Overview of the Full Scale Durability Tests on F-35 Lightning II Program

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• Jeremy Morrison, STOVL Variant Chief, F-35 Structures Test
Tri-Variant Joint Strike Fighter (JSF)

**F-35A CTOL**
- Span: 35 ft / 10.67 m
- Length: 51.4 ft / 15.67 m
- Wing area: 460 ft² / 42.7 m²
- Combat radius (internal fuel): >590 n.mi / 1,093 km
- Range (internal fuel): ~1,200 n.mi / 2,222 km

**F-35B STOVL**
- Span: 35 ft / 10.67 m
- Length: 51.2 ft / 15.61 m
- Wing area: 460 ft² / 42.7 m²
- Combat radius (internal fuel): >450 n.mi / 833 km
- Range (internal fuel): ~900 n.mi / 1,667 km

**F-35C CV**
- Span: 43 ft / 13.11 m
- Length: 51.4 ft / 15.67 m
- Wing area: 668 ft² / 62.06 m²
- Combat radius (internal fuel): >600 n.mi / 1,111 km
- Range (internal fuel): >1,200 n.mi / 2,222 km
F-35 Full Scale Tests and How They Relate to ASIP

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<td>Structural Analyses Stress &amp; DADT Sonic Fatigue Vibration Aeroservoelastic Survivability</td>
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<td>Design Development Tests</td>
<td>Recertification</td>
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**Static Tests**
- First Flight Verification Ground Tests

**Flight Tests**

**Durability Tests**
- Damage Tolerance Tests

**Climatic Tests**

**Interpretation and Evaluation of Test Results**
F-35 Full Airframe Tests Locations & Fixture Sharing

LM Fort Worth, US
- STOVL Static
- STOVL Durability
- CV Static
- CV Durability

BAES Brough, UK
- CTOL Static
- CTOL Durability

Vought Aircraft Industries, Grand Prairie TX, US
- CV Drop

Drop Test Aircraft Also Serves as Test Article for CV Static, Barricade and Live Fire Tests
Full Scale Durability Test Development

• Durability Test Program Builds Upon Static Test
  – Using Same Fixture
  – Same Load Control and Data Acquisition Systems
  – Minor Differences in Load Arrangement

• Some Differences Between Static and Durability Tests
  – Leading Edge Flaps Move Under Load
  – LH and RH “Dummy” Vertical Tails
  – Vertical Tails Tested As Separate Components

Use of Common Test Fixture Reduced Program Cost
Multiple Usage of F-35 Full Airframe Test Fixtures

- Dedicated Test Fixture for CTOL Durability Test Article
  - Enabled Test to Start Upon Delivery of Test Article

STOVL and CV Durability Test Articles Utilize Same Fixture Used for STOVL and CV Static Tests

NH-1 STOVL Installed in Test Fixture

CJ-1 CV Installed in Test Fixture

AJ-1 CTOL Durability Airframe in Test Fixture
F-35 Horizontal Tail Component Tests
Locations & Fixture Sharing

Six Test Articles: Three Static and Three Durability, One Per Variant

Testing Performed at BAE Systems in Brough, UK

Two Common Rig Designs - Interchangeable for Each Aircraft Variant for Both Static and Durability Tests
F-35 Vertical Tail Component Tests Locations & Fixture Sharing

Three VT Durability Test Articles, One Per Variant

Performed at BAES in Brough, UK

• One Maneuver Test Rig
• Built to Accommodate All Three Variants

• Two Buffet/Vibration Test Rigs
• Built to Accommodate All Three Variants

* Rig No. 1 Shown
F-35 Durability Test Program

- Test Articles Representative of Production Build
  - *Omitted Subsystems and Final Finishes*

- Tests Conducted with Test Spectrum for Two Lifetimes to Ensure 90% of Aircraft Achieve 8000 Hour Life
  - *Maneuver, Catapults/Arrestments (CV Only) and Buffet Loads Applied as Separate, Alternating 1000 hr Blocks During the Major Test Sequence*
  - *Buffet Loads Applied Quasi Statically, Except for Vertical Tail Components*

- Local Tests Planned for Execution Between First and Second Lifetimes
  - *Portion of CTOL and STOVL Local Tests Pulled Forward Due to Major Test Finding on FS 496 Bulkhead*

- Approval Received to Perform Third Lifetime on HTs, VTs and Full Airframe Test Articles

- Teardown Planned at End of Three Lifetimes
F-35 Durability Test Status

STOVIL
- Projected 1st LT
  Complete Dec 2012
- Completed 2nd LT
  in Sep 2011
- Completed 2nd LT
  in Apr 2012

CTOL
- Completed 1st LT
  in Aug 2012
- Completed 2nd LT
  in Aug 2011
- Completed 2nd LT
  in Apr 2012

CV
- Achieved 4000 Hours
  in Oct 2012
- Achieved 10000 Hours
  in Oct 2012
- Achieved 2000 Hours in
  Oct 2012
Durability Testing Progress

F-35 Durability Test Schedule (First Life)

Note:
Data does not include delays for AJ-1 and BH-1 due to FS 496 bulkhead anomaly.

Continued Improvement Recognized in Test Performance
## F-35 Durability Test Findings (cont.)

<table>
<thead>
<tr>
<th>STOVL (BH-1)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aft Fuselage Lower Access Covers (LHS and RHS)</td>
<td>Loose fasteners found at 1,000 total hours; numerous fastener failures (LH &amp; RH). Failed fasteners replaced; evaluation ongoing.</td>
</tr>
<tr>
<td>FS 496 Bulkhead Cracks at MLG Trunnion, LHS and RHS</td>
<td>Cracks through bulkhead lower flange and web near MLG attachments at 1,471 maneuver hours. Required extensive repair and modifications to test article.</td>
</tr>
<tr>
<td>NLG Retract Actuator Lug</td>
<td>Lugs failed at 7,182 total hours and replaced with pristine part, which failed again at 12,965 total hours into re-test.</td>
</tr>
<tr>
<td>NLG Retract Actuator Backup Stiffener</td>
<td>Cracks detected at 9,878 total hours, repair required.</td>
</tr>
<tr>
<td>WBD Cradle Lower Forward Lug</td>
<td>Lug crack discovered at 11,353 total hours; cradle replaced.</td>
</tr>
<tr>
<td>WBD Outboard Hinge 4 Fitting</td>
<td>Hinge fitting failed at 13,327 total hours; fitting replaced.</td>
</tr>
<tr>
<td>FS 503 RH Frame</td>
<td>Cracked at 1,753 maneuver hours as expected, testing continued with cracked part installed. Re-design installed on LH side of BH-1.</td>
</tr>
<tr>
<td>IPP Shear Web Lug Crack</td>
<td>Cracked at 2,950 maneuver hours. Joint disconnected and testing continued. Evaluation under way.</td>
</tr>
<tr>
<td>3BSM Door Uplock Failure</td>
<td>3BSM Door Uplock mechanism spline failed at 3,862 maneuver hours.</td>
</tr>
<tr>
<td>Pylon Station 3/9 Aft Rib</td>
<td>Station 3 (LH) crack discovered at 5,000 total hours; Station 9 (RH) crack discovered at 6,000 total hours. Crack locations and timing expected. Cracks stop drilled at 6,000 total hours, and external straps installed at 7,000 flight hours.</td>
</tr>
<tr>
<td>RH Nacelle Vent Inlet</td>
<td>Crack detected at 5,508 maneuver hours.</td>
</tr>
<tr>
<td>FS 472 Bulkhead Flange Crack</td>
<td>Cracked at 6,750 maneuver hours. Stop drilled crack tip and continued testing. Root cause analysis in work.</td>
</tr>
</tbody>
</table>
Loose Fasteners on Lower Aft Access Panels – CTOL and STOVL

- Loose Fasteners in Lower Aft Covers Discovered Shortly After Test Began
  - Similar Results on Both F-35A and F-35B
  - No fastener failures to date on F-35C
- Fasteners on F-35A and F-35B RHS Replaced
- Evaluation of Potential Modifications Ongoing
- No Evidence of Fastener Rotation on Flying A/C
CTOL Wing Forward Root Rib

- Stiffener Crack Found at 2,117 Hours
- Lower Flange Crack Found at 5,089 Hours
- Declared Short Life Pre-Test
- Test Continued to 8,000 Hours
  - Crack Growth Monitored by Strain Gage Responses and Periodic Inspections
- Similar Crack Location and Geometry on LHS

RHS, View Looking Outboard

Crack traces
CTOL Engine Thrust Mount Shear Web

- Shear Web Crack at 3,000 Hours
  - Initiation at Radius of Upper Flange Transition
- Test Continued to 8,000 Hours
  - Anomaly Monitored by Trending Strain Data and Periodic Inspections
- Similar Crack Discovered on LHS at 7,000 Hours
- Root Cause: Stress Concentration at Radius
CV Durability Test Findings

- FS 503 Frame Crack Discovered During Inspection Resulting From Change in Strain
- Known Short Life Location
- Test Article Mod Consists of Splicing in Production Configuration

- Nacelle Vent Inlet Crack Discovered During Inspection Resulting From Change in Strain
- Known Short Life Location
- External Doublers Installed as Repair to Test Article
STOVL FS 496 Bulkhead

- Cracks Discovered at 1,471 Maneuver Hours, Initiating at MLG Trunnion Radius
- Excised LH and RH Bulkhead Segments Outboard of BL60 and Replaced With
  - Production Redesign Geometry, LHS
  - SDD/LRIP Repair Geometry, RHS
- CTOL and CV Durability Test Articles Required Trunnion Blend
STOVL Nose Landing Gear Retract Actuator Backup

• Clevis Failed at 7,182 Hours
  • Root Cause: Bore Scratched During Bushing Install
• Clevis Replaced (Integral to Fuel Floor) and Test Re-started at Zero Hours
• Stiffeners Cracked (Through Thickness) at 9,878 Hours
  • Root Cause: Stress Concentration at Fillet Radius
  • LH Stiffener Repaired with Angle Brackets
  • Performed Trim of RH Stiffener Crack
• Second Failure of Clevis at 12,965 Hours
  • Root Cause: High Stress Concentrations due to Load Peaking
• Re-designs and Modifications Required for Production Aircraft (Increase Radius)
• CTOL and CV NLG Retract Actuator Lug Configurations are Significantly Different
STOVL Wing Pylon Aft Ribs

- Cracks Discovered in Station 3 (LH) Aft Rib at 5,000 Hours and Station 9 (RH) Aft Rib at 6,000 Hours
  - Both are Known Short Life Locations; Crack Geometry and Timing as Predicted
  - Cracks Stop Drilled at 6,000 Hours
  - External Straps Installed (LH and RH) at 7,000 Hours
- Engineering for Modification and Re-designs for Production Aircraft Already Defined
STOVL FS 472 Bulkhead

- FS472 Bulkhead Cracked at 6,750 Maneuver Hours
  - Crack is Through Thickness of Upper Flange
  - Extends From Free Edge Aft to Web, then Outboard Along Web-to-Flange Radius
  - Root Cause In Work
- Stop Drilled Crack Tip and Continued Testing
- Further Actions Required at 8,000 Hours
**F-35 Durability Test Findings**  
**Vertical Tail-Rudder**

<table>
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<tr>
<th>Component Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CTOL</strong></td>
<td></td>
</tr>
<tr>
<td>FS 575 Forward Shear Tie</td>
<td>Discovered premature wear on initial bushing configuration at 1,753 total hours. Replaced bushing with different material. Replaced slip bushings at 12,000 total hours. Modified configuration successfully cycled for 10,000 total hours, exceeding the 8,000 hour wear requirement.</td>
</tr>
<tr>
<td>Rudder Base Bolt and Slip Bushing</td>
<td>Parts replaced at 12,000 total hours due to wear which affected test performance. Strength and functionality undiminished; no design change necessary for flying aircraft.</td>
</tr>
<tr>
<td>Fixed Link Tie-Rod Assembly</td>
<td>Spherical bearing and liner worn without degradation to strength &amp; functionality. Replaced at 7,500 total hours to improve testing performance.</td>
</tr>
<tr>
<td>Rudder Hinge 3 Nut and Locking Washer</td>
<td>Determined to be nonfunctional at 12,000 total hours due to wear. Original installation exceeded wear requirement of 8,000 hours.</td>
</tr>
<tr>
<td>Rudder Hinge 3 Pin</td>
<td>Excessive wear at 16,000 total hours, however maintained strength &amp; functional capability throughout test.</td>
</tr>
<tr>
<td><strong>STOVL</strong></td>
<td></td>
</tr>
<tr>
<td>FS 575 Forward Shear Tie</td>
<td>Inspection performed at 562 total hours based upon findings at forward shear tie on CTOL VT test article. Consistent wear indications found on STOVL, therefore bushing configuration (material change) modified prior to continuing test. No subsequent hardware changes needed; successfully completed 2 lifetimes of durability testing.</td>
</tr>
<tr>
<td>Rudder Hinge 2 Clevis</td>
<td>Rudder Slider Pin seized and gouged the VT-Box clevis at 1,000 total hours. Repaired with installation of wear washers and continued test.</td>
</tr>
<tr>
<td><strong>CV</strong></td>
<td></td>
</tr>
<tr>
<td>Rudder Hinge 4</td>
<td>Bearing liner and pin damaged during vibration surveys due to overtest (dynamic response 2.5 times greater than requirement). Hinge fitting and pin replaced and test continued with improved load control direction in place.</td>
</tr>
<tr>
<td>Rudder V-Tip</td>
<td>Composite laminate damage caused by test fixture interference during maneuver loading during first 2,000 hours of testing. Rudder repaired and testing continued.</td>
</tr>
</tbody>
</table>
**Original Bushing Material Configuration**
- ForceMate: AL-Ni Bronze
- Slider: AL-Ni Bronze
- At 1,753 Hours Testing Exposure

**Retro-Fit Bushing Material Configuration**
- ForceMate: Nitronic 60 Grade C
- Slider: AL-Ni Bronze, molykote
- At 10,247 Hours Testing Exposure

Sect B-B

Worn ForceMate
Worn Slider Bushes

Within Design ForceMate
Worn Slider Bushes

Fwd Bush
Aft Bush
Rudder V-Tip & Hinge 4 Damage
CV Vertical Tail

**Rudder V-Tip**
- C-Beam Load Fixture Contacted Rudder Aft Edge (V-tip) During Maneuver Testing

**Rudder Hinge 3 Lug**
- Severe Over Excitation During Vibration Survey

**LHS Vertical Tail**

**Hinge 4 Bolt**

**View Looking Outboard**

**View Looking Inboard**

**Lug Bearing Liner**

Looking Down

Looking Up
## F-35 Durability Test Findings
### Horizontal Tail

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<th>Section</th>
<th>Details</th>
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<tr>
<td>STOVL</td>
<td>Leading Edge Fasteners</td>
<td>Seven failed fasteners at Inboard Leading Edge discovered during 2 Lifetimes of testing (16,000 total hours).</td>
</tr>
<tr>
<td></td>
<td>Bump Fairing Support Frame</td>
<td>Crack discovered during 12,000 hour planned inspection on fairing support frame.</td>
</tr>
<tr>
<td>CTOL</td>
<td>Leading Edge Fasteners</td>
<td>One fastener failed at Inboard Leading Edge attachment. Fastener rotations were minimal.</td>
</tr>
<tr>
<td></td>
<td>Bump Fairing Support Frame</td>
<td>During 16,000 hour inspection, cracks detected on both forward and aft faces of the fairing support frame.</td>
</tr>
<tr>
<td>CV</td>
<td>Leading Edge Fasteners</td>
<td>Thirteen fasteners failed at Leading Edge attachment during 1&lt;sup&gt;st&lt;/sup&gt; Lifetime (8,000 total hours) of testing. Modification for test article engineered and installed prior to beginning 2&lt;sup&gt;nd&lt;/sup&gt; Lifetime.</td>
</tr>
</tbody>
</table>
CV HT Leading Edge Modification

14 Fastener Failures During 1st LT (8000 flight hours) Testing, Along Leading Edge

- Modified Leading Edge After Completion of 1st Lifetime, 8000 Flight Hours
  - Increased Fastener Diameter to ¼ inch
  - Changed Fastener Material From Inconel to Titanium
  - Decreased Bolt to Hole Clearance
- Completed 3000 Flight Hours With Modified Configuration and No Fastener Failures
Summary

• Concurrency of Full Scale Tests Present Unique Challenges and Opportunities
  – Multi Use of Test Fixtures for Static and Durability Full Airframe and Component Tests
  – Transfer of Lessons Learned Regarding Test Findings

• Continue to Improve Test Efficiencies and Schedule Performance
  – All Durability Tests Completed to Date Have Finished Ahead of Baseline, Except for STOVL VT Which Finished Per Baseline

• Maintaining Excellent Response Time in Test Finding Resolution
  – Provides Insight for Fleet Inspections

• Planning and Preparations for Third Lifetime Underway
  – CTOL HT 3rd Lifetime to Begin 1st Quarter 2013

Test Results Provide Confirmation of Structural Integrity of F-35 Lightning II Design
Questions?