

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



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# Acknowledgements

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- **Phil Gross, Director and Chief Structures Engineer, Deputy for F-35 Structures Development Team**
- **Don Whiteley, Technical Lead for Durability Tests, F-35 Structures Test**
- **Kirsten Adams, Horizontal Tail Component Test Lead, F-35 Structures Test**
- **Keith Jackson, Vertical Tail Component Test Lead, F-35 Structures Test**
- **Josh Martin, CV Variant Chief, F-35 Structures Test**
- **Jeremy Morrison, STOVL Variant Chief, F-35 Structures Test**



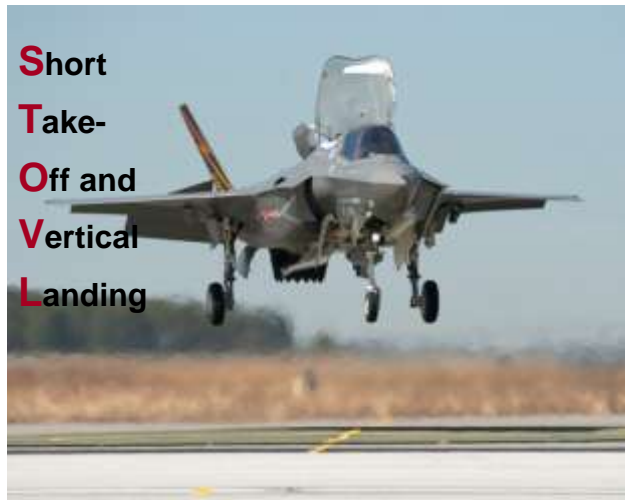
# Tri-Variant Joint Strike Fighter (JSF)



**C**onventional  
**T**ake-  
**O**ff and  
**L**anding



**S**hort  
**T**ake-  
**O**ff and  
**V**ertical  
**L**anding



**C**arrier  
**V**ariant



**F-35A CTOL**

Span ..... 35 ft / 10.67 m  
 Length ..... 51.4 ft / 15.67 m  
 Wing area ..... 460 ft<sup>2</sup> / 42.7 m<sup>2</sup>  
 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 ft<sup>2</sup> / 42.7 m<sup>2</sup>  
 Combat radius (internal fuel) >450 n.mi / 833 km  
 Range (internal fuel) ..... ~900 n.mi / 1,667 km

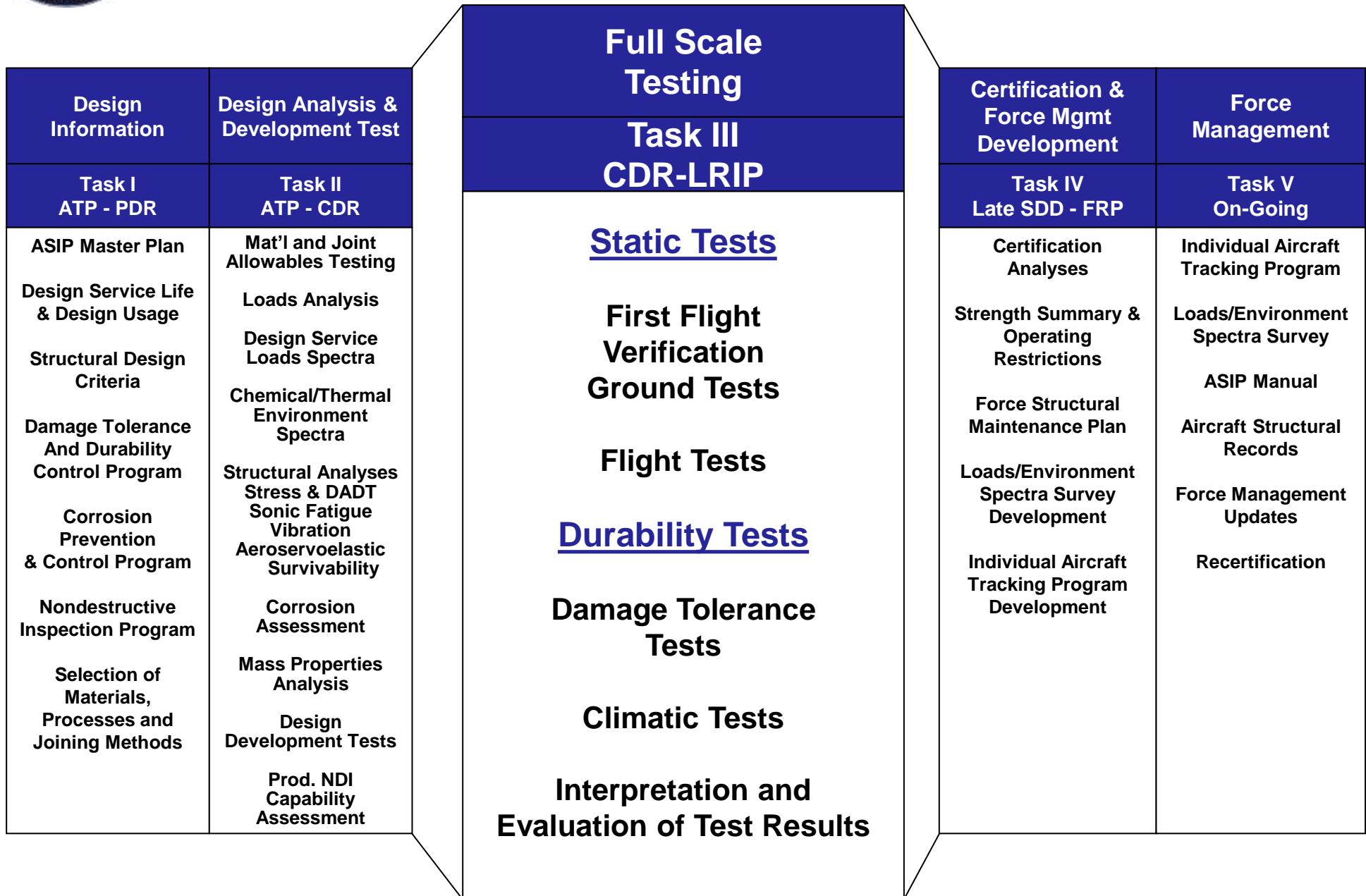


**F-35C CV**

Span ..... 43 ft / 13.11 m  
 Length ..... 51.4 ft / 15.67 m  
 Wing area ..... 668 ft<sup>2</sup> / 62.06 m<sup>2</sup>  
 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

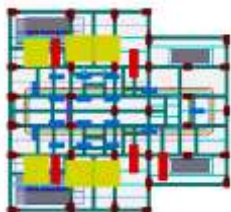




# F-35 Full Airframe Tests Locations & Fixture Sharing



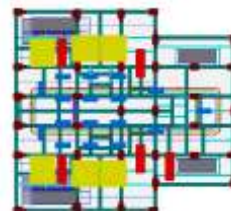
## LM Fort Worth, US



STOVL Static



STOVL Durability

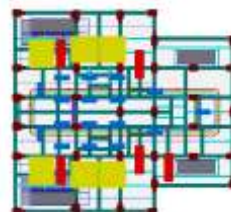


CV Static

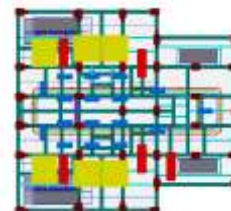


CV Durability

## 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



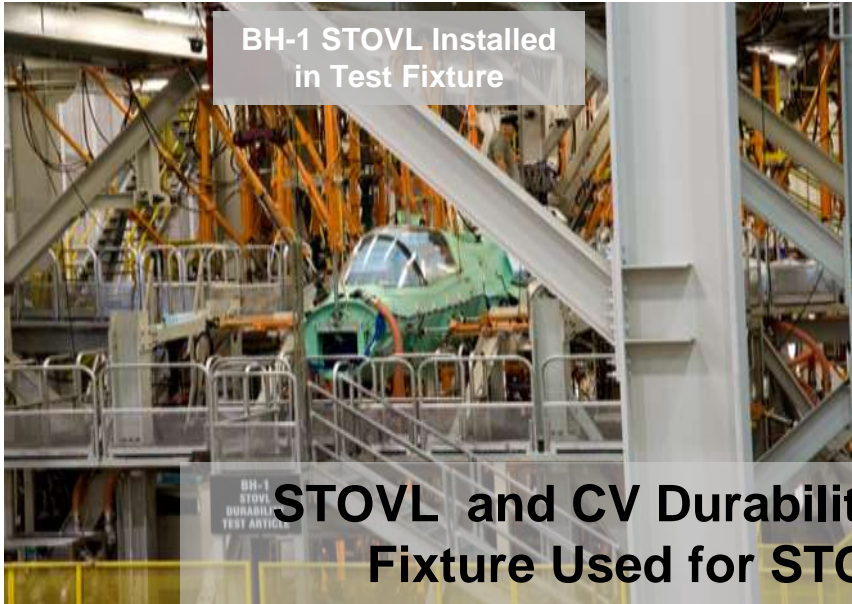
- **Durability Test Program Builds Upon Static Test**
  - *Using Same Fixture*
  - *Same Load Control and Data Acquisition Systems*
  - *Minor Differences in Load Arrangement*
- **Some Differences Between Static and Durability Tests**
  - *Leading Edge Flaps Move Under Load*
  - *LH and RH “Dummy” Vertical Tails*
  - *Vertical Tails Tested As Separate Components*



**Use of Common Test Fixture Reduced Program Cost**



# Multiple Usage of F-35 Full Airframe Test Fixtures



BH-1 STOVL Installed in Test Fixture



CJ-1 CV Installed in Test Fixture

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



AJ-1 CTOL Durability Airframe in Test Fixture

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



# 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 Manoeuvre Test Rig
- Built to Accommodate All Three Variants

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





# 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**



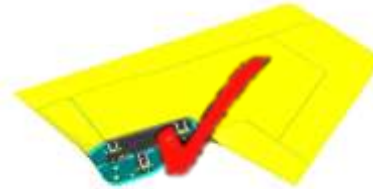
# F-35 Durability Test Status



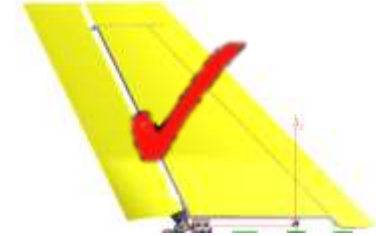
## STOVL



*Projected 1<sup>st</sup> LT  
Complete Dec 2012*



*Completed 2<sup>nd</sup> LT  
in Sep 2011*



*Completed 2<sup>nd</sup> LT  
in Apr 2012*

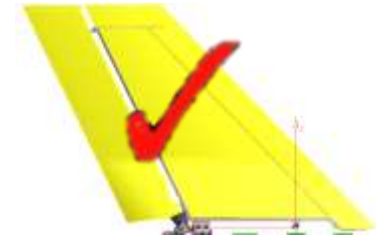
## CTOL



*Completed 1<sup>st</sup> LT  
in Aug 2012*



*Completed 2<sup>nd</sup> LT  
in Aug 2011*



*Completed 2<sup>nd</sup> LT  
in Apr 2012*

## CV



*Achieved 4000 Hours  
in Oct 2012*



*Achieved 10000 Hours  
in Oct 2012*



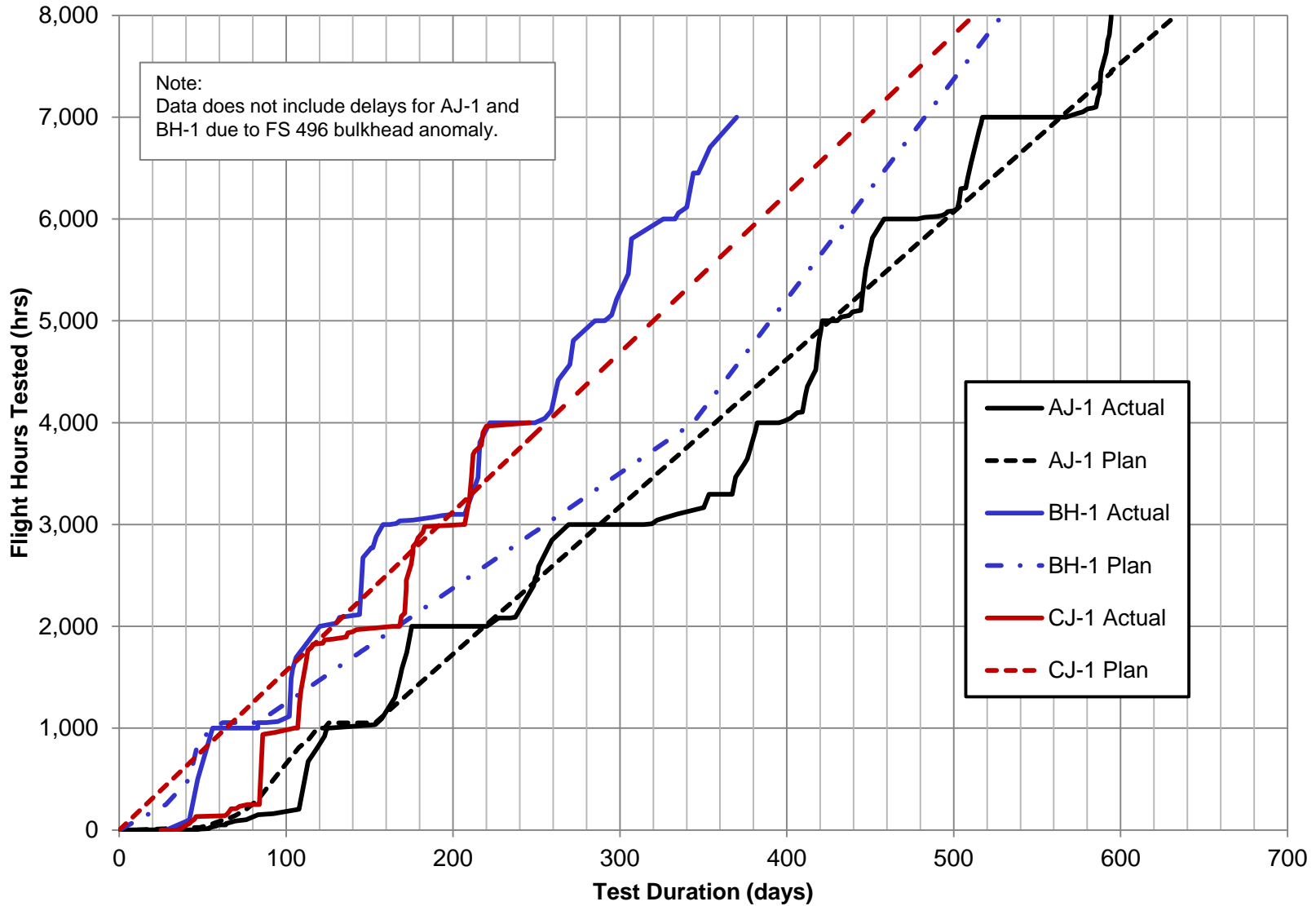
*Achieved 2000 Hours in  
Oct 2012*



# Durability Testing Progress



F-35 Durability Test Schedule (First Life)



**Continued Improvement Recognized in Test Performance**



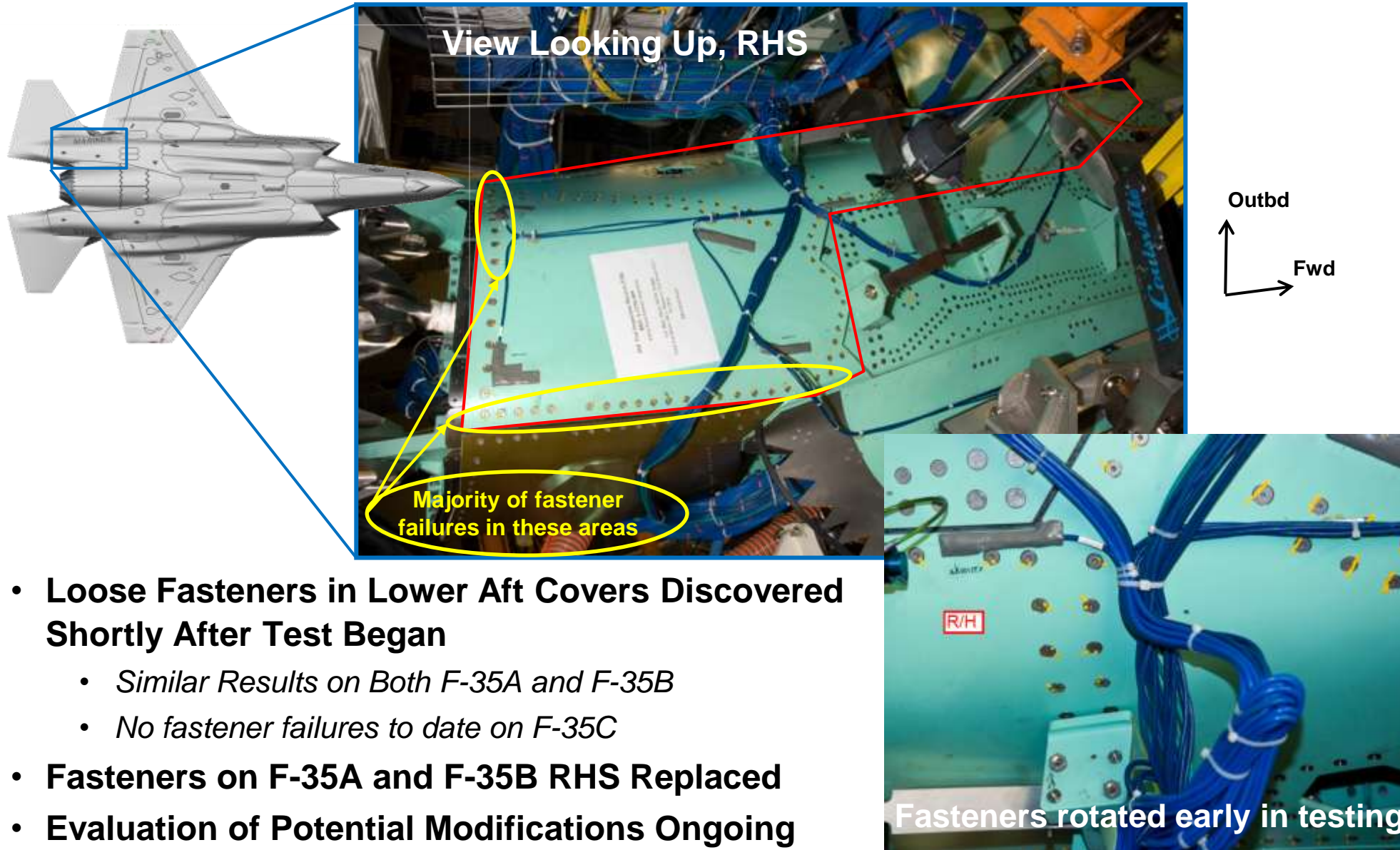
# F-35 Durability Test Findings (cont.)



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



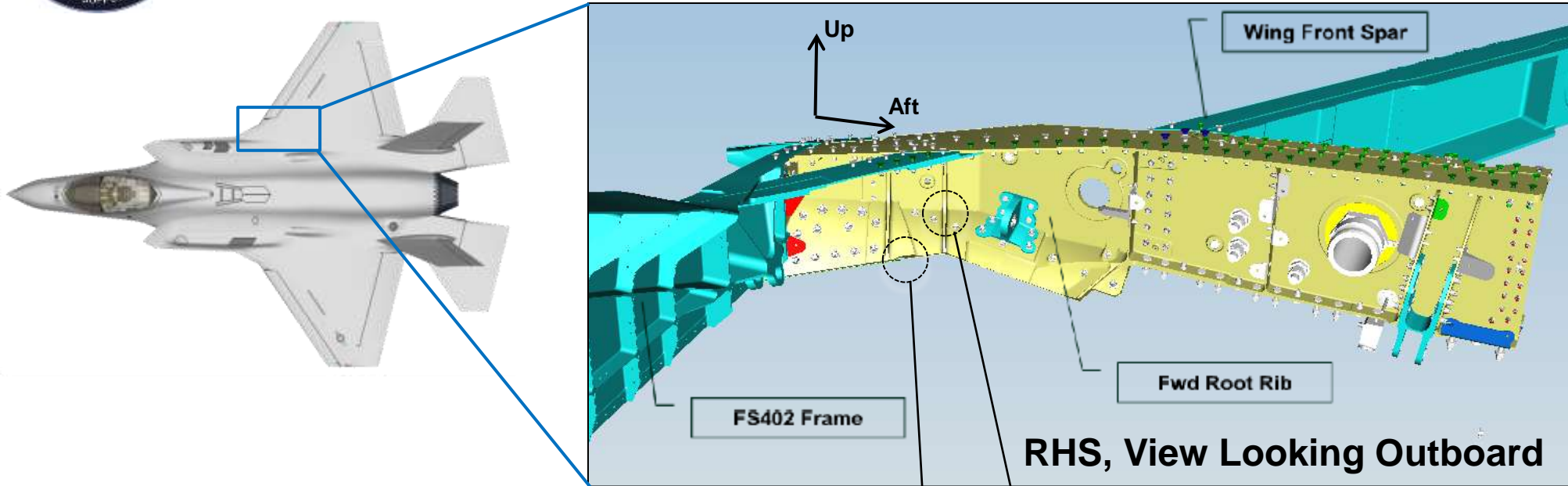
# Loose Fasteners on Lower Aft Access Panels – CTOL and STOVL



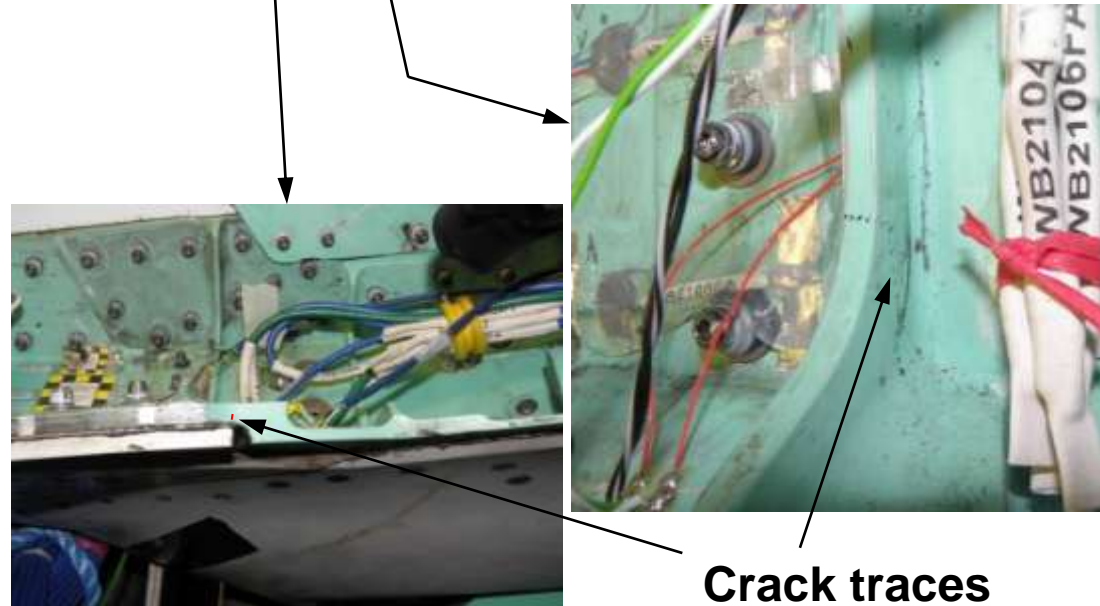
- **Loose Fasteners in Lower Aft Covers Discovered Shortly After Test Began**
  - *Similar Results on Both F-35A and F-35B*
  - *No fastener failures to date on F-35C*
- **Fasteners on F-35A and F-35B RHS Replaced**
- **Evaluation of Potential Modifications Ongoing**
- **No Evidence of Fastener Rotation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



# CTOL Wing Forward Root Rib

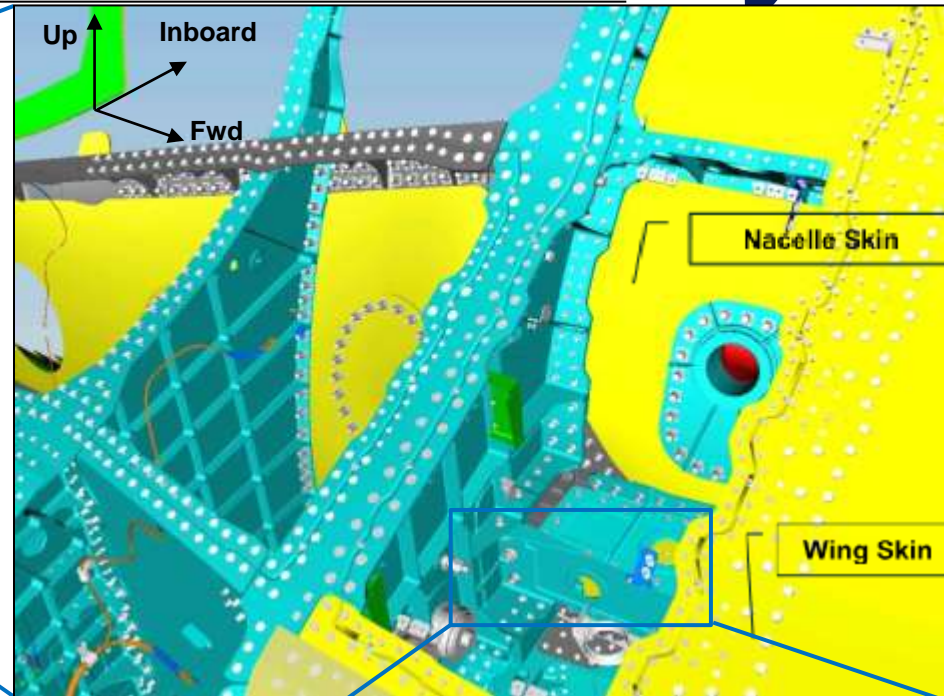
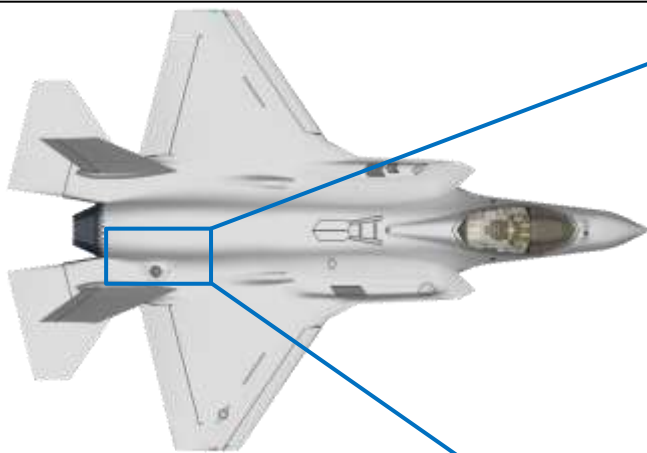


- **Stiffener Crack Found at 2,117 Hours**
- **Lower Flange Crack Found at 5,089 Hours**
- **Declared Short Life Pre-Test**
- **Test Continued to 8,000 Hours**
  - *Crack Growth Monitored by Strain Gage Responses and Periodic Inspections*
- **Similar Crack Location and Geometry on LHS**

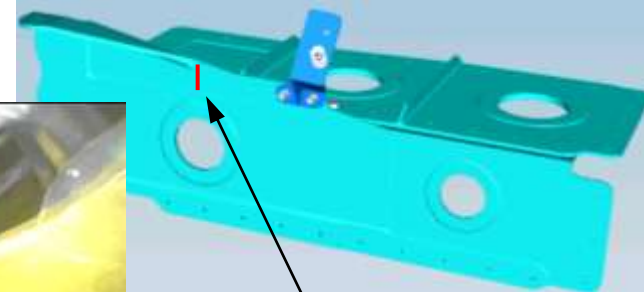




# CTOL Engine Thrust Mount Shear Web



RH side



Crack location



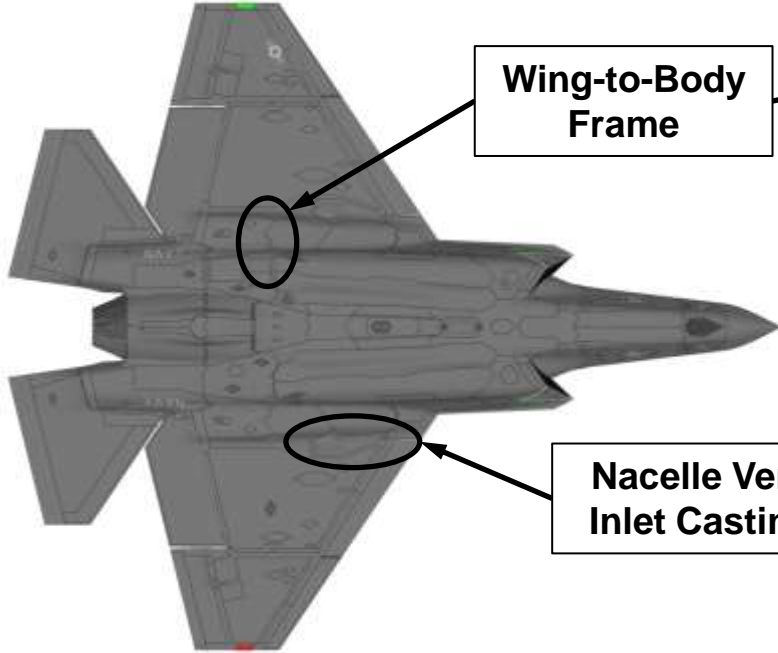
- **Shear Web Crack at 3,000 Hours**
  - *Initiation at Radius of Upper Flange Transition*
- **Test Continued to 8,000 Hours**
  - *Anomaly Monitored by Trending Strain Data and Periodic Inspections*
- **Similar Crack Discovered on LHS at 7,000 Hours**
- **Root Cause: Stress Concentration at Radius**



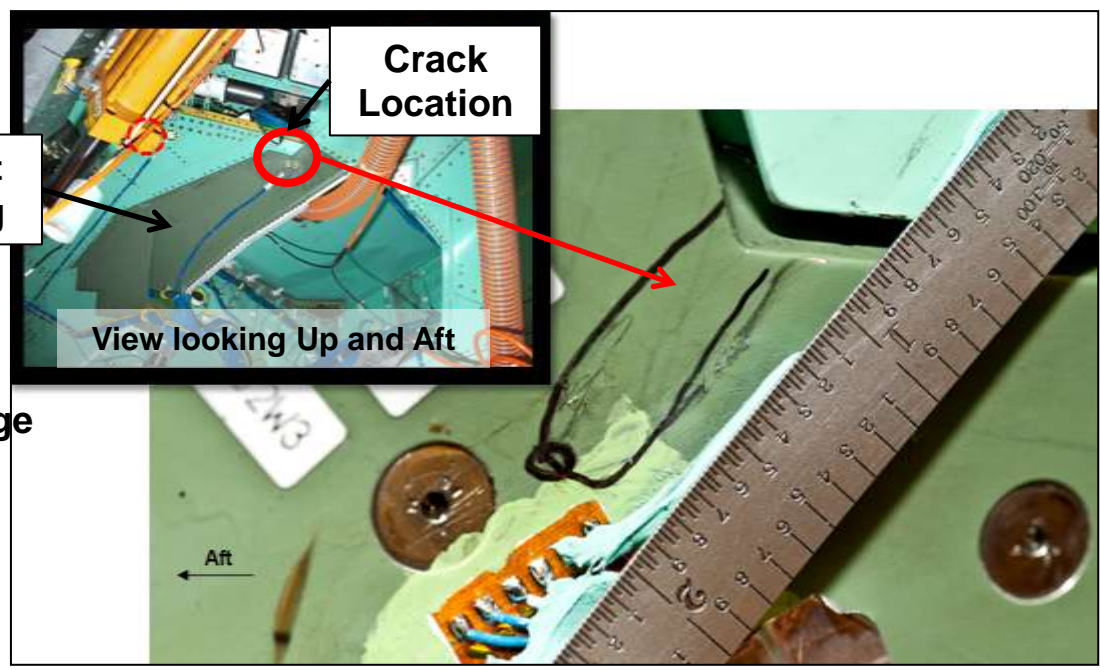


# CV Durability Test Findings

- 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

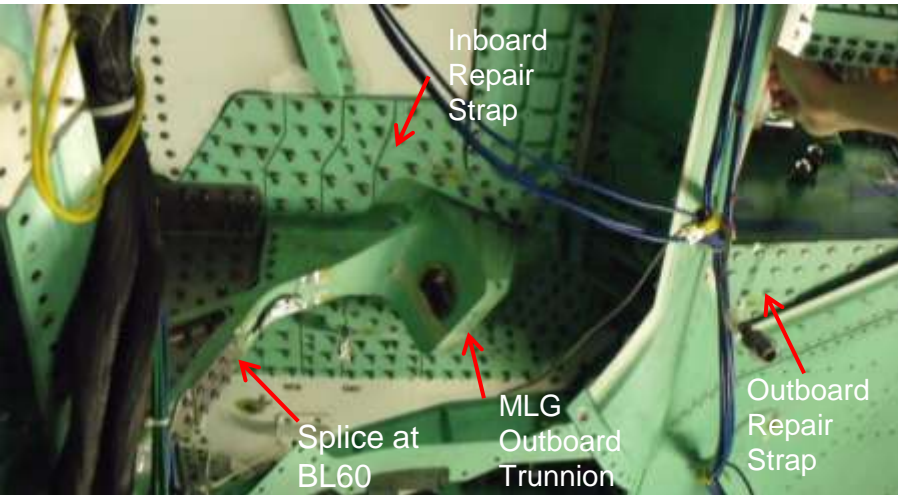


- Nacelle Vent Inlet Crack Discovered During Inspection Resulting From Change in Strain
- Known Short Life Location
- External Doublers Installed as Repair to Test Article

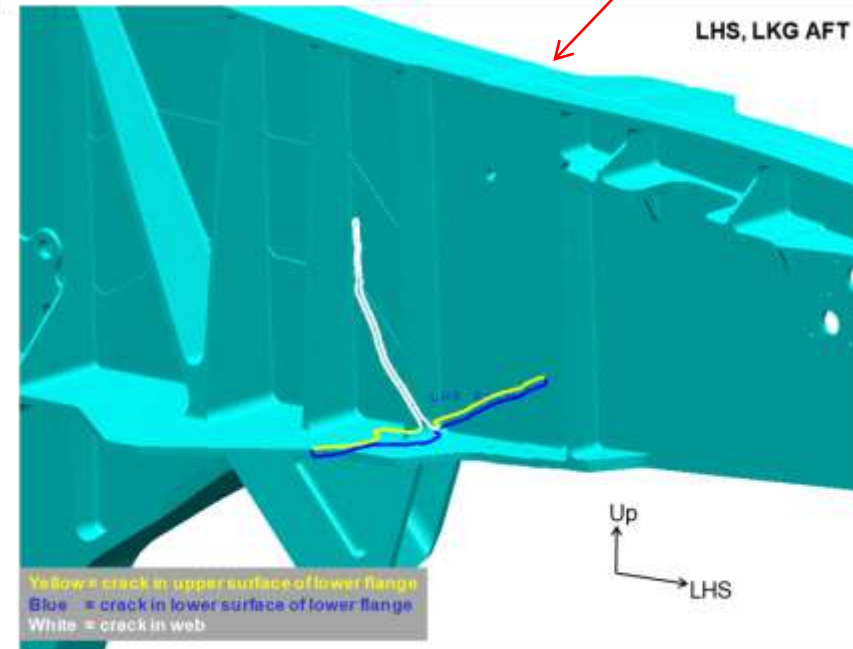
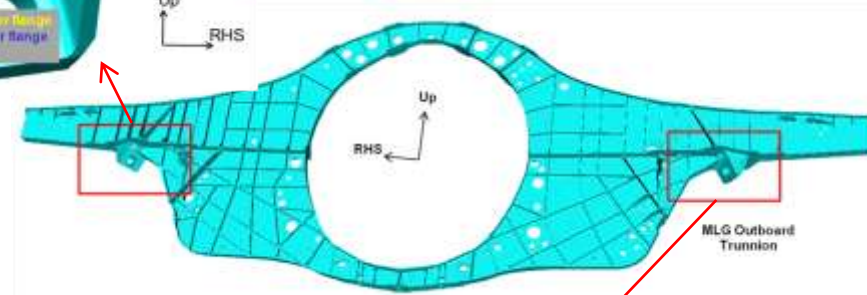
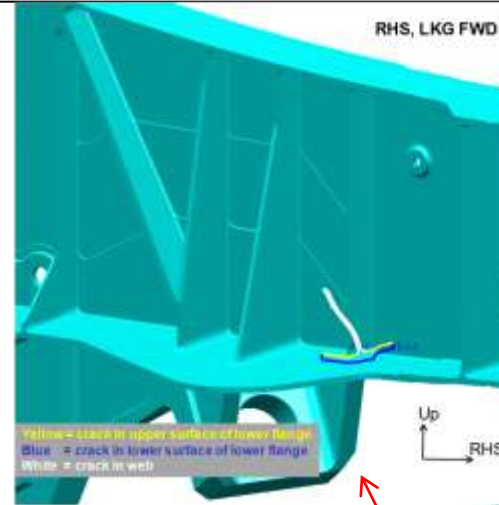




# STOVL FS 496 Bulkhead



**FS 496 Bulkhead Repair (LH) View  
Looking Up and Aft**



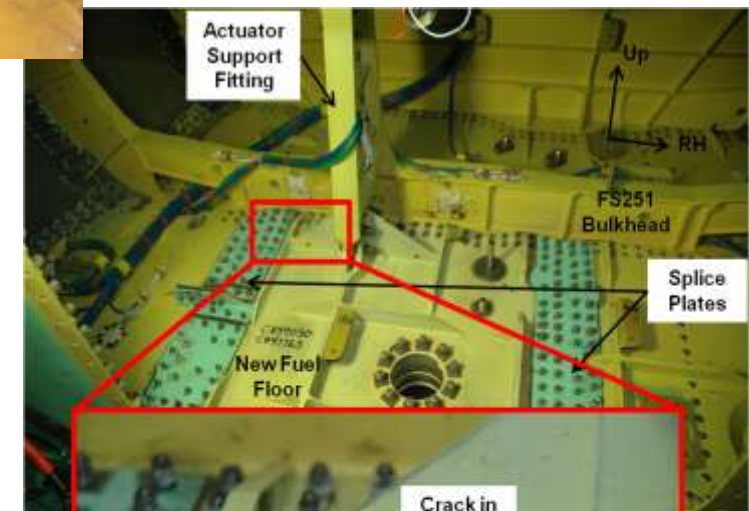
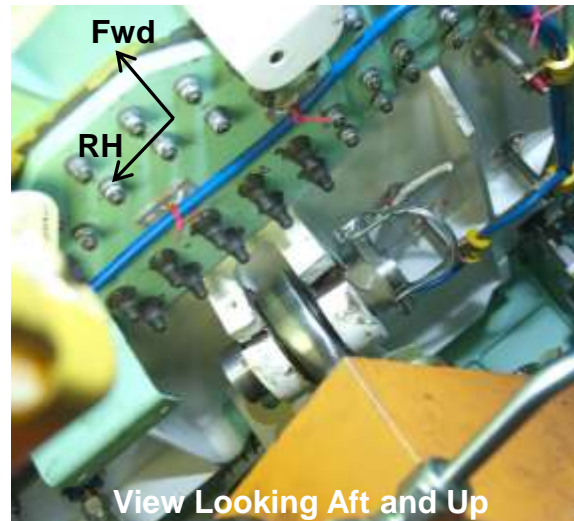
- **Cracks Discovered at 1,471 Maneuver Hours, Initiating at MLG Trunnion Radius**
- **Excised LH and RH Bulkhead Segments Outboard of BL60 and Replaced With**
  - *Production Redesign Geometry, LHS*
  - *SDD/LRIP Repair Geometry, RHS*
- **CTOL and CV Durability Test Articles Required Trunnion Blend**



# STOVL Nose Landing Gear Retract Actuator Backup

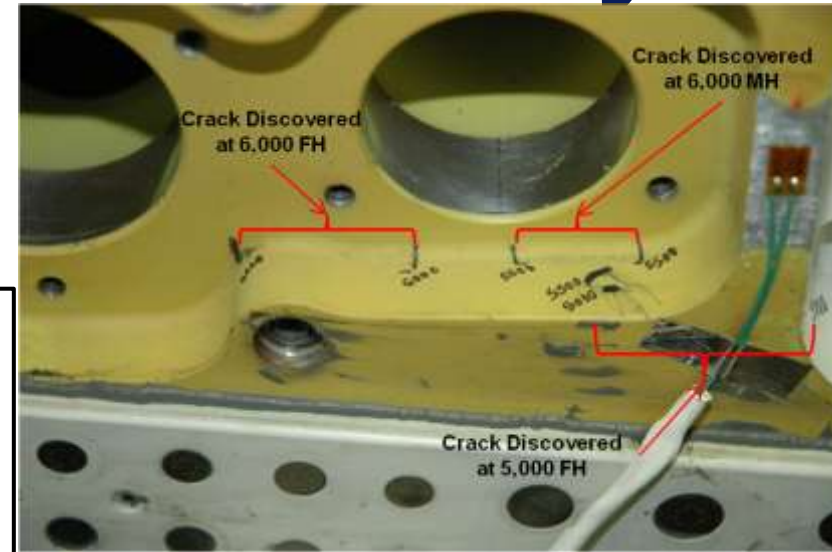
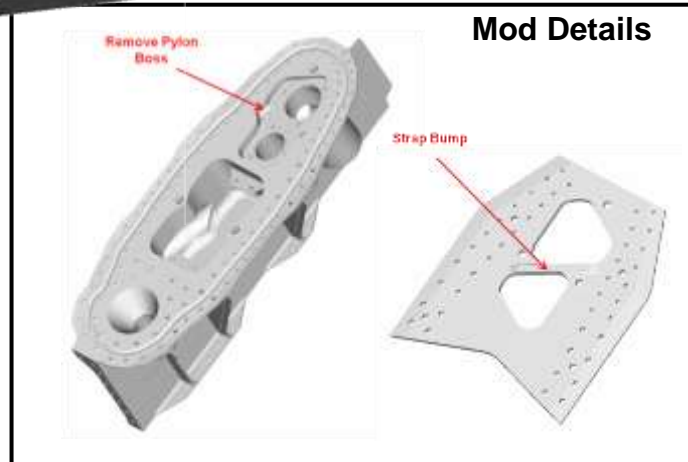


- **Clevis Failed at 7,182 Hours**
  - *Root Cause: Bore Scratched During Bushing Install*
- **Clevis Replaced (Integral to Fuel Floor) and Test Re-started at Zero Hours**
- **Stiffeners Cracked (Through Thickness) at 9,878 Hours**
  - *Root Cause: Stress Concentration at Fillet Radius*
  - *LH Stiffener 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**

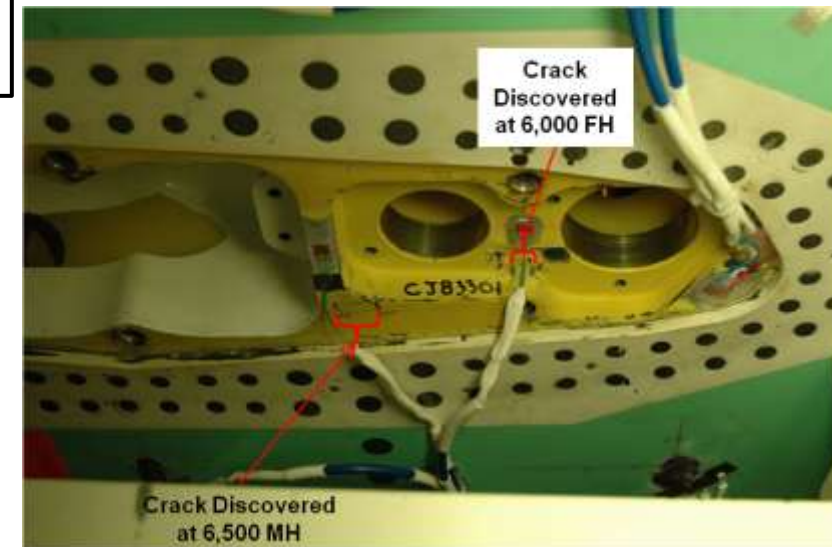




# STOVL Wing Pylon Aft Ribs



View Looking Inboard and Up (Station 3 – LH)

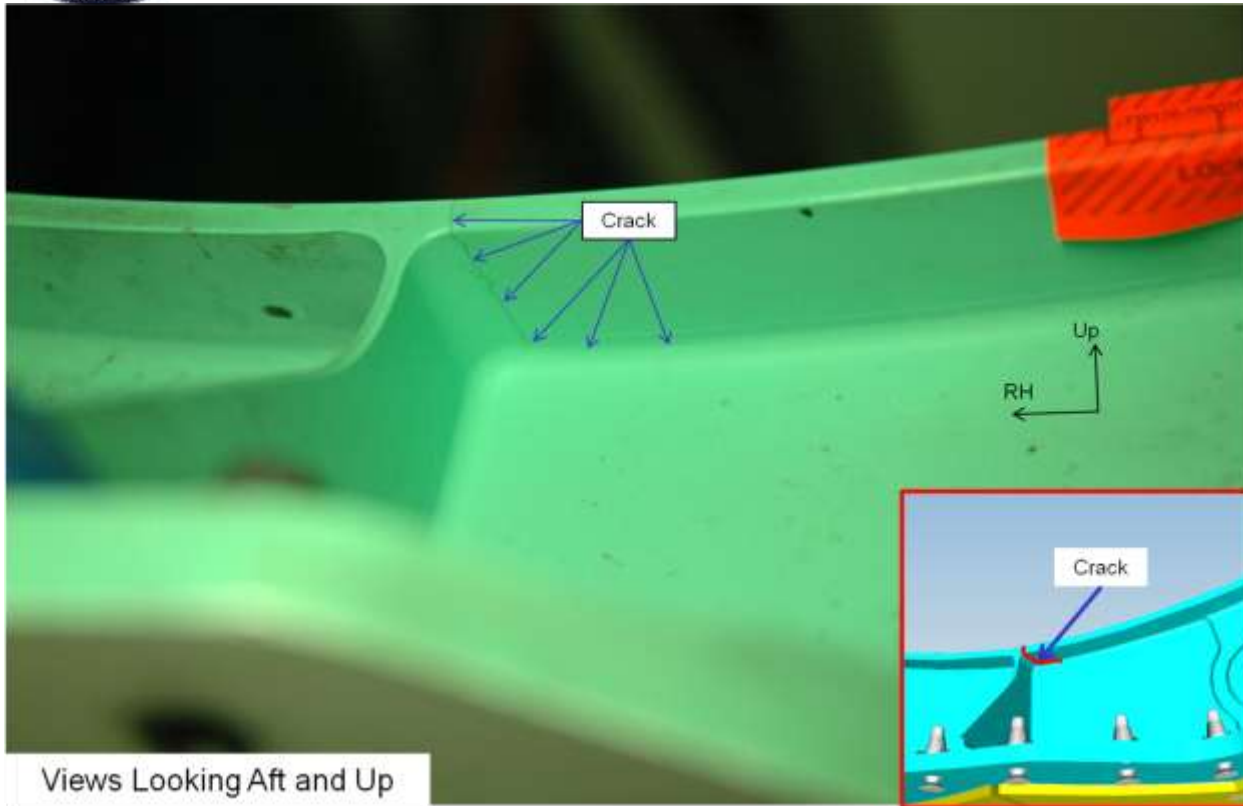


View Looking Inboard and Up (Station 9 – RH)

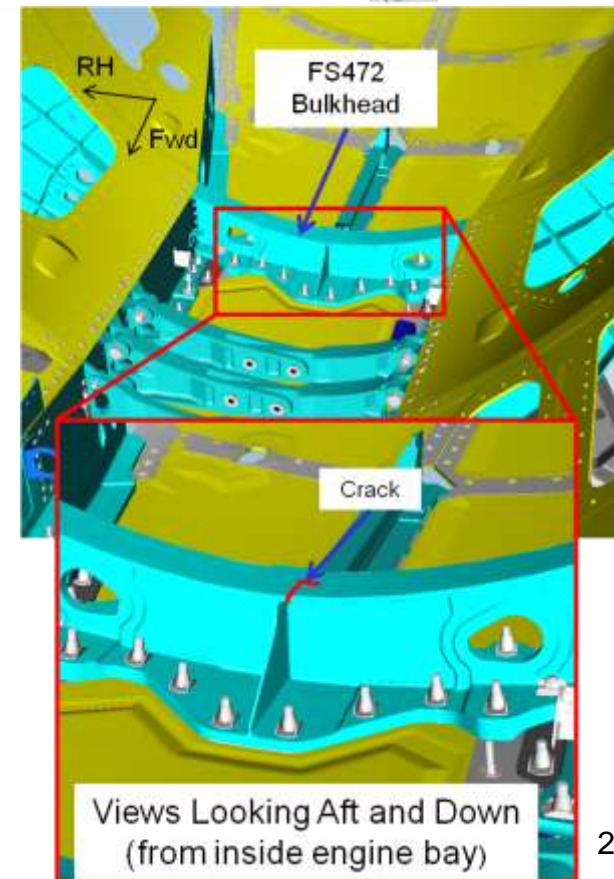
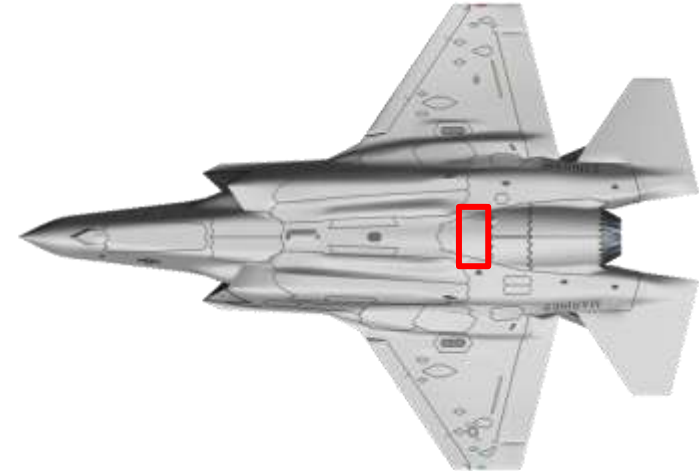
- **Cracks Discovered in Station 3 (LH) Aft Rib at 5,000 Hours and Station 9 (RH) Aft Rib at 6,000 Hours**
  - *Both are Known Short Life Locations; Crack Geometry and Timing as Predicted*
  - *Cracks Stop Drilled at 6,000 Hours*
  - *External Straps Installed (LH and RH) at 7,000 Hours*
- **Engineering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



# STOVL FS 472 Bulkhead



Views Looking Aft and Up



Views Looking Aft and Down  
(from inside engine bay)

- **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



CTOL	FS 575 Forward Shear Tie	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.
	Rudder Base Bolt and Slip Bushing	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.
	Fixed Link Tie-Rod Assembly	Spherical bearing and liner worn without degradation to strength & functionality. Replaced at 7,500 total hours to improve testing performance.
	Rudder Hinge 3 Nut and Locking Washer	Determined to be nonfunctional at 12,000 total hours due to wear. Original installation exceeded wear requirement of 8,000 hours.
	Rudder Hinge 3 Pin	Excessive wear at 16,000 total hours, however maintained strength & functional capability throughout test.
STOVL	FS 575 Forward Shear Tie	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.
	Rudder Hinge 2 Clevis	Rudder Slider Pin seized and gouged the VT-Box clevis at 1,000 total hours. Repaired with installation of wear washers and continued test.
CV	Rudder Hinge 4	Bearing liner and pin damaged during vibration surveys due to overttest (dynamic response 2.5 times greater than requirement). Hinge fitting and pin replaced and test continued with improved load control direction in place.
	Rudder V-Tip	Composite laminate damage caused by test fixture interference during maneuver loading during first 2,000 hours of testing. Rudder repaired and testing continued.



# FS 575 Fwd Shear-Tie Bushing Wear CTOL Vertical Tail

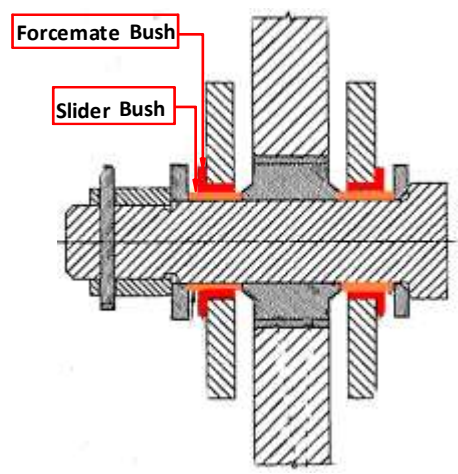
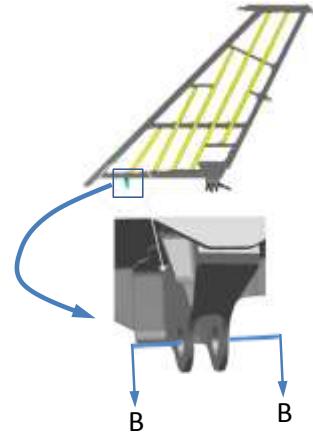


## Original Bushing Material Configuration

- ForceMate: AL-Ni Bronze
- Slider: AL-Ni Bronze
- At 1,753 Hours Testing Exposure



Worn ForceMate  
Worn Slider Bushes



Sect B-B

## Retro-Fit Bushing Material Configuration

- ForceMate: Nitronic 60 Grade C
- Slider: AL-Ni Bronze, molykote
- At 10,247 Hours Testing Exposure



Within Design ForceMate  
Worn Slider Bushes

Fwd Bush



Aft Bush



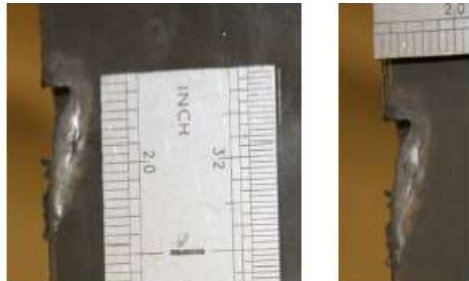


# Rudder V-Tip & Hinge 4 Damage CV Vertical Tail



## Rudder V-Tip

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



View Looking Outboard



View Looking Inboard



### LHS Vertical Tail

## Rudder Hinge 3 Lug

- Severe Over Excitation During Vibration Survey



Looking Down

Lug Bearing Liner



Looking Up



### Hinge 4 Bolt





# F-35 Durability Test Findings Horizontal Tail



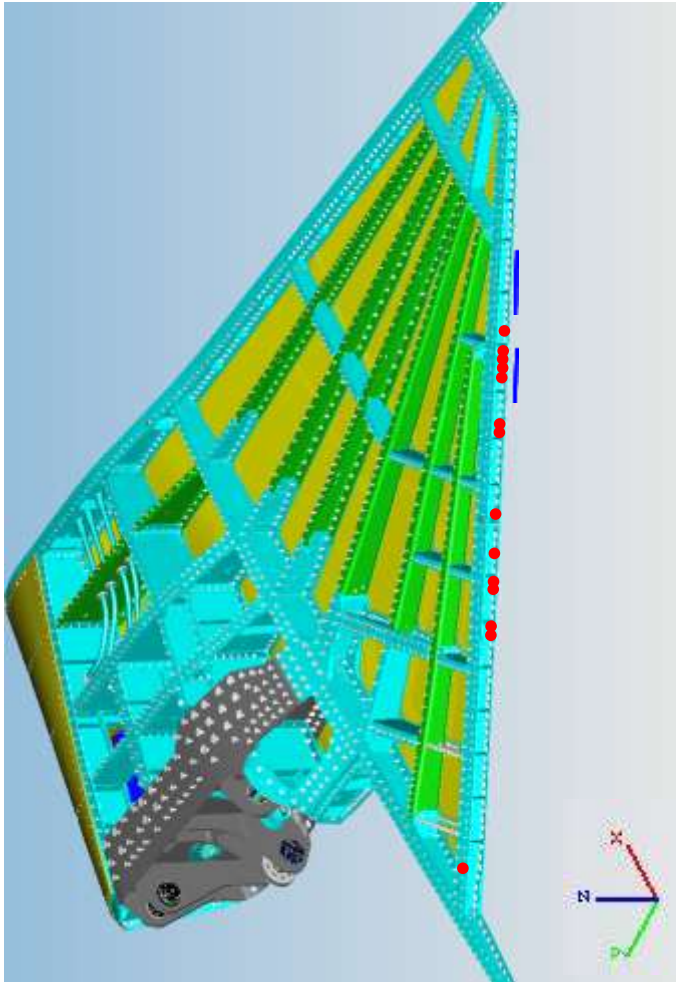
STOVL	Leading Edge Fasteners	Seven failed fasteners at Inboard Leading Edge discovered during 2 Lifetimes of testing (16,000 total hours).
	Bump Fairing Support Frame	Crack discovered during 12,000 hour planned inspection on fairing support frame.
CTOL	Leading Edge Fasteners	One fastener failed at Inboard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



# CV HT Leading Edge Modification

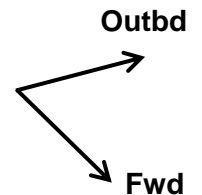


## CV HT (4DB6)



**14 Fastener Failures During 1<sup>st</sup> LT (8000 flight hours) Testing, Along Leading Edge**

- **Modified Leading Edge After Completion of 1<sup>st</sup> 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 3<sup>rd</sup> Lifetime to Begin 1<sup>st</sup> Quarter 2013*

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



# Questions?

