Space Shuttle Update

Bill Hill

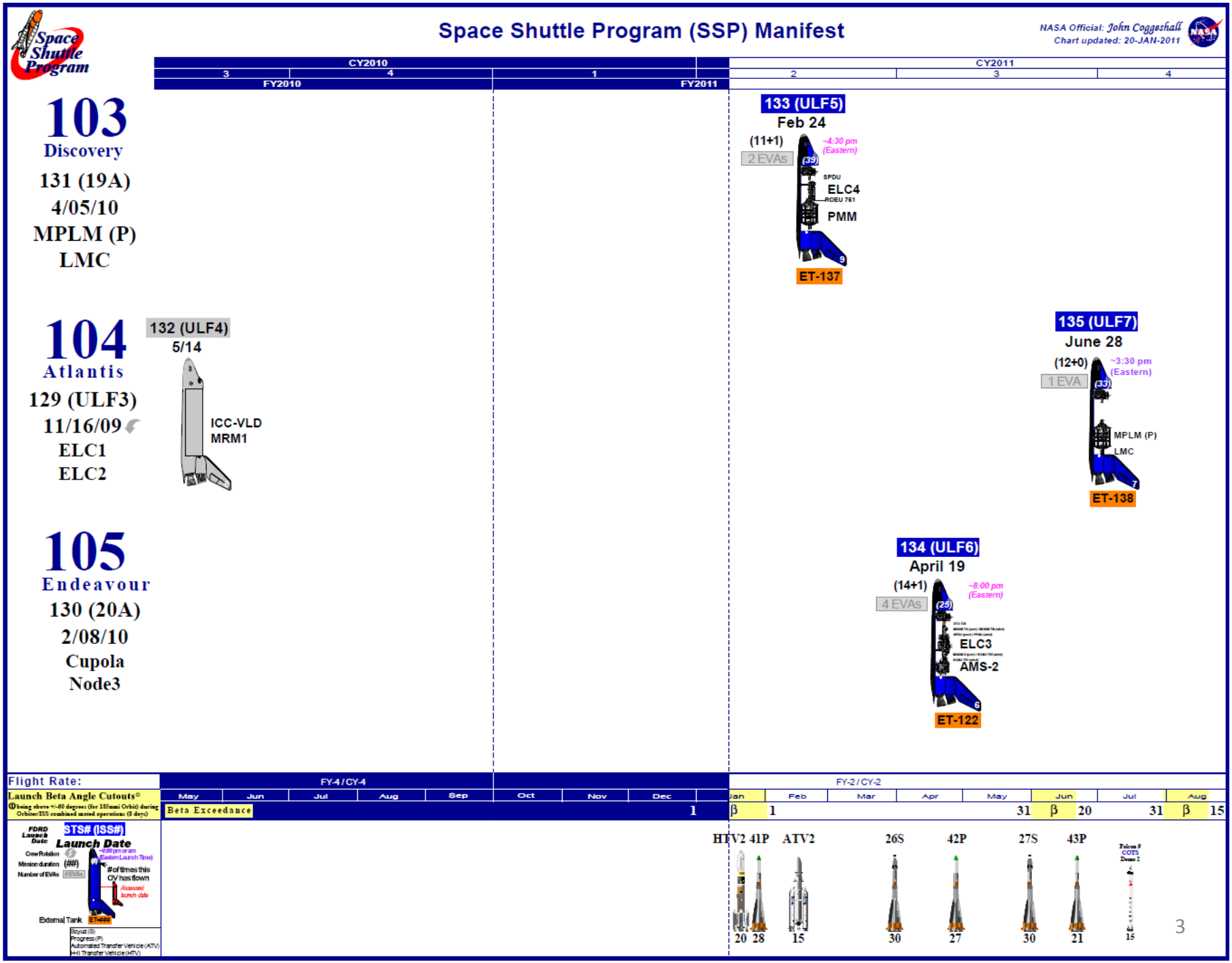
Assistant Associate Administrator

for Space Shuttle

February 8, 2011

Agenda

- **Shuttle Manifest**
- **STS-135 Decision**
- **Shuttle Transition & Retirement**
- **STS-133 External Tank Intertank Stringer Cracks and Repair Status**


Space Shuttle Program
Space Shuttle Program (SSP) Manifest
NASA Official: John Coggeshall
Chart updated: 20-JAN-2011
CY2010
CY2011
3
4
1
2
3
4
FY2010
FY2011
103
Discovery
131 (19A)
4/05/10
MPLM (P)
LMC
133 (ULF5)
Feb 24
(11+1)
2 EVAs
~4:30 pm (Eastern)
(39)
SPDU
ELC4
ROEU 761
PMM
9
ET-137
104
Atlantis
129 (ULF3)
11/16/09
ELC1
ELC2
132 (ULF4)
5/14
ICC-VLD
MRM1
135 (ULF7)
June 28
(12+0)
1 EVA
~3:30 pm (Eastern)
(33)
MPLM (P)
LMC
7
ET-138
105
Endeavour
130 (20A)
2/08/10
Cupola
Node3
134 (ULF6)
April 19
(14+1)
4 EVAs
~8:00 pm (Eastern)
(25)
ELC3
AMS-2
6
ET-122
Flight Rate:
Launch Beta Angle Cutouts©
FY-4 / CY-4
FY-2 / CY-2
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Beta Exceedance
1
β
1
31
β
20
31
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15
FDRD Launch Date
STS# (ISS#)
Launch Date
Crew Rotation
Mission duration
(##)
Number of EVAs
#EVAs
~4:30 pm or am (Eastern Launch Time)
#of times this OV has flown
Assessed launch date
External Tank
ET-###
Soyuz (S)
Progress (P)
Automated Transfer Vehicle (ATV)
H-II Transfer Vehicle (HTV)
HTV2
41P
ATV2
26S
42P
27S
43P
Falcon 9 COTS Demo 2
20
28
15
30
27
30
21
15

STS-135 Update

- **Direction issued by letter to the International Space Station and Space Shuttle Program Managers on December 23, 2010**

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

December 23, 2010

Reply to Attn of: Space Operations Mission Directorate

TO: Manager, International Space Station Program
Manager, Space Shuttle Program

FROM: Associate Administrator for Space Operations

SUBJECT: Maintaining Capability to Conduct the STS-135 Mission

The NASA Authorization Act of 2010 (P.L. 111-267) directs NASA to conduct the above-referenced mission. As of this date, the Congress has not cleared final FY 2011 appropriations for the Federal government, including NASA. However, the FY 2011 Continuing Appropriations Act provides funding for most Federal departments and agencies, including NASA, through March 4, 2010, at FY 2010 enacted levels. Funding made available in this measure will enable NASA to work towards the STS-135 mission.

For this reason, I ask that you continue planning and preparations efforts to execute this mission in late June 2011 as currently planned. This includes maintaining the requisite workforce to safely conduct this mission and extending contracts if necessary. We must focus on STS-135 as a real mission as well as a Launch-On-Need capability for the STS-134. Without clarity in focus now we reduce the probability of safely executing this critical mission. The purpose of this memorandum is to provide clear direction for the teams. STS-135 is critical to health of the International Space Station.

If there are any questions concerning this direction, please contact me immediately.

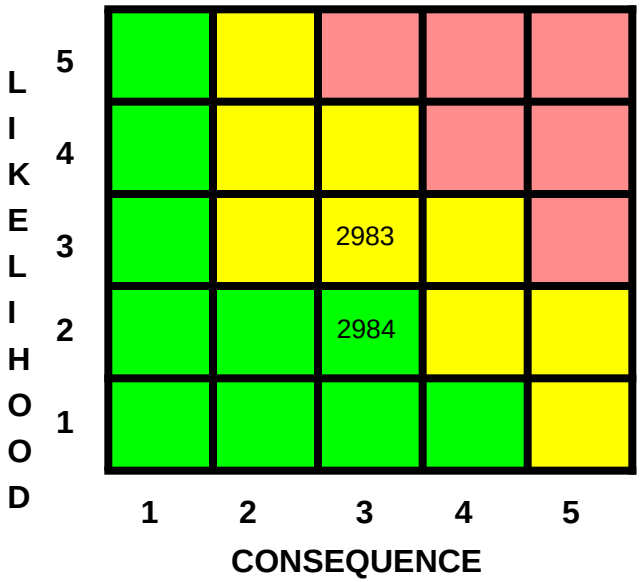
William H. Gerstenmaier

William H. Gerstenmaier

Shuttle Transition and Retirement

Risk—Loss of Critical Skills

- ***Contractor – Risk 2983***
  - Voluntary attrition rates continue to decrease or stay level. However, could be impacted by size of recent and upcoming layoffs and the uncertainty around NASA's future programs.
  - All prime contractors have critical skills plans in place.



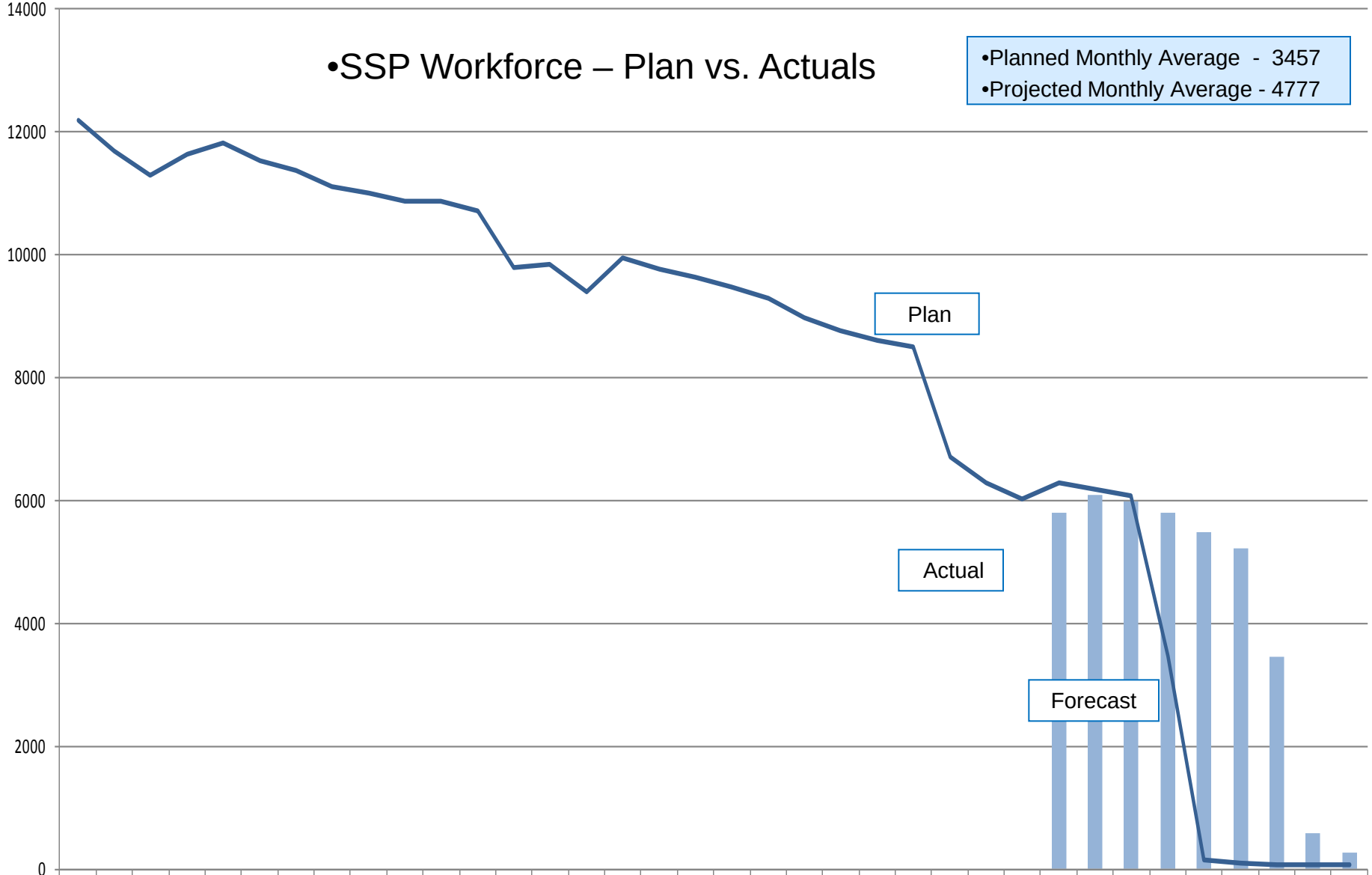
- ***Civil Service – Risk 2984***
- Majority of projects and associated civil service workforce are "green".
- From recent Employee Survey:
  - Intent to stay with the Program until the end—80% (83% in 2009)
  - Current search for jobs outside the SSP--68% aren't looking right now (69.2 % '09); 8.8% are actively looking (5% in '09 and 10.8% in '06)
- Civil Service supervisors confidence in ability to support the Program for next 6 months (95% green) and to the end of the program (91% green) for civil service workforce

Risk—Timing of WARN Notices

- ***Concern with WARN Notice requirements relative to:***
  - STS-135 decision – Mitigated for now
  - Extension of prime contracts
  - Critical skills retention

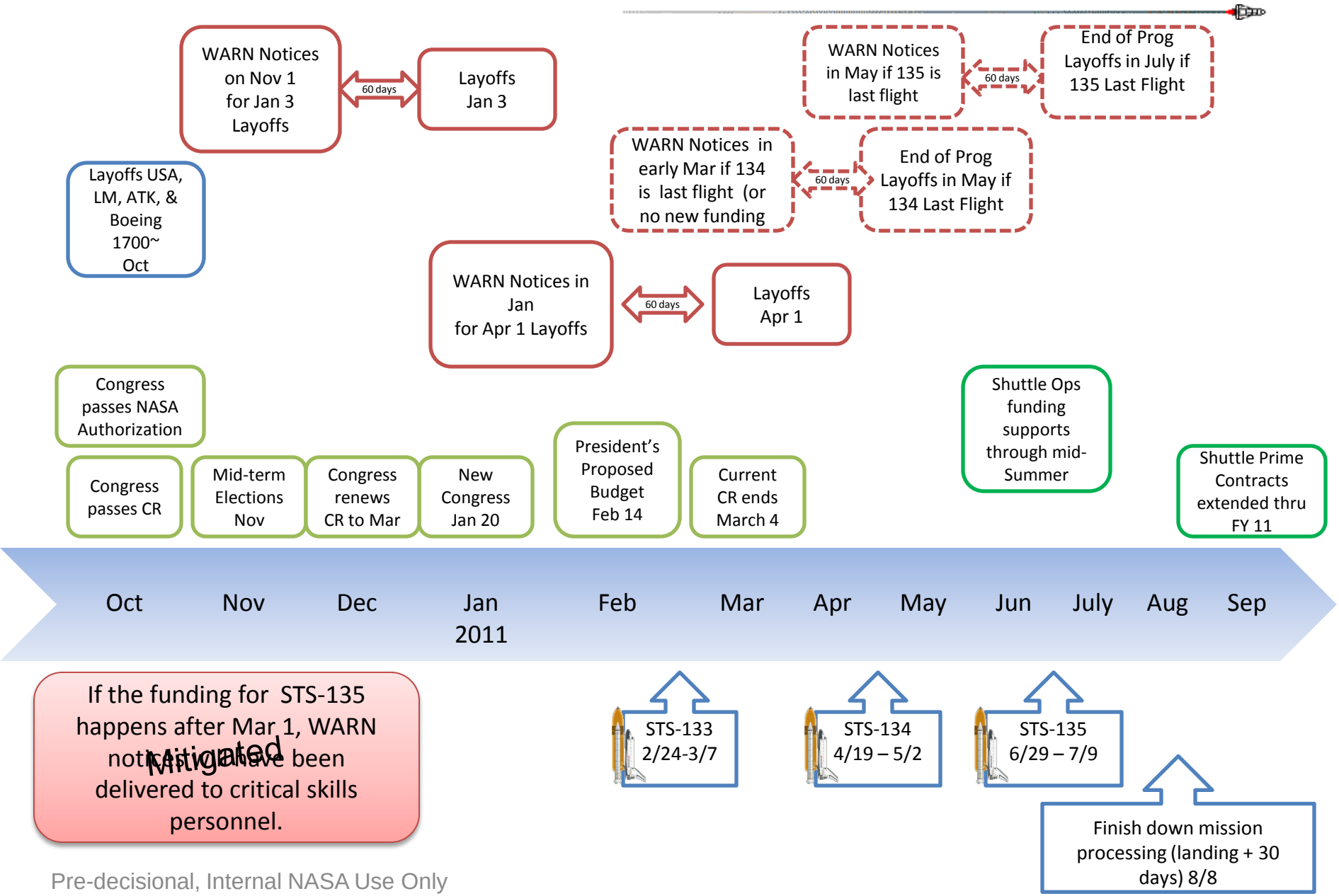
- **Recommendation**
  - Keep critical skill retention an area of emphasis
  - Develop a communication strategy
  - Continue to share timing/impact story with decision makers

- **Additional risk to support contractors**
  - Program focused on primes due to follow on opportunities for support contractors
  - Changes in Cxp have increased the risk to these critical skills
  - Problems are unique to each project
  - Recommend managing at the project level and not adding a Program risk



	O 08	N 08	D 08	J 09	F 09	M 09	A 09	M 09	J 09	J 09	A 09	S 09	O 09	N 09	D 09	J 10	F 10	M 10	A 10	M 10	J 10	J 10	A 10	S 10	O 10	N 10	D 10	J 11	F 11	M 11	A 11	M 11	J 11	J 11	A 11	S 11
SSP Actuals	1200	1174	1116	1146	1175	1173	1140	1133	1123	1075	1076	1066	9693	9566	8942	9698	9599	9213	9092	8811	8125	7828	7860	7763	6731	6148	5765									
SSP Forecast																												5788	6083	5984	5809	5483	5211	3449	592	276
SSP Plan	1218	1170	1130	1164	1181	1154	1138	1111	1100	1088	1087	1072	9786	9851	9404	9938	9768	9643	9477	9297	8967	8771	8596	8512	6716	6285	6017	6294	6191	6067	3471	136	86	76	74	65

Shuttle Workforce Timeline



Pre-decisional, Internal NASA Use Only

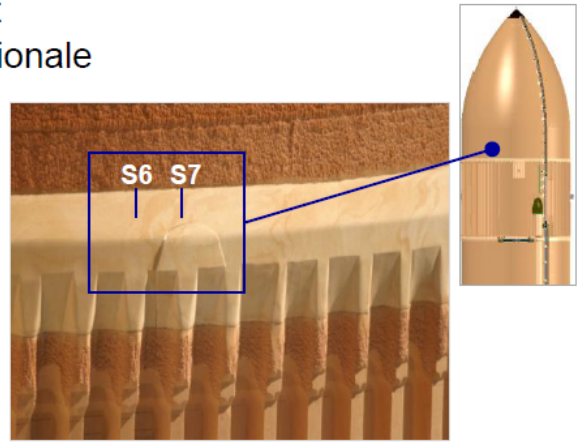
STS-133 External Tank Intertank Stringer Cracks and Repair Status

February 8, 2011

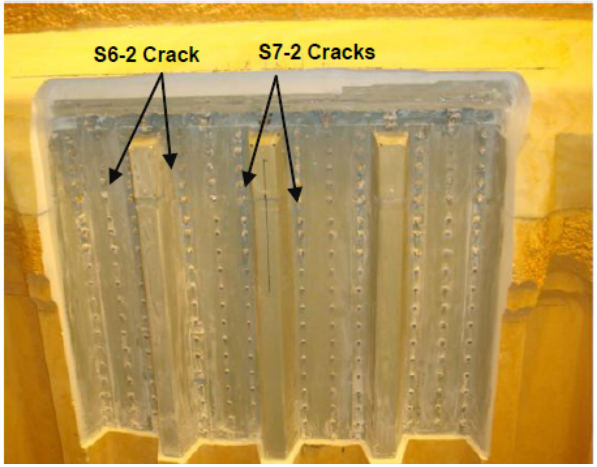
STS-133 / ET-137 Intertank Stringer Cracks

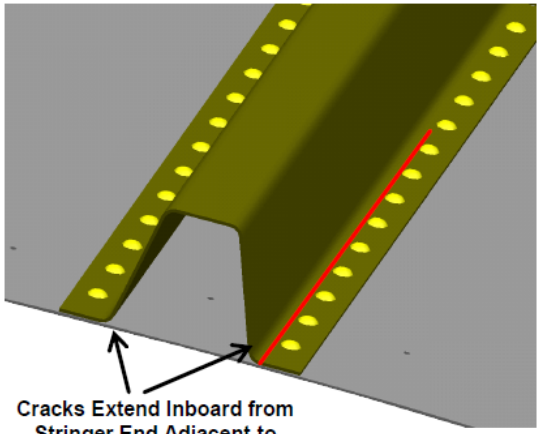
- ***Purpose***
  - Provide high-level status of plans in-work to assess structural anomaly observed on ET-137 during loading
    - Tasks in work to document potential contributors and proximate root cause
    - Structural and TPS repairs to restore tank configuration for flight
    - Additional tests, analyses, and inspections for potential flight rationale

- ***Background***
  - TPS crack observed on LO_2-Intertank Flange Closeout during loading for STS-133 (1st occurrence in history of program)
    - Subsequent TPS removal showed TPS cracks were caused by sub-surface cracks in stringer feet at attachment to skin panels
    - Anomaly observed during loading as fill level passed flange
    - Total of four cracks observed following TPS removal
      - 2 @ ~9" at stringer 7
      - 2 @ ~3.5" at stringer 6

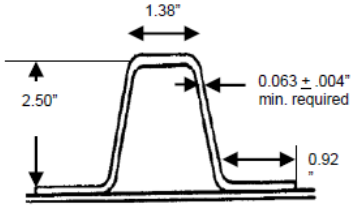


LO_2-Intertank Flange Closeout Crack with Visible Off-Set

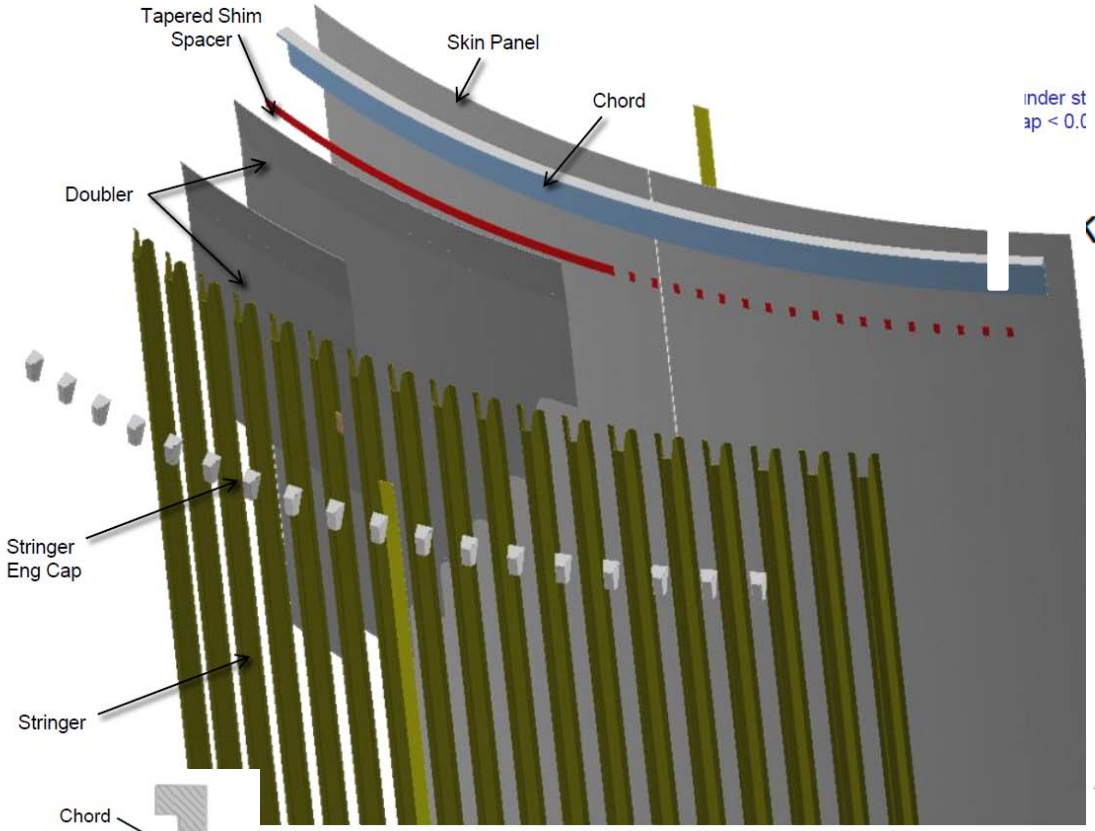


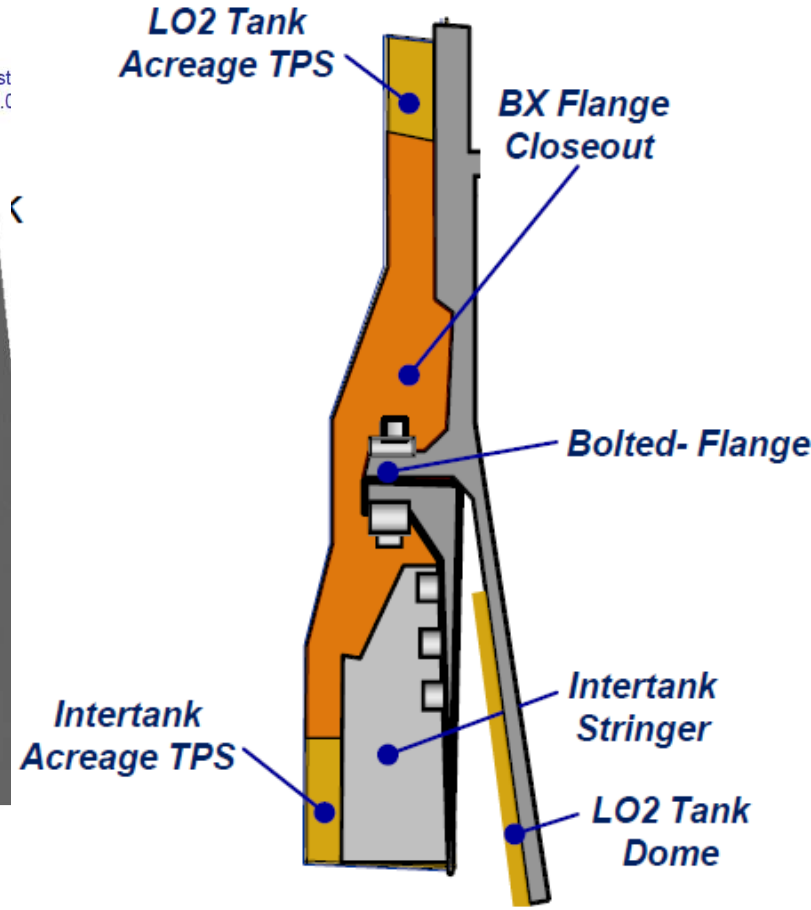


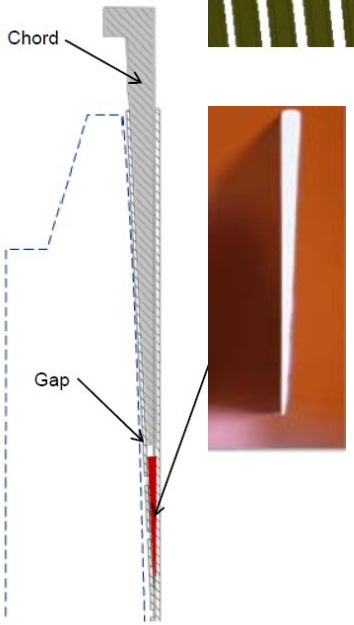
Cracks Extend Inboard from Stringer End Adjacent to Inboard Edge of Holes



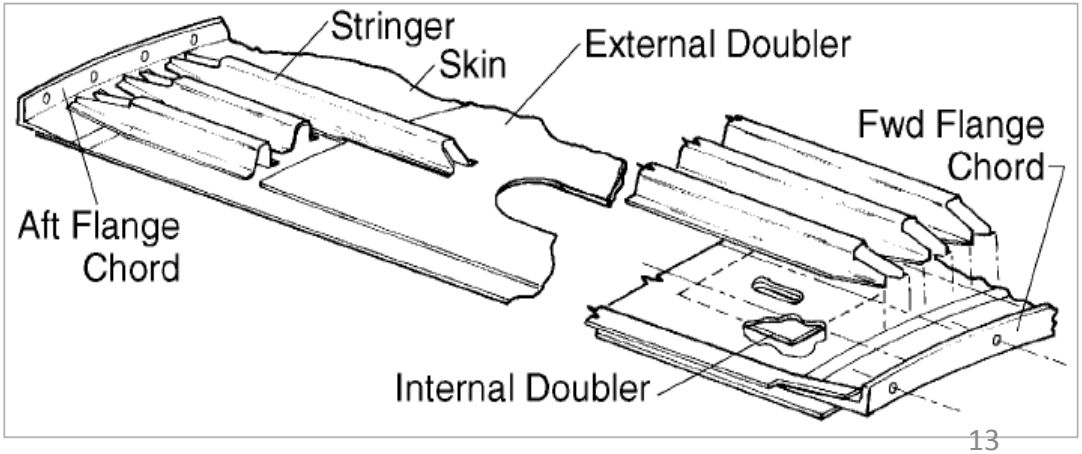
Intertank Stringer, Fwd and Aft Ends only (X-Section)







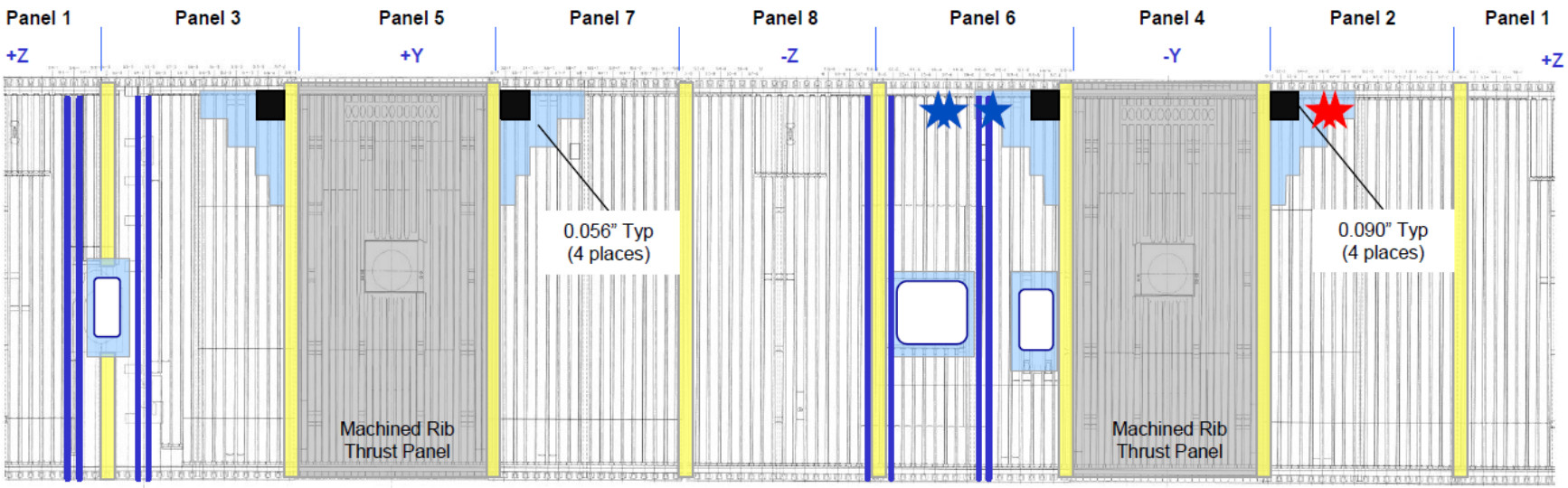
Tapered Shim Space (aka Extruded Shim)

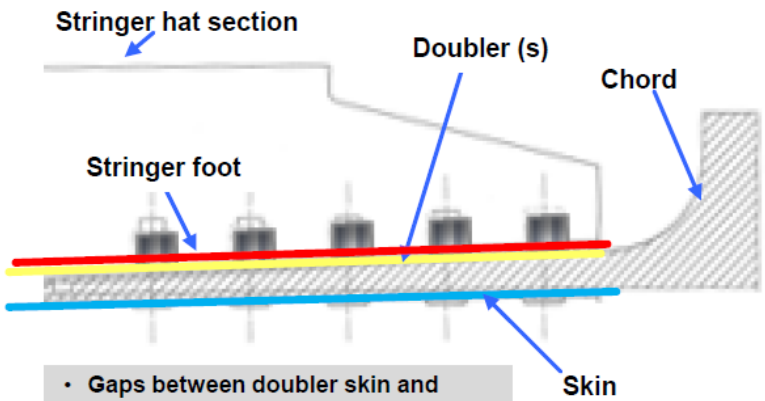


Intertank Stringer Panel

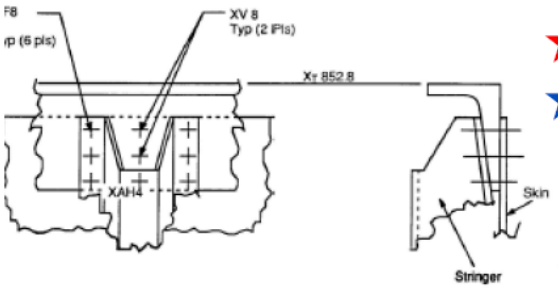
STS-133 / ET-137 Intertank Stringer Cracks

- ***Background / Structural Configuration Overview (continued)***
  - Intertank structure designed for high compression loading due to LO_2 inertia and SSME/SRB thrust
    - Al-Li 2090 sheet metal construction except for thrust panels (machined Al-Li 2297 plate)





- **Gaps between doubler skin and tapered shim not verified due to access limitations**



- **Stringer end fasteners manually installed at chord assembly (last 8)**
- **All other skin/stringer fasteners are auto-rivet installations**

Location of Cracks

- ★ Observed after STS-133 scrub
- ★ Observed after STS-133 tanking test (NDE not performed prior to tanking test)

Legend

- Al 2024 Extruded Stringer
- External Doubler
- Internal Doubler
- Splice

STS-133 / ET-137 Intertank Stringer Cracks

- ***Investigation Approach and Summary***
  - Developed plans to identify most likely cause of cracks, implement necessary corrective actions, and develop data necessary to support flight rationale / characterize risks

ET-137 Assessment Approach

Fishbone Investigation (Root Cause / Contributors)

Assessment Scope

1. Requirements, Design and Analysis
2. Raw Materials / Supplier Processing
3. Assembly / Production Processing
4. Transportation / KSC Processing
5. Day of Launch Environments

Perform Tests / Analysis to Demonstrate Physics-Based Failure Scenarios

Assessment Scope

- FEM Stress and Thermal Analysis
- Component / Fracture Tension Tests
- Stringer Bend Tests
- Instrumented Tanking Test

Develop Design Enhancements to Mitigate Residual Risk (radius blocks)

Assessment Scope

- FEM Stress Analysis
- Component Tension Tests
- Stringer Bend Tests
- Tanking Test

Perform Tests / Analysis to Understand Risk Exposure (Probability and Consequence)

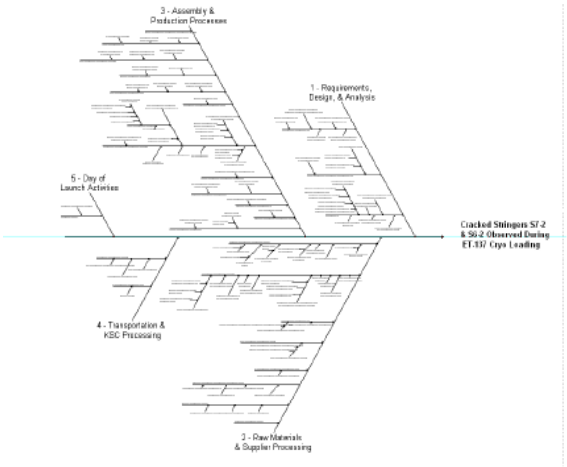
Assessment Scope

- Structural Fail Safe Analysis
- TPS Debris Assessments
- Stringer Debris Assessments
- Critical Flaw Analysis
- NDE Detection Capability
- Cryogenic 'Proof Test' for LO_2 and LH_2 locations

ET Project and Shuttle Technical Community Continues to Pursue Test and Analysis to Improve Understanding of Stringer Cracking Phenomenon and Provide Effective Risk Mitigations

STS-133 / ET-137 Intertank Stringer Cracks

- ***Root Cause Assessment Approach***
  - Fishbone Cause Methodology used to investigate possible cause/s or contributors/s to failure
    - Fishbone provides potential cause (s) and structure to compile, collect & interrogate evidence
    - Collected 'likely' causes, contributors, and as-built evidence to develop root cause scenarios
      - "Bones' selected based on Hardware Lifecycle
      - Tasks developed (tests and analyses) to screen likelihood and mature scenarios



Graphical View of Fishbone

Fishbone Focus Areas

1. Design & Analysis
2. Raw Materials & Supplier Processing
3. Assembly & Production Process
4. Transportation & KSC Processing
5. Day of Launch Activities

Likely causes / As-built evidence

Root Cause Hypotheses

- Scenario 1
- Scenario 2
- Scenario …

Providing relevant process analysis / evidence from fishbone to scenario(s) being pursued

Track root cause scenarios being pursued

Hardware Lifecycle

1.0 Requirements, Design and Analysis → **2.0 Raw Materials and Supplier Processing** → **3.0 Assembly and Production Processing** → **4.0 Transportation and KSC Processing** → **5.0 Day of Launch**

STS-133 / ET-137 Intertank Stringer Cracks

- ***Fishbone Observations / Findings to Date***

1.0 Requirements, Design and Analysis	2.0 Raw Materials and Supplier Processing	3.0 Assembly and Production Processing	4.0 Transportation and KSC Processing	5.0 Day of Launch

• Analysis of design supplemented by coupon tests confirms design capability (FS ~ 3.0)
• No significant anomalies observed in tanking test data
	• Chemical composition, hardness and tensile measurements consistent with expectations/requirements
	• Fracture shows evidence of tensile and shear overstress and no evidence of fatigue
	• Fractography indicates no evidence of pre-existing crack, voids, inclusions, or surface dents near crack
	• Suspect fracture toughness identified on S6 / S7 and similar material (suspect heat lots identified) and previously flown since ET-131
	• Material thickness at or below low end of the tolerance band
	• Component tests show reduced capability with 'suspect' material
		• Anomalous conditions identified that could be induced at stringer feet during processing / assy at MAF
		  • Undetected damage / cracks at stringer feet
		  • High residual stresses in stringer feet
		• Component stringer pull tests show reduction in capability for thru cracks (~50%)
		• Component stringer pull tests show significant reduction in capability with S6/S7-like material and thru cracks (>50%)
			• Review of barge accel. data and barge off load through roll to pad confirmed nominal processing	• Pad processing anomalous events evaluated (GUCP leak and drain configuration error) were determined to be independent non-contributing events
				• Confirmed no accumulation of water, ice or frozen N2/LN2 in the Intertank crotch during post scrub inspection and no over-pressurization of Intertank (due to vent area blockage)

No anomalous events	***Likely Contributor to Failure Identified - - Investigation Tasks to Be Discussed***	***Likely Contributors to Failure Identified - - Investigation Tasks to be Discussed***	***No anomalous events***	***No anomalous events***

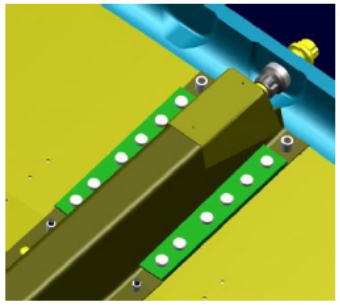
STS-133 / ET-137 Intertank Stringer Cracks

- ***Investigation Summary***
  - Fishbone assessment complete (final documentation in work)
    - High contributors isolated to Raw Material / Vendor Processing and MAF Processing / Assembly
      - Include reduced fracture toughness, reduced thickness, and high residual stress
    - Combination required to cause failure at limit load not yet demonstrated by test
  - Tests and analysis performed to characterize effect of contributors and support working failure scenario
    - Results show each high contributor has a significant effect on part performance
      - Either increases stress (residual stress) or degrades capability (reduced thickness, low toughness)
    - High contributors combined with cryogenically-induced stresses to cause observed stringer cracks
  - Additional scenario tests in-work to continue root cause demonstration
  - Additional material property evaluations in-work to determine cause of low fracture toughness / unstable crack growth behavior
  - Suspect material lots impact ET-137 and ET-138 and in previous flight history since ET-131

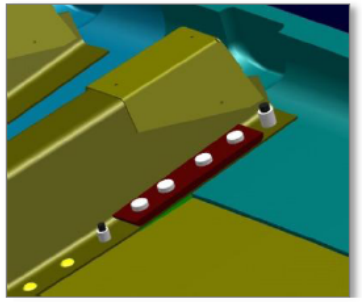
High Contributors to Cause Identified
- - Combination of Material Properties, Reduced Thickness, and Assembly Residual Stresses
- - - Design Mitigation Implemented for Locations Susceptible to High Contributors

STS-133 / ET-137 Intertank Stringer Cracks

- ***Design Enhancement Overview / Objective***
  - Radius block modification increases capability and provides effective mitigation for suspect conditions identified through Fishbone investigation
    - Provides local increase in bending stiffness
      - Similar designs previously flown on ET
    - Implemented at all Al-Li LO_2 stringer end locations less locations with repairs
    - TPS repair within previous flight-demonstrated experience

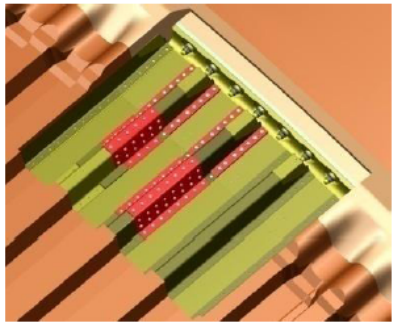


6-Hole Radius Block (long chord, doublers)



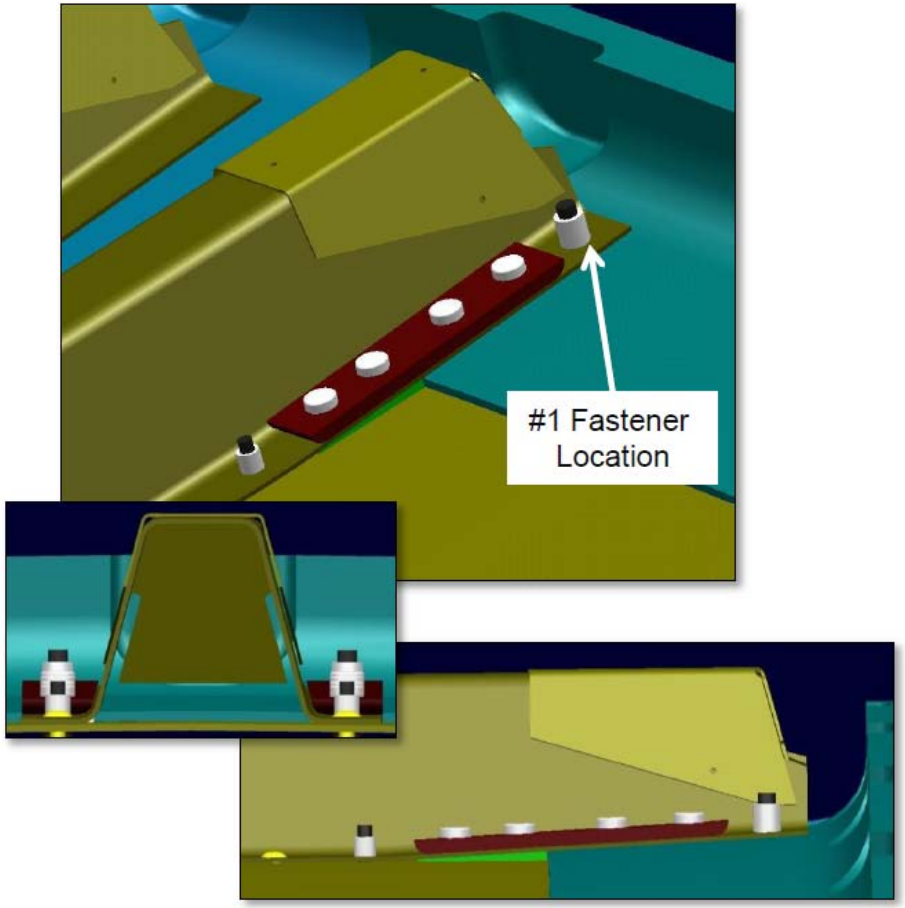
4-Hole Radius Block (short chord, no doublers)

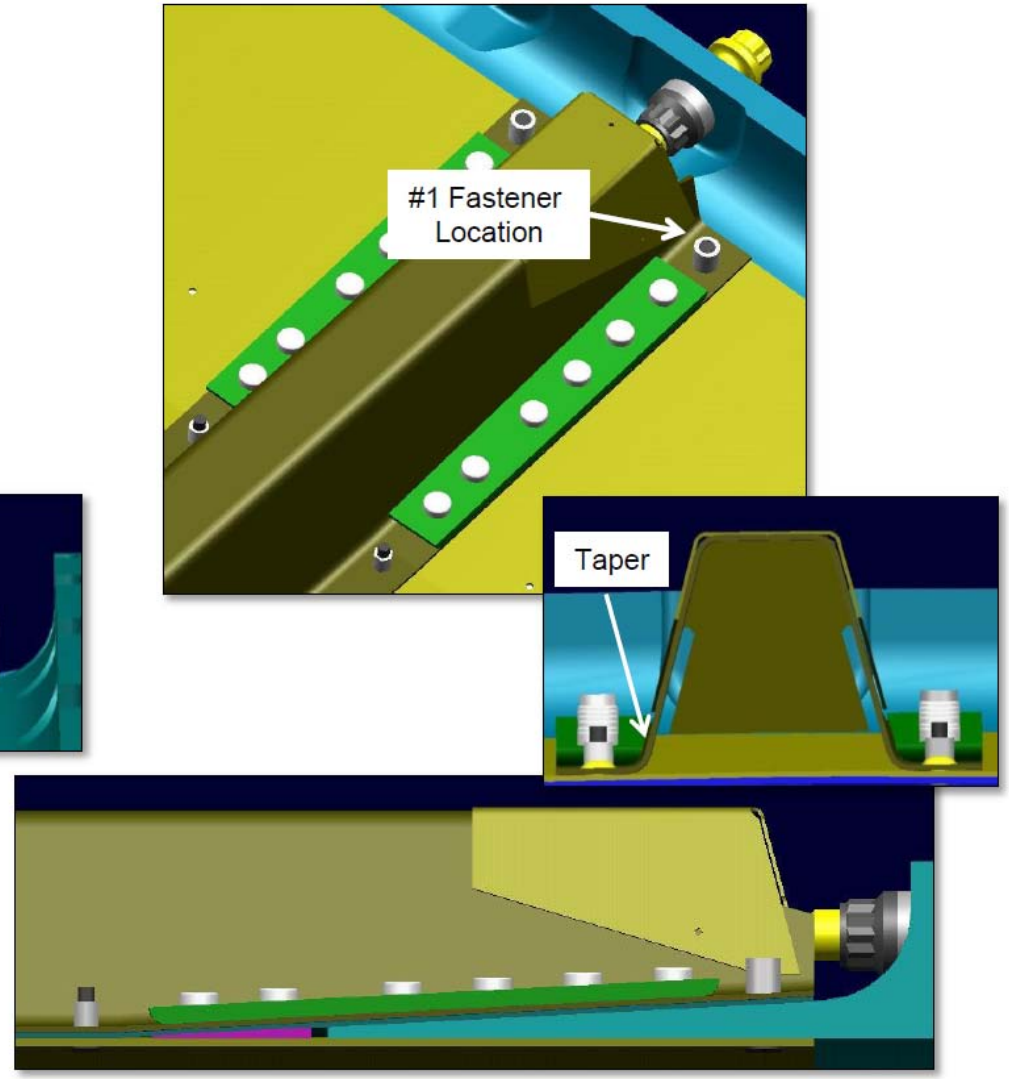
- ***Design Description***
  - Tapered radius block installed at fastener row 2 – 7 location (panels 2, 3, 6, and 7) and 2 - 5 locations (panels 1 and 8)
    - First fastener row not removed to preclude issues with clearance
    - Visual inspection pre- / post-installation
    - Radius block material, Al2024-T81 0.190" STK
    - Repair fasteners similar to design but can be installed 'blind'
      - Similar capability well beyond design requirements
  - TPS material re-applied using demonstrated process and meets all performance requirements
    - Minor OML change required and accepted by Level II
      - No change to ascent environments
      - Revision to ICD in work
  - Repairs resulted in +~51 lbs (includes TPS repair)
    - No change to control weight / No change to CG



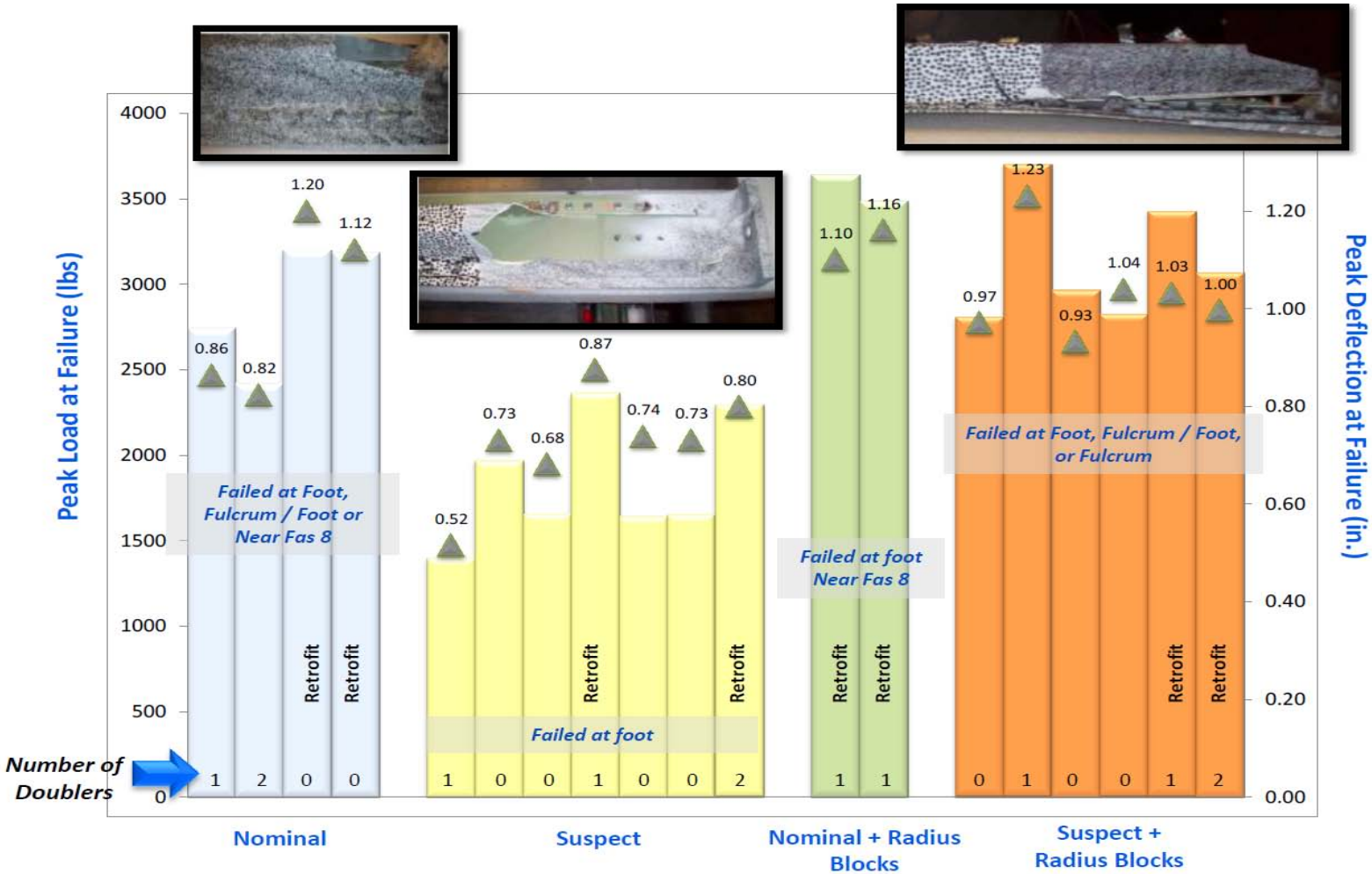
Repairs Implemented at Cracked Stringer Locations on ET-137

STS-133 / ET-137 Intertank Stringer Cracks





STS-133 / ET-137 Intertank Stringer Cracks



Testing to date supports following conclusions
- Suspect material exhibits brittle failure with unstable crack growth similar to ET-137 observations
- - Nominal material failure modes is not brittle nor similar to ET-137 failures
- - - Radius blocks with suspect material improves capability and eliminates ET-137-like failures

STS-133 / ET-137 Intertank Stringer Cracks

- ***ET-137 Rationale for Acceptance Summary***
  - Fishbone tests and analysis identified likely contributors to ET Intertank stringer cracks at LO_2 tank flange
    - Combined effects of suspect low fracture toughness of Al 2090 used on Intertank stringers + residual stresses, defects, and reduced thickness
  - Radius blocks provide adequate mitigation at LO_2 side for high contributors / scenarios identified by Fishbone
    - Engineering tests and analysis show radius blocks increase capability and 'does no harm'
    - Design change is local to structure and does not affect integrated stiffness or loads
    - Similar repairs visually inspected post tanking on ET-137 – No issues identified
  - Successful post tanking NDE results and FEM analysis data show low probability of cracks occurring on LH_2 stringer ends during ascent
    - No cracks observed in NDE of LH_2 and LO_2 flanges with similar configurations / loading
    - Analysis shows stringer ends (1st 3 fasteners) demonstrated to >100% design limit ascent load for stringer bending failure mode
    - Assembly tolerances and resulting residual stress conditions less severe than LO_2 flange
  - Stringer mid-bay sections not susceptible to foot bending failure mode (i.e. no bending, axial tension/compression only)
    - Bounding safe life analysis shows > 400 mission life capability (4 required)
  - Intertank skin/stringer panels 'fail safe' against structural collapse for stringer failure conditions assuming 3 consecutive stringer with cracks similar to observed condition on LO_2 side