F-35 Aircraft Structural Integrity
Program Overview
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F-35 – Many Programs in One

Interoperability

Global Sustainment

Domestic / International Suppliers

Autonomic Logistics

3 Flight Test Facilities

Training

CV

CTOL

STOVL

3 Services

8 International Partners

2 Security Cooperation Participants

Team F-35
LM Aero
NGC BAES

P&W F135
GE/RR F136

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Introduction


- 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**
- Span (ft): 35
- Length (ft): 51.2
- Wing Area (ft²): 460

240B-4.3

**CTOL**
- Span (ft): 35
- Length (ft): 51.4
- Wing Area (ft²): 460

240A-4.4

**CV**
- Span (ft): 43
- Length (ft): 51.5
- Wing Area (ft²): 667

240C-4.5
F-35 Integrity Program

Air System Integrity Program
MIL-HDBK-515

Aircraft Structural Integrity Program (ASIP)
MIL-STD-1530

Propulsion Systems Integrity Program (PSIP)
MIL-STD-1798

Mechanical & Electrical Systems Integrity Program (MESIP)
MIL-STD-1789

Autonomic Logistics Integrity Program (AutoLog IP)

Low Observables Integrity Program (LOIP)

C-17 Program

F-22 Program

F-35 Program

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

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LM JSF Team Program Information
## ASIP Task Overview

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<th>PDR to CDR</th>
<th>CDR to Production Go-Ahead</th>
<th>Production Go-Ahead to Operational Life Management</th>
<th>On-going</th>
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<tr>
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<td>Design &amp; Analysis Criteria</td>
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<tr>
<td>Characterize Environment</td>
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<tr>
<td>Characterize Materials</td>
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<td>Update</td>
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<tr>
<td>Characterize Production &amp; Quality</td>
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<td>Validate</td>
<td>Execute</td>
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<td>Critical Items</td>
<td>Initial</td>
<td>Update</td>
<td>Update</td>
<td>Update</td>
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<td>Structural Analysis</td>
<td>Initial</td>
<td>Update</td>
<td>Validate</td>
<td></td>
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<tr>
<td>Test</td>
<td>Coupons &amp; Elements</td>
<td>Element to Sub-Component</td>
<td>Component to Full Scale</td>
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<td></td>
</tr>
<tr>
<td>Life Management</td>
<td>Initial</td>
<td>Update</td>
<td>Update</td>
<td>Validate</td>
<td>Execute</td>
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</tbody>
</table>
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**

<table>
<thead>
<tr>
<th>Material</th>
<th>CTOL Percent</th>
<th>STOVL Percent</th>
<th>CV Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALUMINUM</td>
<td>43.4%</td>
<td>45.7%</td>
<td>33.4%</td>
</tr>
<tr>
<td>GRAPHITE/EPOXY</td>
<td>13.7%</td>
<td>12.1%</td>
<td>15.1%</td>
</tr>
<tr>
<td>GRAPHITE/BMI</td>
<td>21.4%</td>
<td>21.3%</td>
<td>20.0%</td>
</tr>
<tr>
<td>TITANIUM</td>
<td>15.4%</td>
<td>13.6%</td>
<td>25.4%</td>
</tr>
</tbody>
</table>
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.
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**

<table>
<thead>
<tr>
<th>Model</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-2: Full Span; 12% Scale CTOL/STOVL Pressure Model. L-3: New Model (240A/B-4.1)</td>
<td>CTOL/STOVL external aerodynamic pressure distributions.</td>
</tr>
<tr>
<td>L-2.1: Full Span; 12% Scale CV Pressure Model. L-3C: New Model (240C-4.5)</td>
<td>CV external aerodynamic pressure distributions.</td>
</tr>
<tr>
<td>CFD analysis by AEDC</td>
<td>Store Loads For External Carriage of A-A Missiles.</td>
</tr>
</tbody>
</table>

- 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**

- Vortexes Interact and "Burst" Forward of the Tails
- Vortex From Inlet Lip
- Vortex From Wing LE Fillet
- Turbulent Flow Field Can Couple w/ Structural Modes

**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.
- Data Per 1000 Flight Hours
  - Includes 5% MSS Filtering

- 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
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

CTOL Flutter Boundary
STOVL Flutter Boundary
CTOL Envelope
STOVL Envelope

KEAS

MACH
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
Structure 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

Detailed Thermal Model Of Representative Part

Discrete Zones Identified

Max Temps Within Required Envelope

<table>
<thead>
<tr>
<th>Condition Type</th>
<th>Location</th>
<th>Stress Type</th>
<th>Assumption</th>
<th>Landing</th>
<th>Ground Handling</th>
<th>Flight</th>
<th>Altitude 41K</th>
<th>Altitude 61K</th>
<th>Altitude 81K</th>
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<td>A</td>
<td>C</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
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Knockdowns From M&PE

Material Knockdowns From M&PE

Expected Lifetime Time-At-Temperature

Material Knockdowns From M&PE

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LM JSF Team Program Information
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
- Sub-Components
- Elements
- Coupons

Manufacturing Development
- Material Qualification
- Process Development & Verification
- Risk Reduction
- Fabrication & Assembly Development

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

Legacy Non-Metallics
- Design Allowables
- Epoxy & BMI

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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
Structural Certification Tests

BMI Nacelle Skin Fire Resistance

Lightning Strike Verification

Acoustic Fatigue
- Wing Spar Box
- Weapons Bay Sidewall
- Horizontal Tail
- Control Surfaces
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?