*

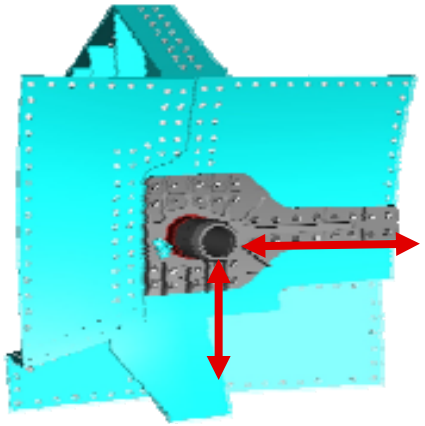


Structural Certification Tests

Engine Mounts

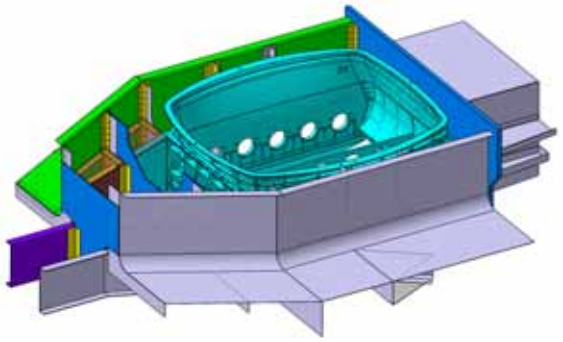
- *Fwd Upper Mount*
- *Fwd Side Mount*
- *Aft Thrust Mount*
- *Aft Sidelink*





Lift Fan (STOVL)

- *Fwd Mount*
- *Aft Mount & Back Up*
- *Vane Box & Back Up*



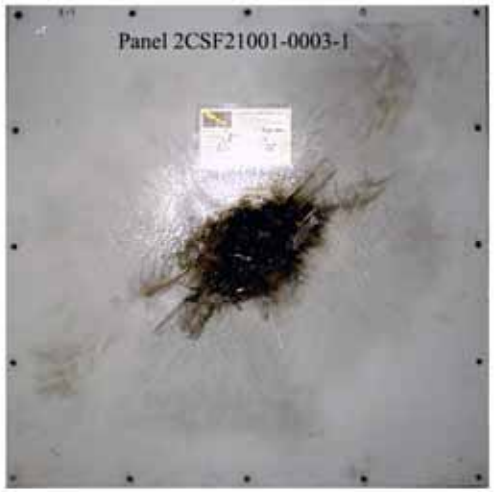
Vane Box & Back Up

Structural Certification Tests

BMI Nacelle Skin Fire Resistance

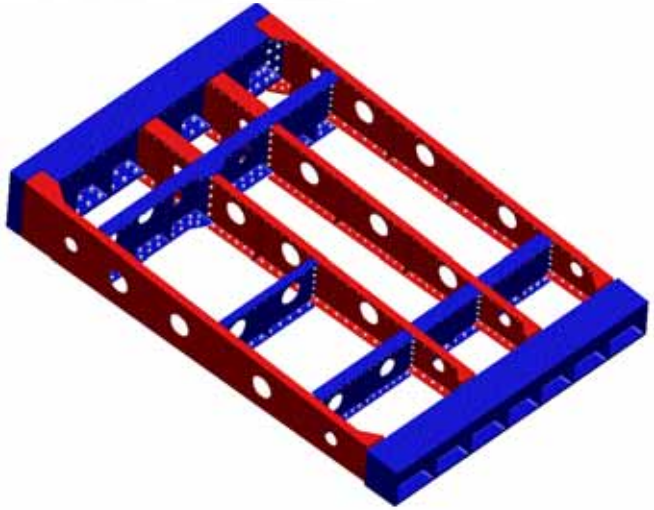
Fire Resistance Test Set Up

Lightning Strike Verification



Acoustic Fatigue

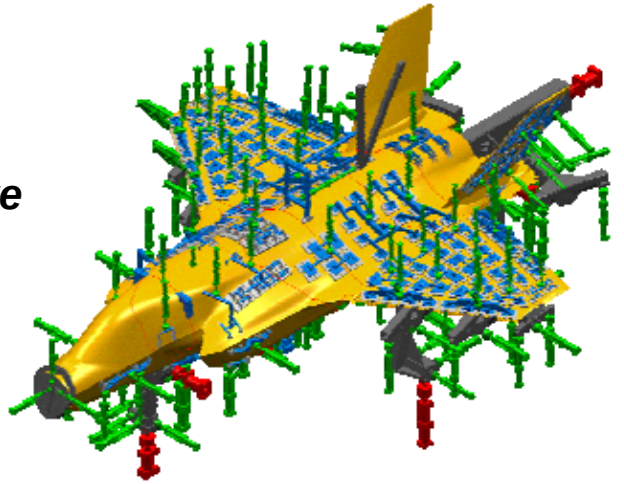
- *Wing Spar Box*
- *Weapons Bay Sidewall*
- *Horizontal Tail*
- *Control Surfaces*

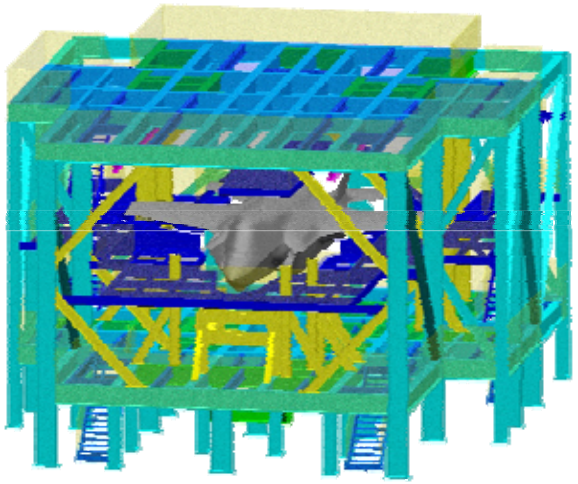


Wing Acoustic Box Internal Structure

Pillar 3 - Full Scale Tests

- **Full Scale Ground Tests**
  - ***One Static Article per Variant***
  - ***One Durability Article per Variant***
  - ***One Combined Drop Test, Barricade Test, and Live Fire Article for the CV Variant***
- **On Aircraft Tests**
  - ***Proof Tests***
  - ***Freeplay Tests***
  - ***Ground Vibration Tests***
  - ***Structural Coupling Tests***
- **Common Test Arrangements Support Affordability**
  - ***Full Scale Fixtures Designed to be Common***
  - ***Common Data Acquisition Systems Selected***
  - ***Tests to be Conducted at Multiple Locations to Support Program Schedule***
- **Design of Loading Arrangement Enables Rapid Reconfiguration Between Loading Conditions**
- **Automated Structural Analysis Tools Developed to Enable Rapid Evaluation of Test Load Arrangement**





Pillar 4 – Certification and Force Management Development

- **The Certification Plans Which Document The Means To Provide The Evidence Needed To Support Certification Of The Aircraft Structure Are In Work For All Three Variants.**
  - ***STOVL & CTOL Plans Are Released For Initial Reviews***
  - ***CV Is Currently In Draft Form***
- **The Force Management Package Development Is Not Yet Started Due To The Maturity Of The Three Variants.**

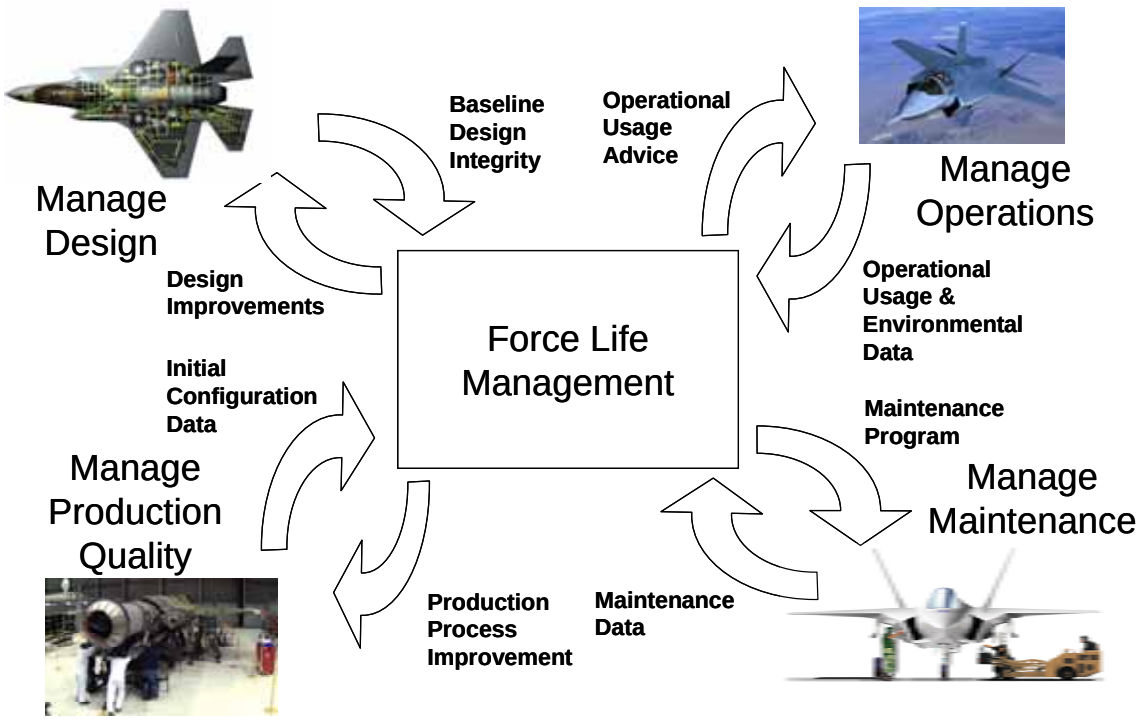
Pillar 5 – Force Management

- **The Development Of The Force Management System Started Earlier On The F-35 Program Than On Recent Legacy Programs.**
- **The Autonomic Logistics Portion Of The F-35 Program Will Provide A Robust System For Storing, Retrieving And Presenting The Usage Data For Each Aircraft, Squadron Or Mission Type In A Useful Format For Decision Makers.**
  - ***The Prognostics Health Management (PHM) And Structural Prognostics Health Management (SPHM) Data Will Be Resident Within This System***
  - ***Ten Percent Of The Fleet Is Planned To Be Instrumented During The Production Phase With SPHM Strain Gages***
    - 100% of SDD Aircraft are Instrumented

Force Life Management

- **Plan for F-35 Force Life Management Established Early in Program**

- **Plan Establishes**
  - ***Organizational Structure For Logistics Support***
  - ***FLM Operational Concept***
  - ***Direction For Effective Aircraft Management***



F-35 Life Cycle Support

Overall ASIP Status

- **Pillar 1 – Essentially Complete**
- **Pillar 2 – Nearing Completion for STOVL & CTOL, Under Way for CV**
- **Pillar 3 – Detailed Planning in Place for AA:1, Detailed Planning In Work For STOVL & CTOL**
- **Pillar 4 – Plan In Place for Development of Data Package, Detailed Plans Maturing**
- **Pillar 5 – Planning for Force Management System In Place Early, Development of System In Work.**

Summary

- **A Rigorous & Disciplined ASIP Program Led By a Centralized Structures Group Remains the Best Means of Ensuring Structural Integrity and Providing Certification and Verification Evidence in a Performance Based Specification Environment**
- **The F-35 ASIP Program is Currently In The Midst of Pillars 2 & 3, with Groundwork Laid for Pillars 4 & 5, and is Progressing Toward Flight Certification.**

Bob Wants to Know – Yous Guys Got Any Questions?