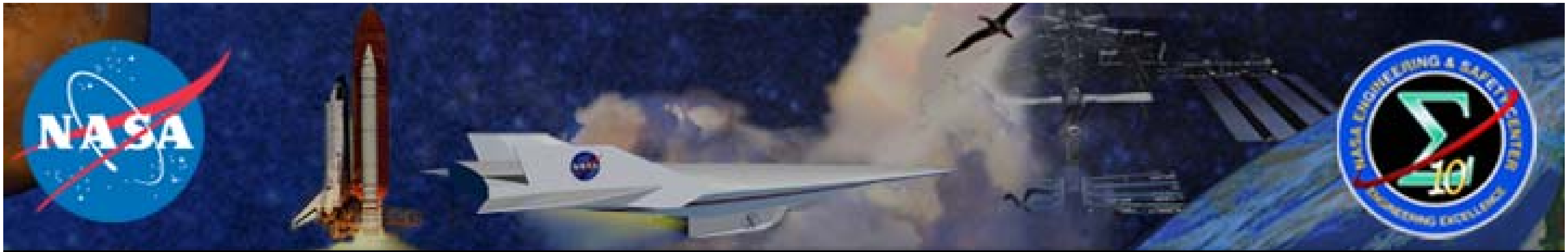


NASA Engineering and Safety Center (NESC) Mechanical Analysis SPRT Contributions to Return to Flight

Julie Kramer White

NESC Mechanical Analysis Lead

Johnson Space Center

FEMCI Workshop Keynote Address

Goddard Space Flight Center

May 2005

Outline

- NASA Engineering and Safety Center (NESC) Overview
  - Purpose
  - Scope
  - Organization
- Mechanical Analysis Super Problem Resolution Team (SPRT)
  - Purpose
  - Scope
  - Organization
- RTF Mechanical Analysis Efforts
  - Independent Technical Assessments
  - Consultations / Peer Review
- Conclusion

NASA Engineering and Safety Center

NESC was formed in direct response to the findings of the Columbia Accident Investigation Board (CAIB)

"The safety organization sits right beside the (shuttle) person making the decision, but behind the safety organization there is nothing there, no people, money, engineering, expertise, analysis."

" … there is no 'there' there"

- Adm. Harold Gehman

NASA Engineering and Safety Center

On July 15, 2003,
Administrator O'Keefe announced plans to create the NASA Engineering and Safety Center at Langley Research Center (LaRC)

Charter of NESC to provide "value added" independent assessment of technical issues within its programs and institutions.

NASA Engineering and Safety Center

NESC Philosophy & Culture:

- Mission Success Starts with ***Safety***
- Safety Starts with ***Engineering Excellence***

NESC fosters this culture by providing

- Knowledgeable, technical senior leadership
- Open environment
- Emphasis on tenacity and rigor

NASA Engineering and Safety Center

NESC is administered from LaRC, however, it is a decentralized organization which utilizes ***tiger team*** approach to problem solving

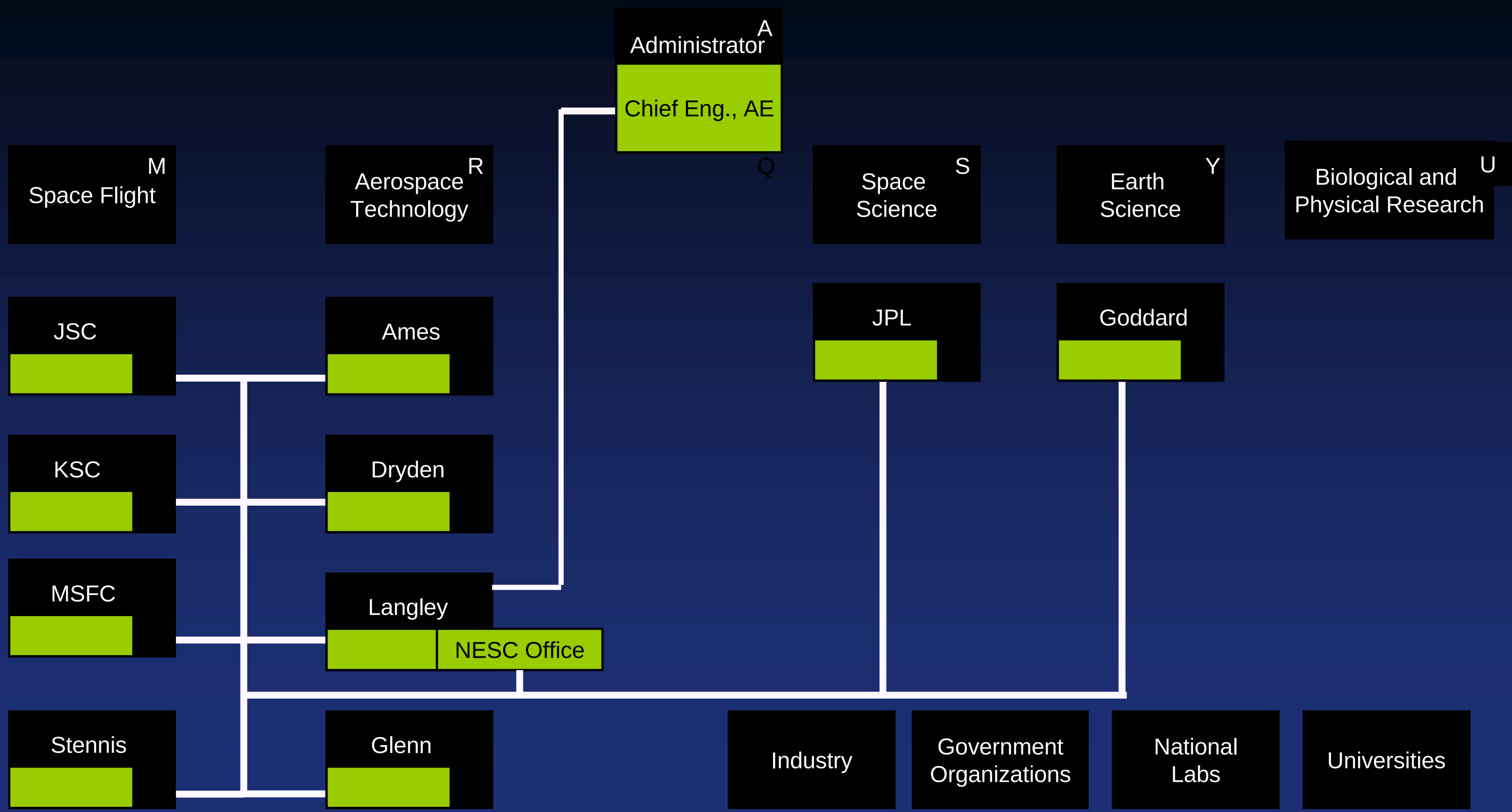
Representatives from all centers play key roles in the day to day management and technical assessment work of the NESC

- Insight at center and program level into potential issues
- Engineers need to be where the problems are to stay relevant

Model of One NASA

NASA Engineering and Safety Center

“One NASA” NESC Organization



NESC Organization

Office of the Director

Director, NESC
Deputy Director
Deputy Director for Safety
S&MA Integration
Chief Astronaut
Chief Scientist
Technical Asst. (2)
Secretary

LaRC

Business Management & Support Office

Business Manager (COTR)
Human Resources Support
Procurement Support
Academic Liaison
DOD/National Lab Liaison
Configuration Control
Knowledge Capture
Training
Technical Writing
Outreach
Administrative Support
Secretary

LaRC

Systems Engineering Office

Systems Engineering Manager
Engineers (TBD)
Secretary

LaRC

Principal Engineers Office

Principal Engineers (3-4)
Back-up P.E. (3-4)
Secretary

LaRC

NESC Chief Engineers Office

ARC	JSC
DFRC	KSC
GRC	LaRC
GSFC	MSFC
JPL	SSC

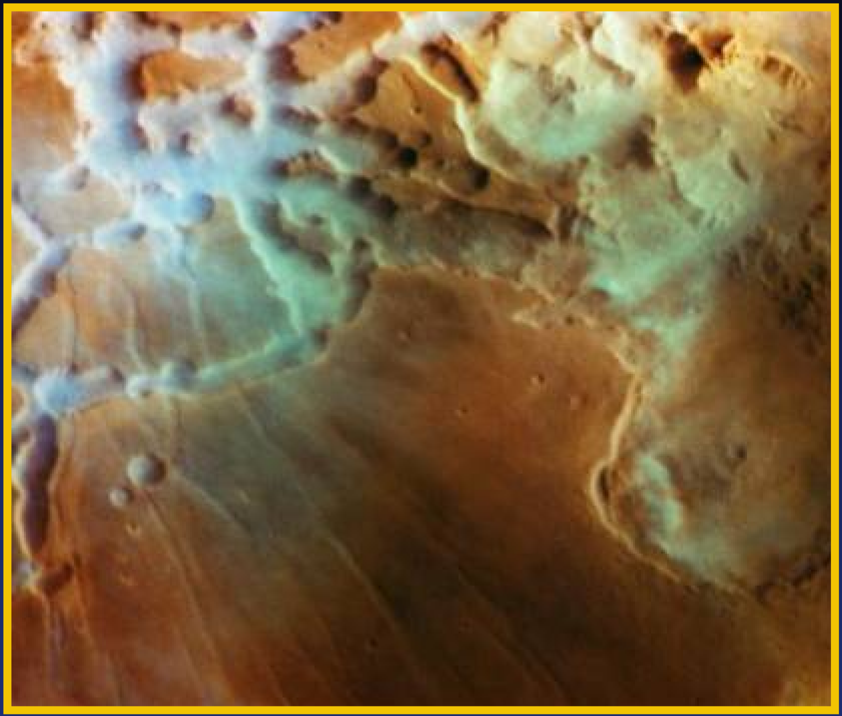
NASA Centers

Discipline Chief Engineers Office

Materials
Structures
Power & Avionics
Flight Sciences
Software
GNC
NDE
Propulsion
Human Factors
Mechanical Systems
Mechanical Analysis
Fluids/Life Support/Thermal

NASA Centers

NASA Engineering and Safety Center



Scope of NESC activities

- Independent in-depth technical assessments
- Independent trend analysis
- Independent systems engineering analysis
- Mishap Investigations
- Technical support to Programs
- Focus on High Risk Programs

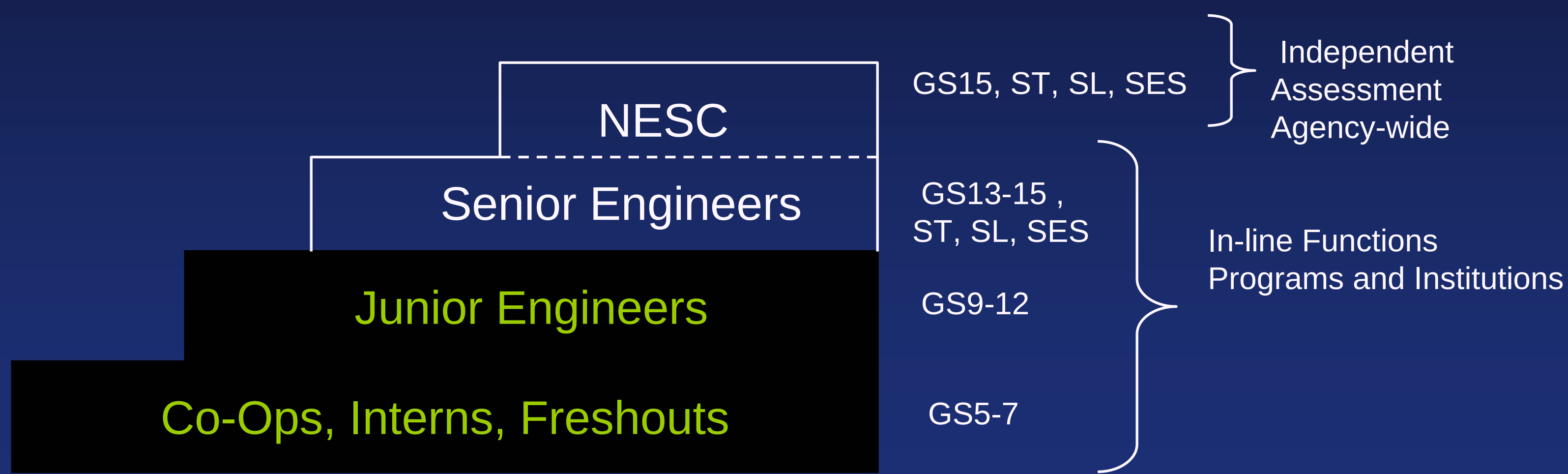
Super Problem Resolution Teams

- Super Problem Resolution Teams (SPRTs) are the backbone of the NESC
  - They have membership from multiple sources:
    - NASA
    - Industry
    - Academia
    - Other Government Agencies
  - They provide technical support of NESC activities with independent test, analysis and evaluation – *not just technical opinions*
- Overcome negative connotation of "independent assessment" by offering our best technical personnel
  - Select recognized agency discipline experts to lead SPRTs
  - Utilize expertise at each center

Super Problem Resolution Teams

NESC goal is to establish an extension to the natural hierarchy of engineering progression

- **A true "technical ladder"**
- **If successful, engineers will aspire to be in the NESC**
- **Challenging work, visibility, *pay and promotion***

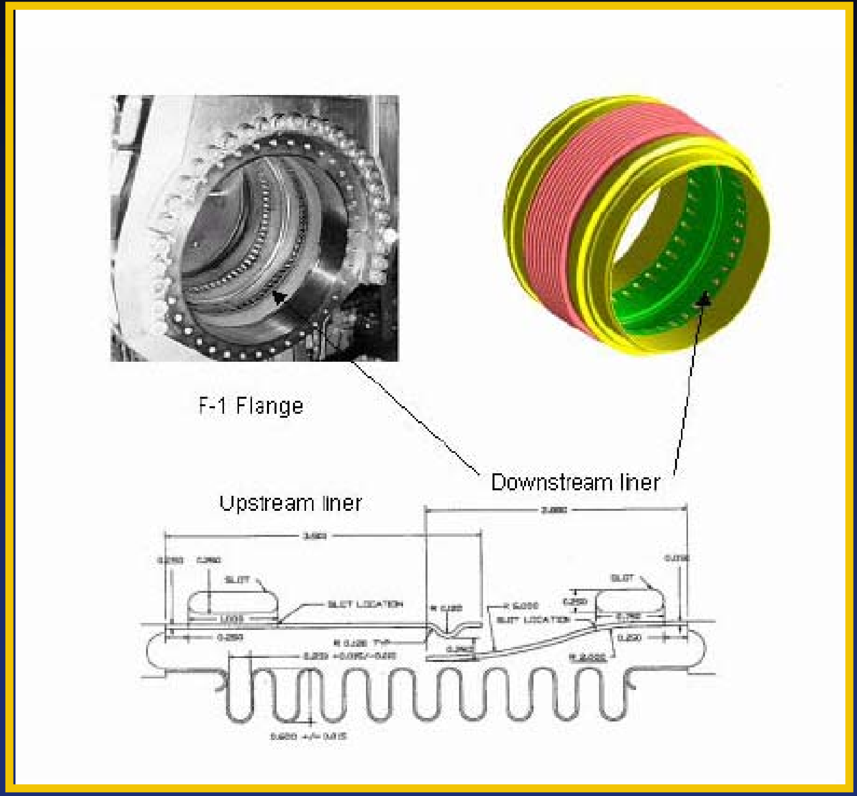


Mechanical Analysis SPRT

Strength Analysis
- Linear and non-linear structural behavior
- Stress intensity factor
- Margin of safety

Dynamic Analysis and Loads
- Vibroaccoustics
- Modal & frequency analysis
- Coupled loads

Structural Testing
- Model Correlation
- Failure modes



Mechanical Analysis SPRT

Core Mechanical Analysis SPRT represents 9 centers:

- ARC: Ken Hamm
- DFRC: Kajal Gupta
- GRC: George Stefko & Mei-Hwa Liao
- GSFC: Jim Loughlin & Dan Kaufman (deputy)
- JPL: Frank Tillman & Paul Rapacz
- JSC: Joe Rogers & Julie Kramer White (lead)
- LaRC: Scott Hill
- MSFC: Greg Frady
- SSC: David Coote

Mechanical Analysis SPRT

Core represents a broad spectrum of analysis experience

- Identification of appropriate skills and resources for analytical tasks
- Cognizant of structural analysis related task to ensure proper analysis expertise support (including peer review)
- Proactively engage structural analysis related issues throughout the agency

- Supplemented by additional resources from:
  - Center institutional engineering
  - Industry (Aerospace Corporation, ATA, Sverdrup-Jacobs, Swales)
  - Academia (Naval Post Graduate School, Georgia Tech)

Assessments vs. Consultations

Assessments and Inspections: a ***request to independently conduct an assessment or inspection*** of a problem received from an individual, Programs/Projects, Centers, or an NESC member. Conduct an end-to-end technical assessment or inspection of the problem. The assessment or inspection may only require an independent peer review or may require ***independent tests and analyses***. The product of the assessment or inspection will be a ***comprehensive engineering report*** which will include findings, recommendations, and lessons learned.

Consultations: a ***request to participate*** in a problem resolution received from an individual, Programs/Projects, Centers, or an NESC member. A consultation usually will not include extensive independent tests or analyses.

Program/Project Insight: ***routine interactions*** with Programs/Projects and Centers. Render advice and engineering judgment, issue technical position papers to address technical issues, and participate in boards and panels.

Mechanical Analysis SPRT Tasks

Independent Technical Assessments:

- Orbiter Main Propulsion System Feedline Flowliner cracks
- Orbiter Wing Leading Edge Metallic Hardware Integrity
- Orbiter Tile and RCC Impact Damage Assessment Tools
- Space Shuttle Return to Flight Rationale
- Shuttle Solid Rocket Booster Stud Hangup
- SOFIA Acoustic Resonance

Consultations/Peer Review:

- Shuttle External Tank Bellows Ice Liberation Testing
- Shuttle T-O umbilical margin dissenting opinion
- Shuttle Main Engine High Pressure Oxygen Turbo Pump (HPOTP) blade seal cracking

Mechanical Analysis SPRT RTF

Independent Technical Assessments:

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Orbiter Main Propulsion System Feedline Flowliner Cracks

Issue

- In May of 2002, three cracks were found in the downstream flowliner at the gimbal joint in the LH2 feedline of Space Shuttle Main Engine (SSME) #1 of orbiter OV-104 (Atlantis)
- Subsequently, all orbiters were found to have LH2 feedline flowliner cracks

Space Shuttle program had previously produced a flight rationale for STS-107; however, post 107 many fight rationale were carefully reevaluated, including flow liner

Due to the potentially catastrophic consequence of a flow liner failure and the complex nature of the problem, the Space Shuttle Program manager, asked the NESC to engage in an Independent technical assessment of this issue

Orbiter Main Propulsion System Feedline Flowliner Cracks

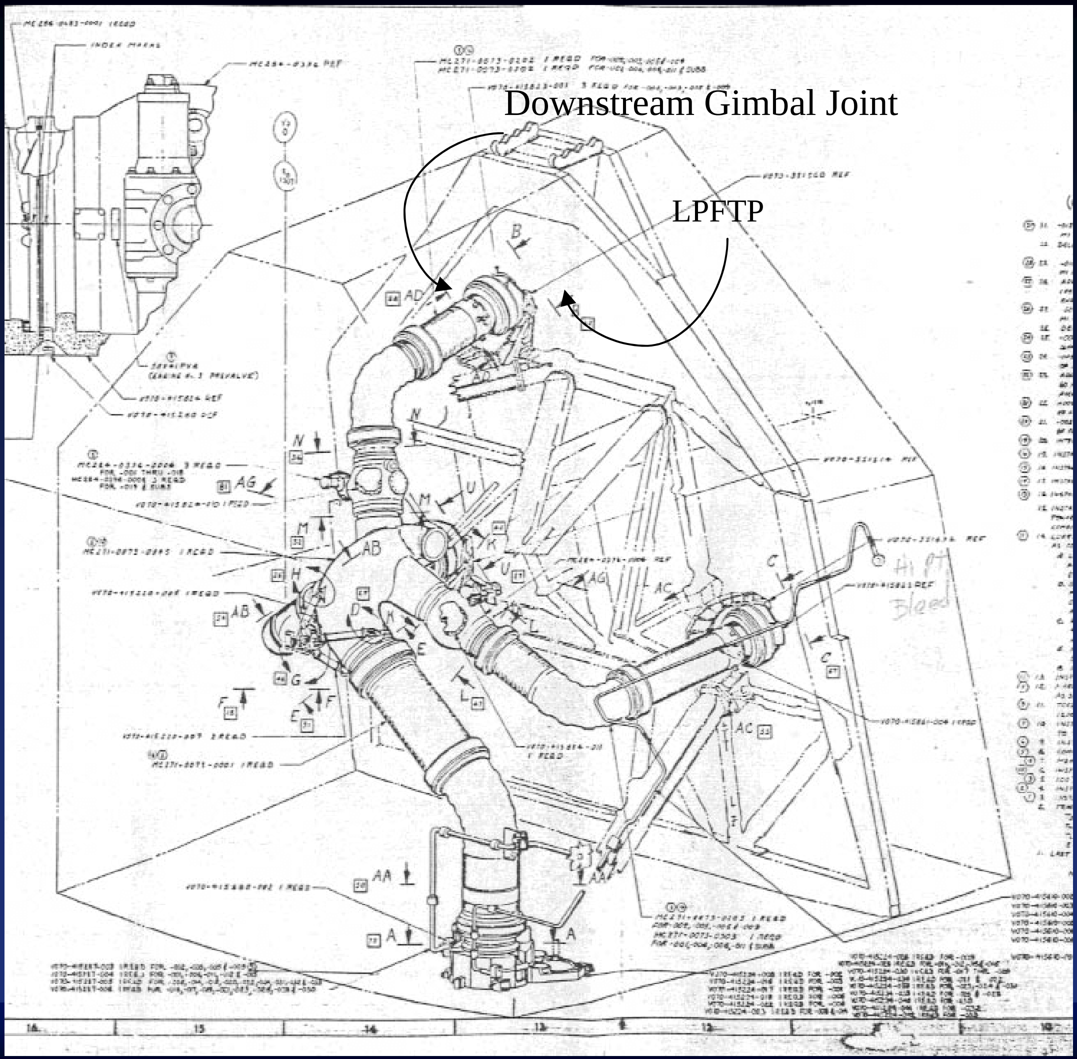
Scope of Assessment

- Identify the primary contributors to the cracking in the flowliner
- Implement a strategy to resolve the problem and/or mitigate risks to acceptable flight levels

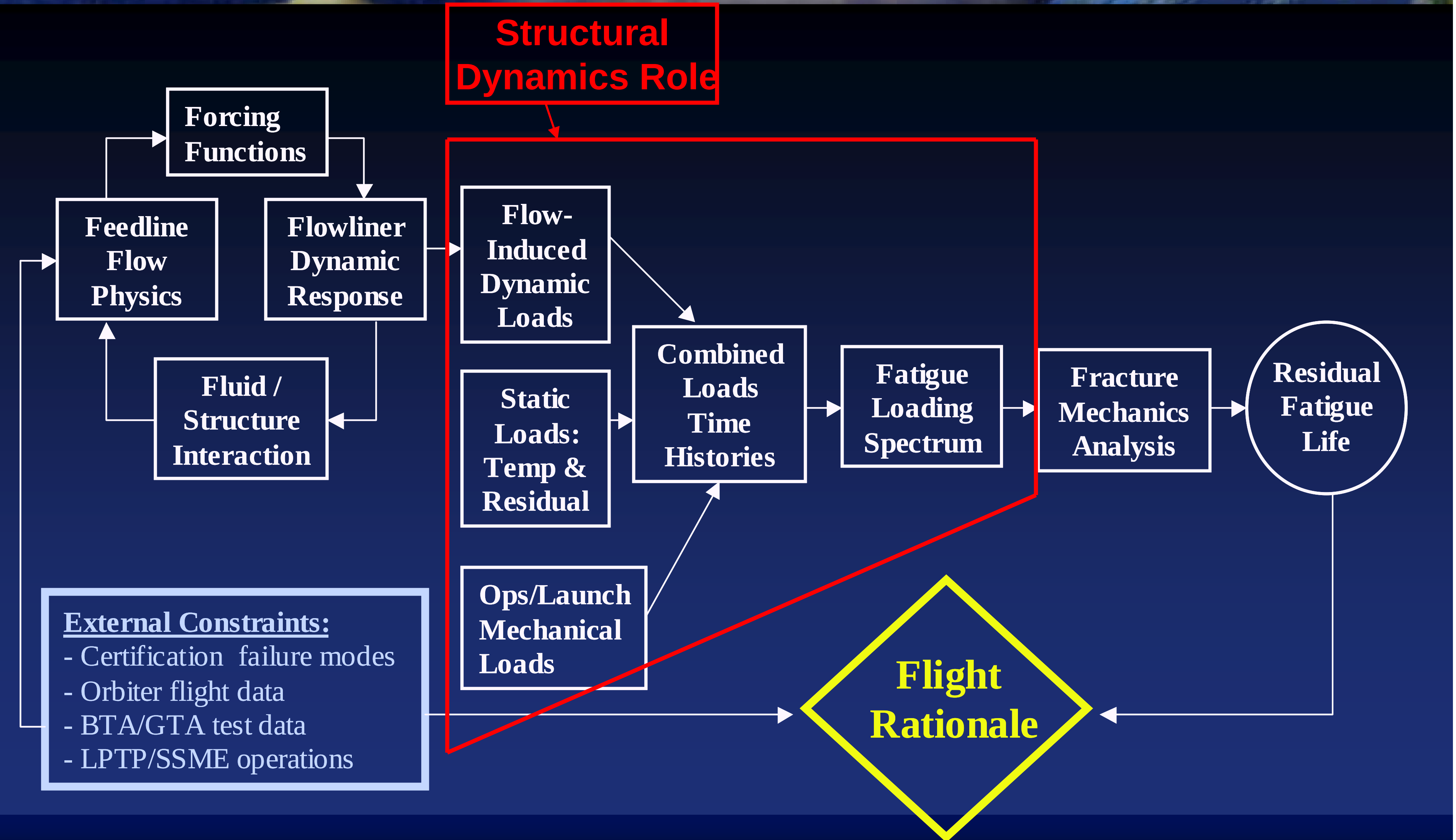
Orbiter Main Propulsion System Feedline Flowliner Cracks

Challenges:

- Characterizing dynamic environment with limited means of verification
  - Not readily accessible for R&R or instrumentation
  - Qualification and test facilities dismantled
  - Highly dynamic, cavitating, cryogenic flow environment



Orbiter Main Propulsion System Feedline Flowliner Cracks

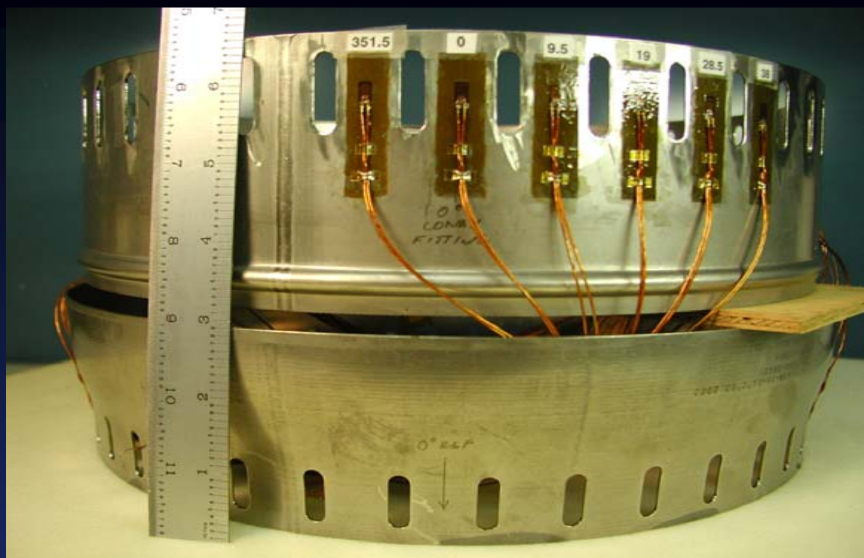


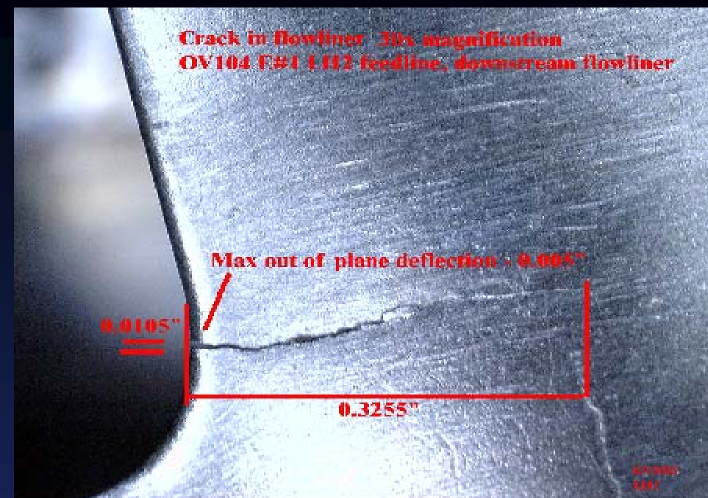
Orbiter Main Propulsion System Feedline Flowliner Cracks

Structural Dynamics Tasks

- Assess loads and environments on flowliner
- Analyze hot fire tests data (flow induced environments)
- Modal response identification of Shuttle flowliners
- Assess strain transfer factors (test measured locations at mid ligament to crack initiation / field stress)
- Identify relevant modes for each flight condition (single mode approach / multimode very complex and perhaps impractical)
- Develop loading spectra for fracture analysis
- Fill gaps in previous program approach and rationale

Orbiter Main Propulsion System Feedline Flowliner Cracks



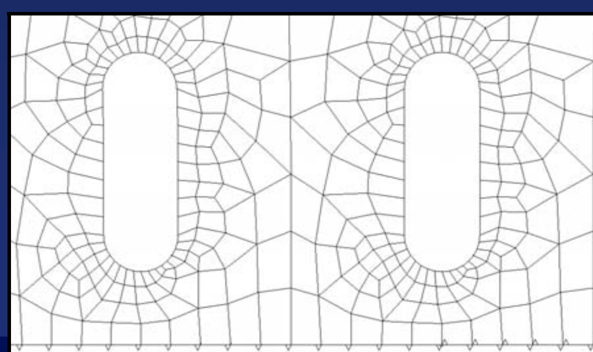


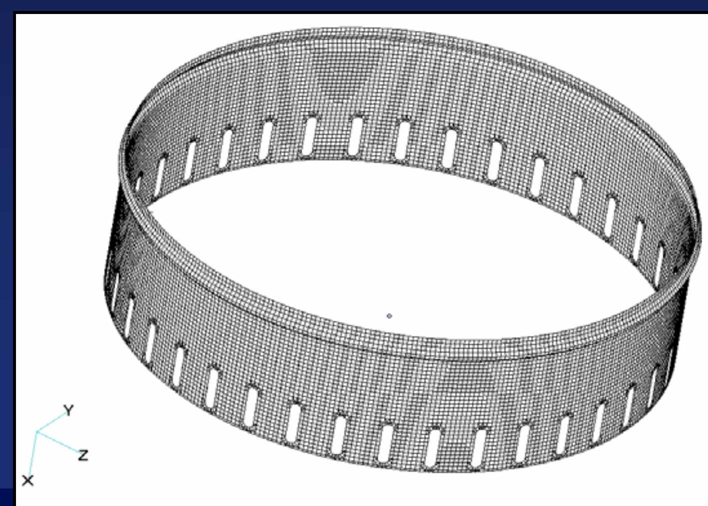
Material:

Inconel 718

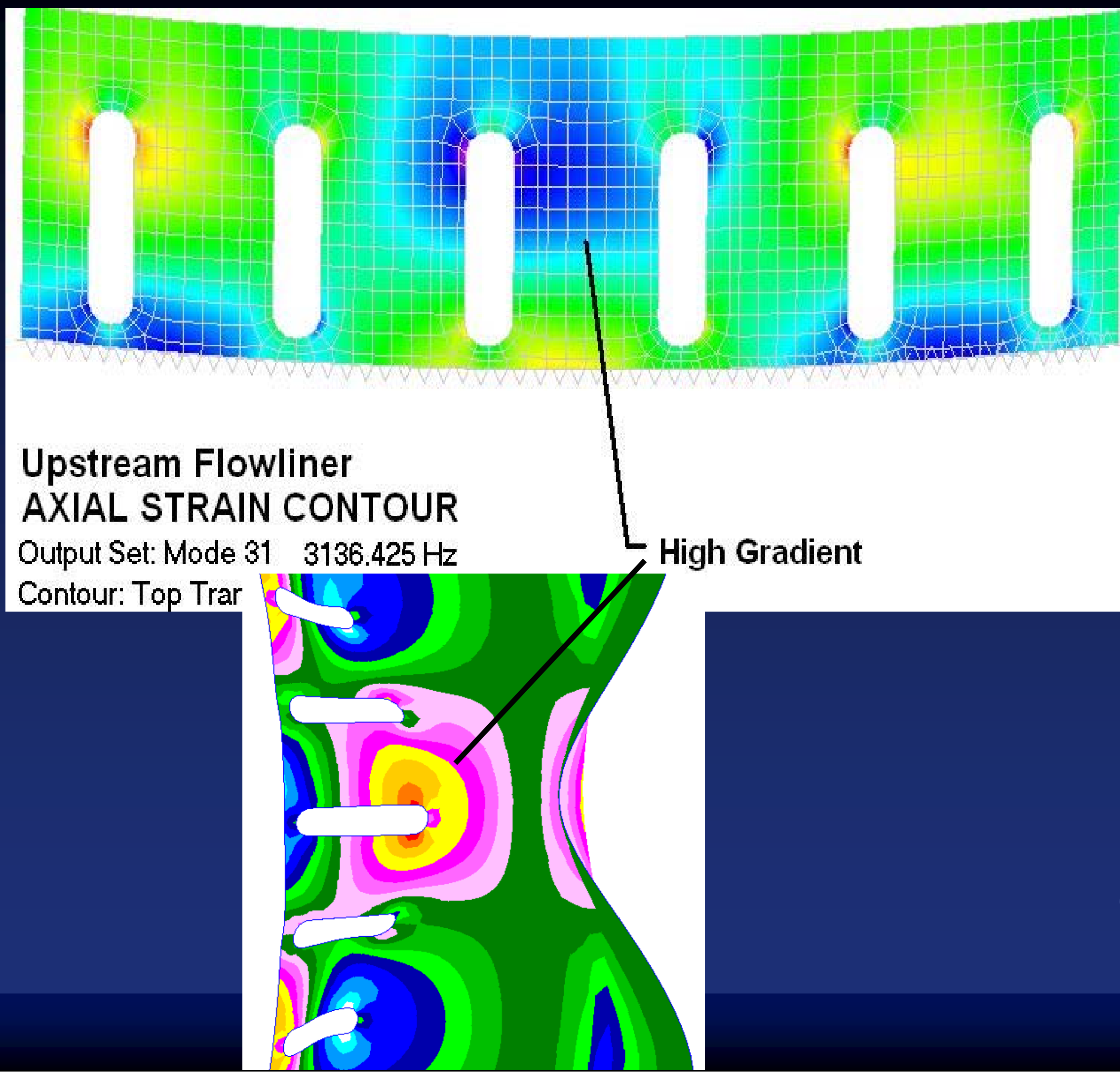
Thickness:

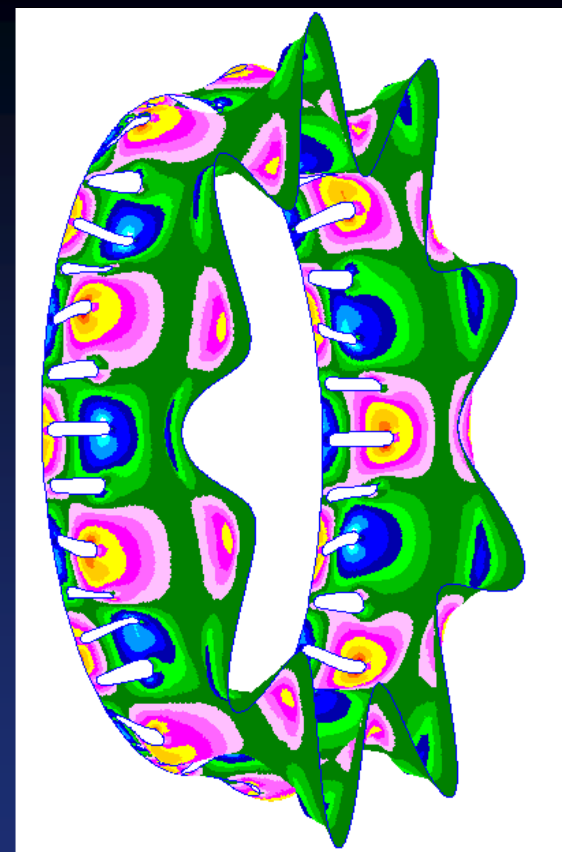
0.050 in





Orbiter Main Propulsion System Feedline Flowliner Cracks





Complex Mode Shapes
1000 to 4000 Hz

Orbiter Main Propulsion System Feedline Flowliner Cracks

Results:

Validation of issue & program rationale through independent:

- Test of flowliner dynamic response
- Dynamic analysis and development of load spectra
- Fracture analysis and computation of expected service life

Mitigation of risk through the development of alternate NDE techniques which significantly reduce initial flaw size in hardware and in analysis of service life

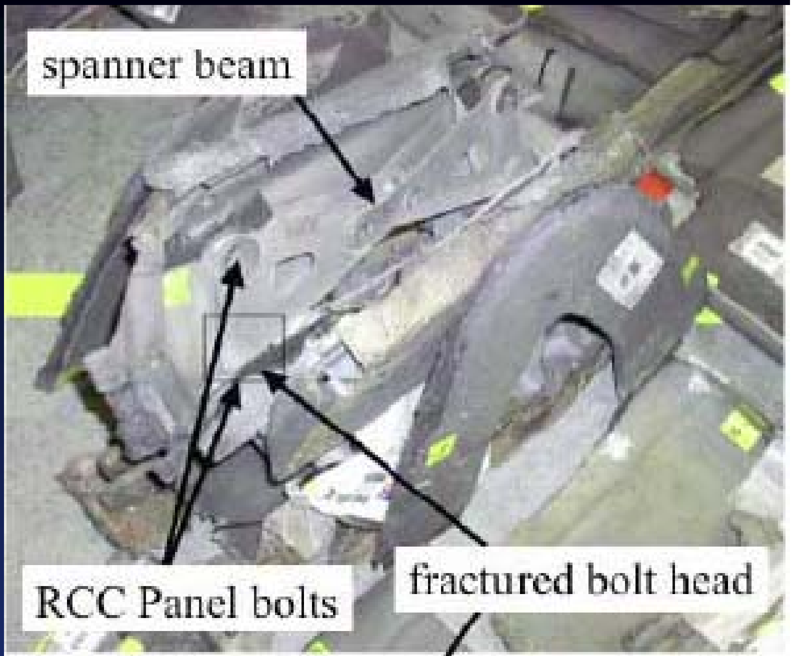
Significant decrease in defect size, reduces likelihood of crack re-initiation in future

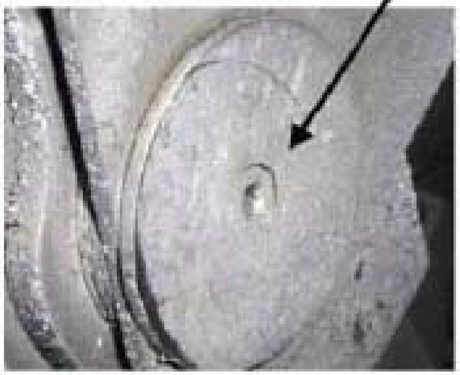
Orbiter Wing Leading Edge Metallic Hardware Integrity

Issue

- A member of the CAIB expressed concern to NESC about the hardware that attaches the carbon leading edge panels to the wing

- Unusual failure features in the *Columbia* debris highlighted potential susceptibility to and degradation from:
  - oxygen embrittlement
  - corrosive environment
  - high temperature exposure during entry
  - stresses induced by installation





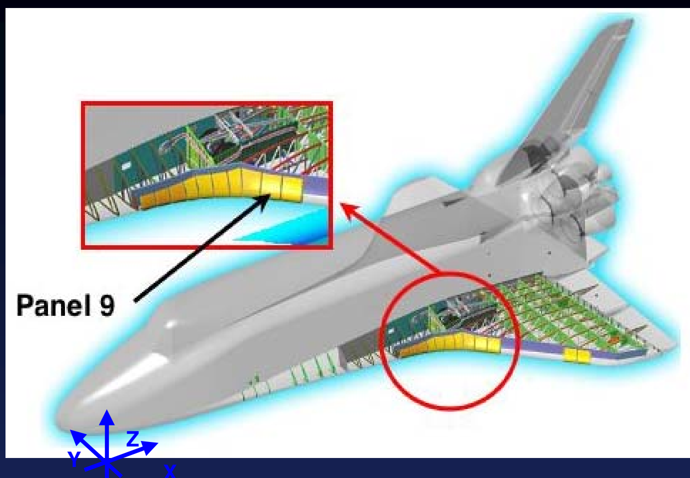
Debris from Panel 16 of the right WLE

Orbiter Wing Leading Edge Metallic Hardware Integrity

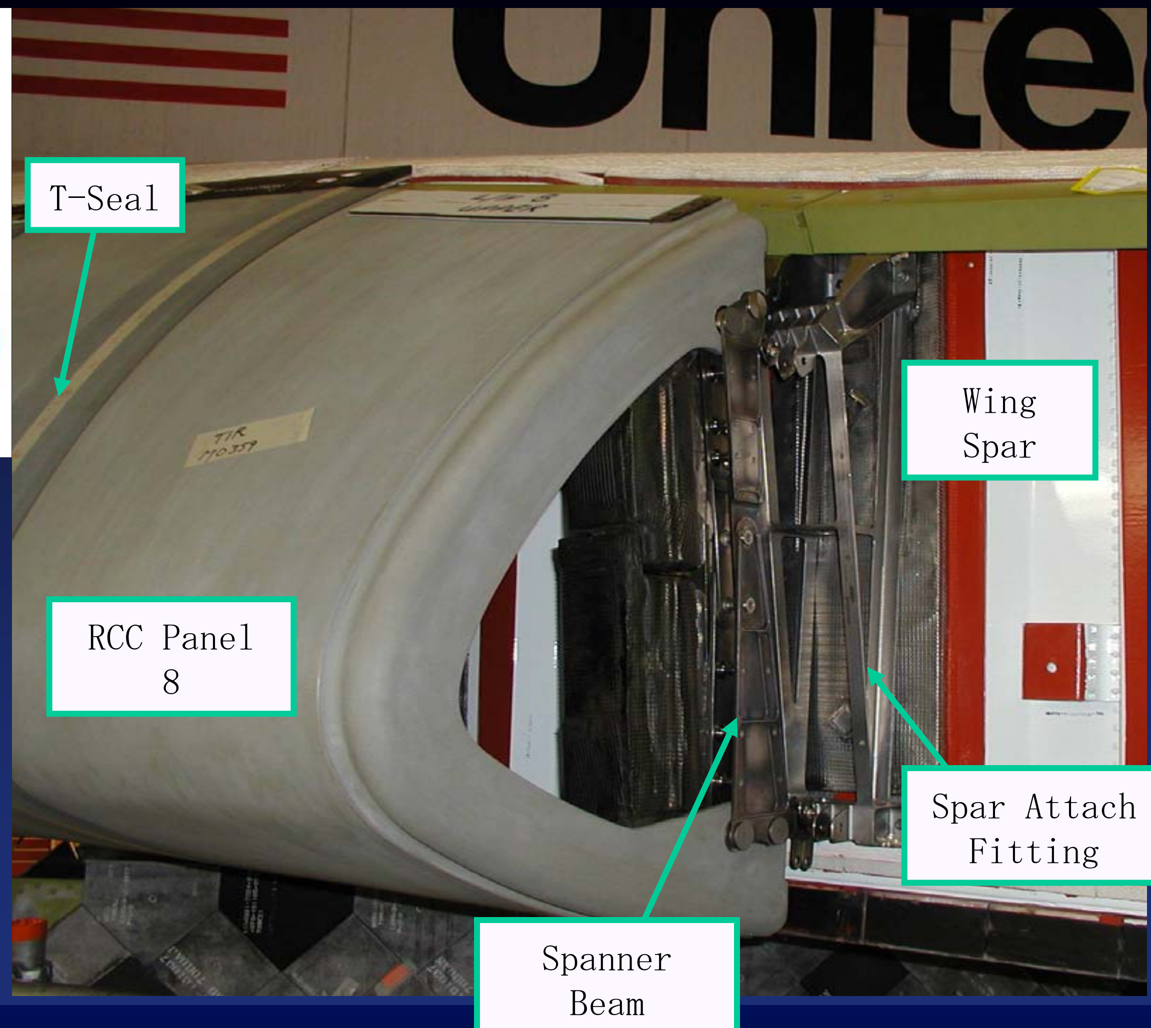
Scope

- Assess the potential for aging-related degradation mechanisms to reduce the Design Allowables of the metallic components or result in failure mechanisms not originally accounted for in the orbiter certification
- Assess the structural integrity of the Wing Leading Edge (WLE) spar and RCC panel attach hardware for debris impacts that may occur during ascent

Orbiter Wing Leading Edge Metallic Hardware Integrity



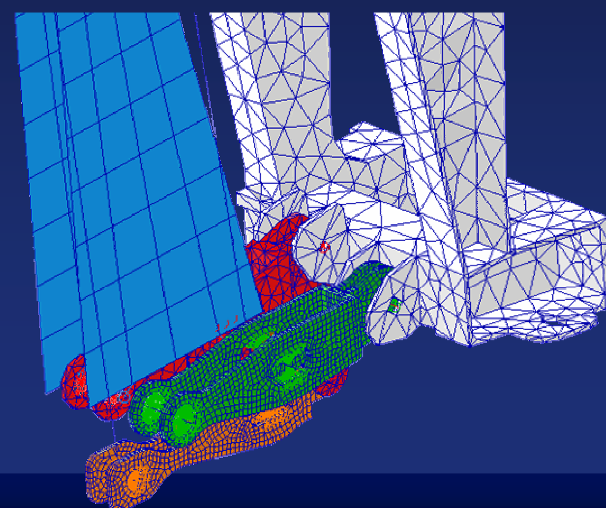
"Attach hardware" represents the metallic parts that connect the RCC panels to the wing spar



Orbiter Wing Leading Edge Metallic Hardware Integrity

Challenges:

- **Producing a relevant assessment of capability without running full certification rigor analysis**
  - **Wing leading edge design loads are determined by hundreds of load cases run through many global and local models**
  - **Detailed FEMs of attach hardware not available in many cases**



Orbiter Wing Leading Edge Metallic Hardware Integrity

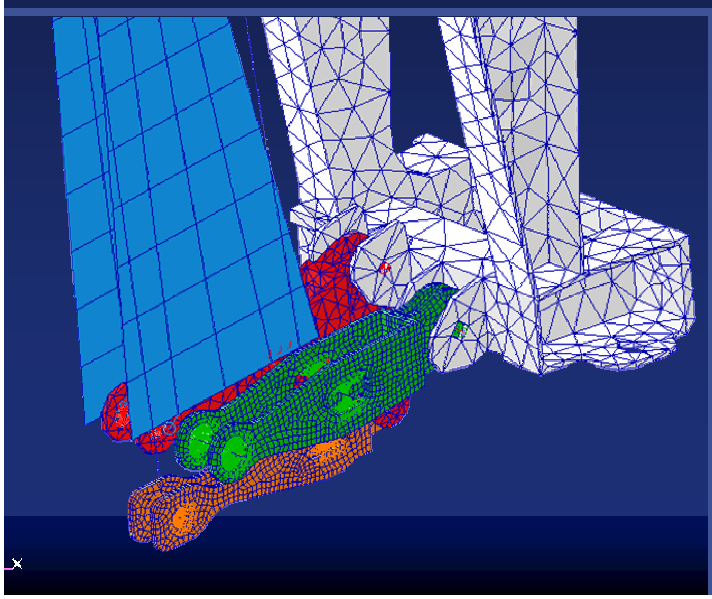
Analysis Approach

- Analysis of critical panels for impact and heating effects (9 and 10 with associated T-seal)
- Transient analysis with impact loads
  - LS/Dyna analysis used to obtain loads at lug points
  - impact analysis with foam impacting at apex on T-seal
- Buckling analysis with loads at impact loading points
  - Lugs on clevises
  - Spar attach fitting on wing spar
- Maximum stress from impact loads used to determine margin
- Superimposed on margin from nominal cases with no factor of safety
  - Loads could not be obtained from orbiter
  - margins were used to superimpose impact event

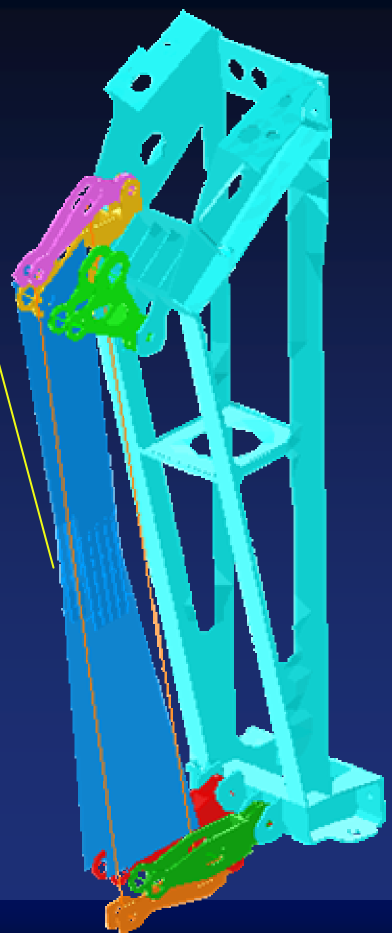
Orbiter Wing Leading Edge Metallic Hardware Integrity

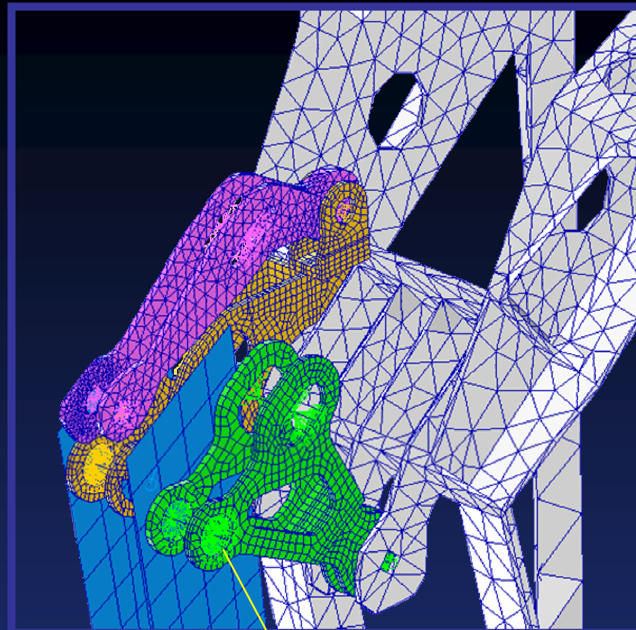
- Model Generation
  - CATIA solid models of panel 9 hardware generated by Boeing
  - Translated into Pro/Engineer and defeatured as much as possible (non-parametric geometry required creating cuts and protrusions to remove fillets, holes, etc.)
  - Generated FEMs from this geometry
- Model consists of clevises, spanner beams, spar attach fitting
- Element types
  - Solid for clevises, spar attach fitting
  - Shell for spanner beams with spring elements
  - Beams/MPCs for pins

Orbiter Wing Leading Edge Metallic Hardware Integrity



Springs connect spanner beams and prevent in plane motion

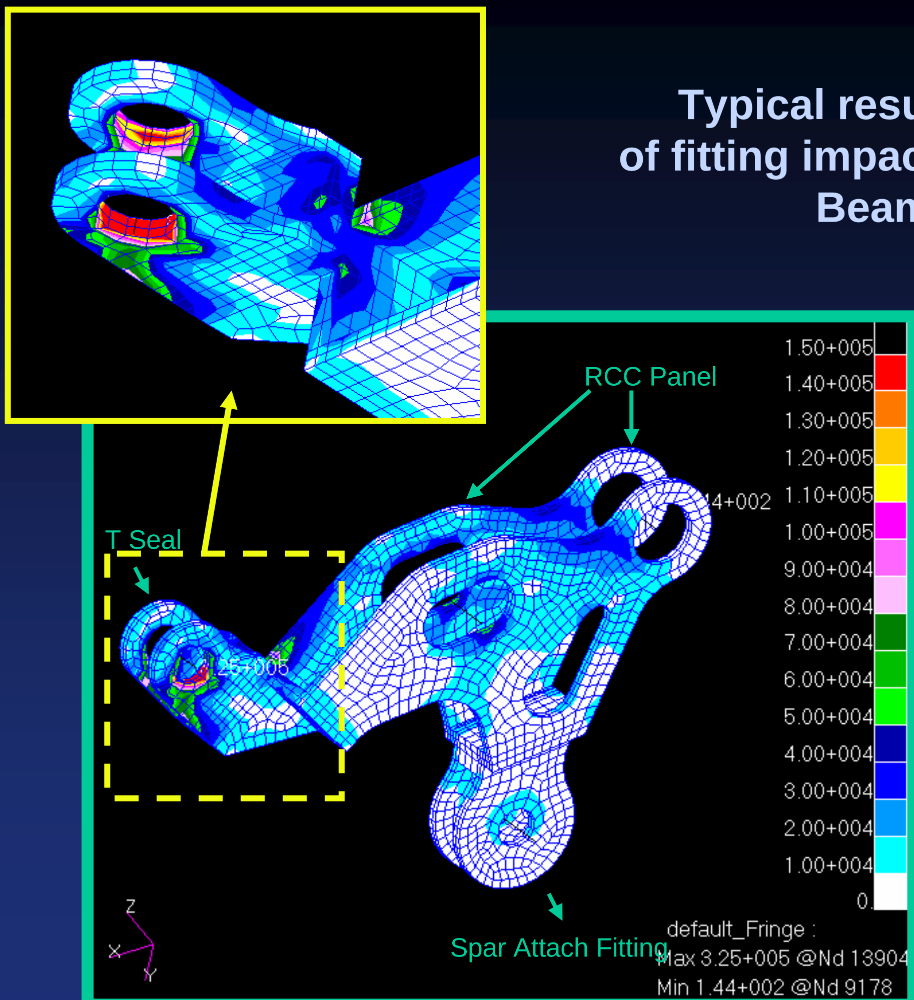


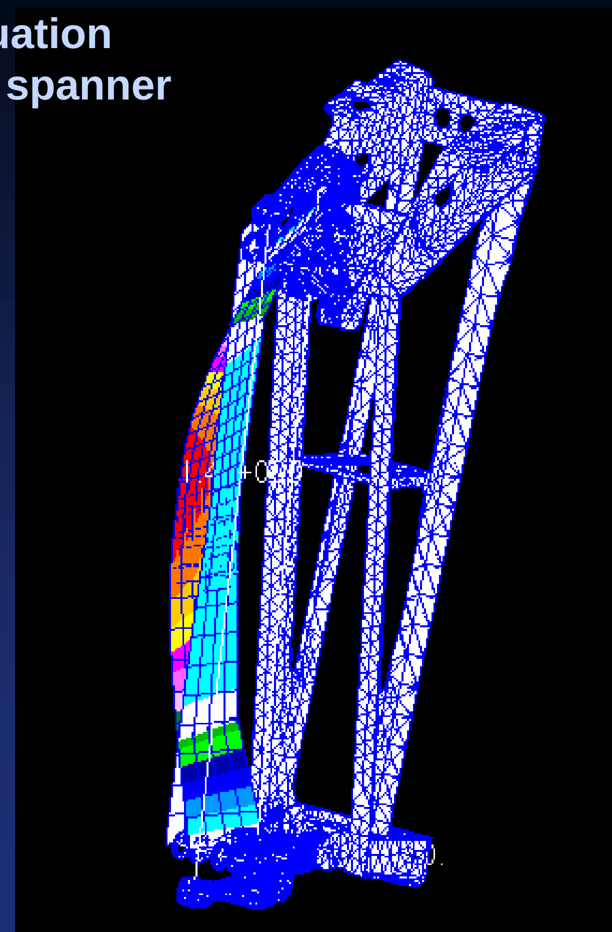


Pins modeled with beam elements and MPCs

Orbiter Wing Leading Edge Metallic Hardware Integrity

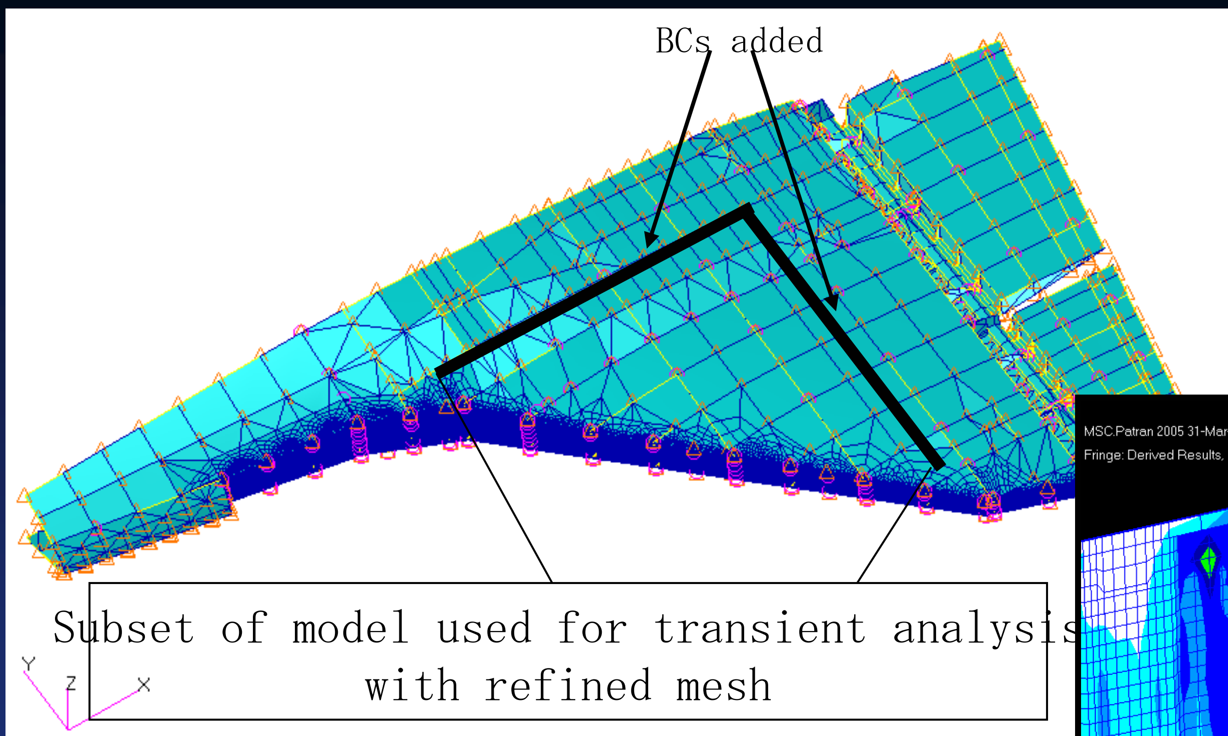
Typical results for evaluation of fitting impact loads and spanner Beam buckling



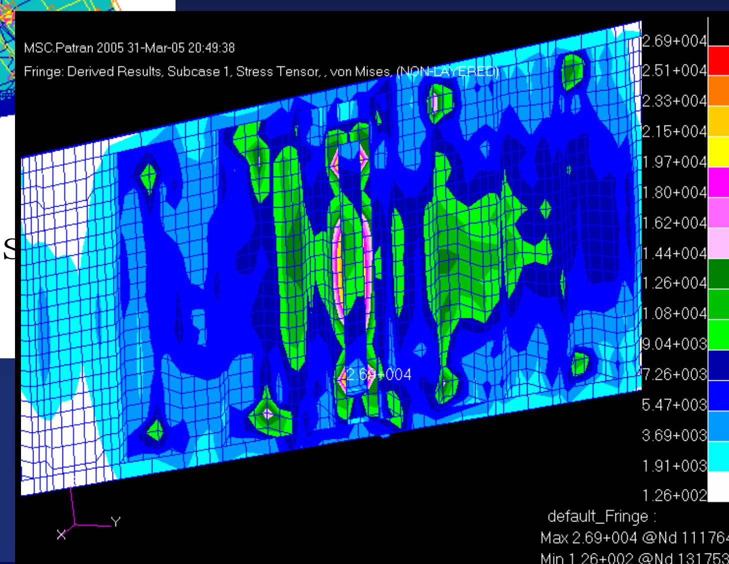


Orbiter Wing Leading Edge Metallic Hardware Integrity

Updated Spar Left Wing Model



Typical results for evaluation
Spar buckling



- Correct spar fitting attach locations
- Corrugated spar panel updates
- Improved local definition
- Validate with spar panel tap test

Orbiter Wing Leading Edge Metallic Hardware Integrity

Preliminary Results – CURRENTLY IN PEER REVIEW

- No evidence of material degradation or applicable degradation mechanisms were found
- The margins of safety on ascent for all attach hardware components and the wing leading edge spar are adequate to accommodate the increases in stress due to a foam impact on T-seal #9 (rib splice #10) of 1500 ft-lbs.
- The spanner beams and spar web are not predicted to buckle due to a foam impact on T-seal #9 (rib splice #10) of 1500 ft-lbs.

Orbiter Tile and RCC Impact Damage Assessment Tools

Issue

- Since STS-107, the Shuttle Orbiter project has invested significant resources in the development of a suite of analytical tools to characterize damage due to debris impact and the resulting capability of the Thermal Protection System and primary structure to reenter with this damage

- The NESC has been tasked with providing independent peer review of these tools, and is reporting out results to Stafford-Covey as a part of their RTF review

Orbiter Tile and RCC Impact Damage Assessment Tools

Scope

- The objectives of this review are to ensure sound methodologies have been applied in development of tools, limitations and assumptions have been properly identified and validated, and model performance has been sufficiently validated

- There are 4 major tools assigned to mechanical analysis for review:
  - Rapid Response Foam on tile damage tool
  - Rapid Response Ice on tile damage tool
  - Bondline and tile stress tool
  - Structural stress assessment tool

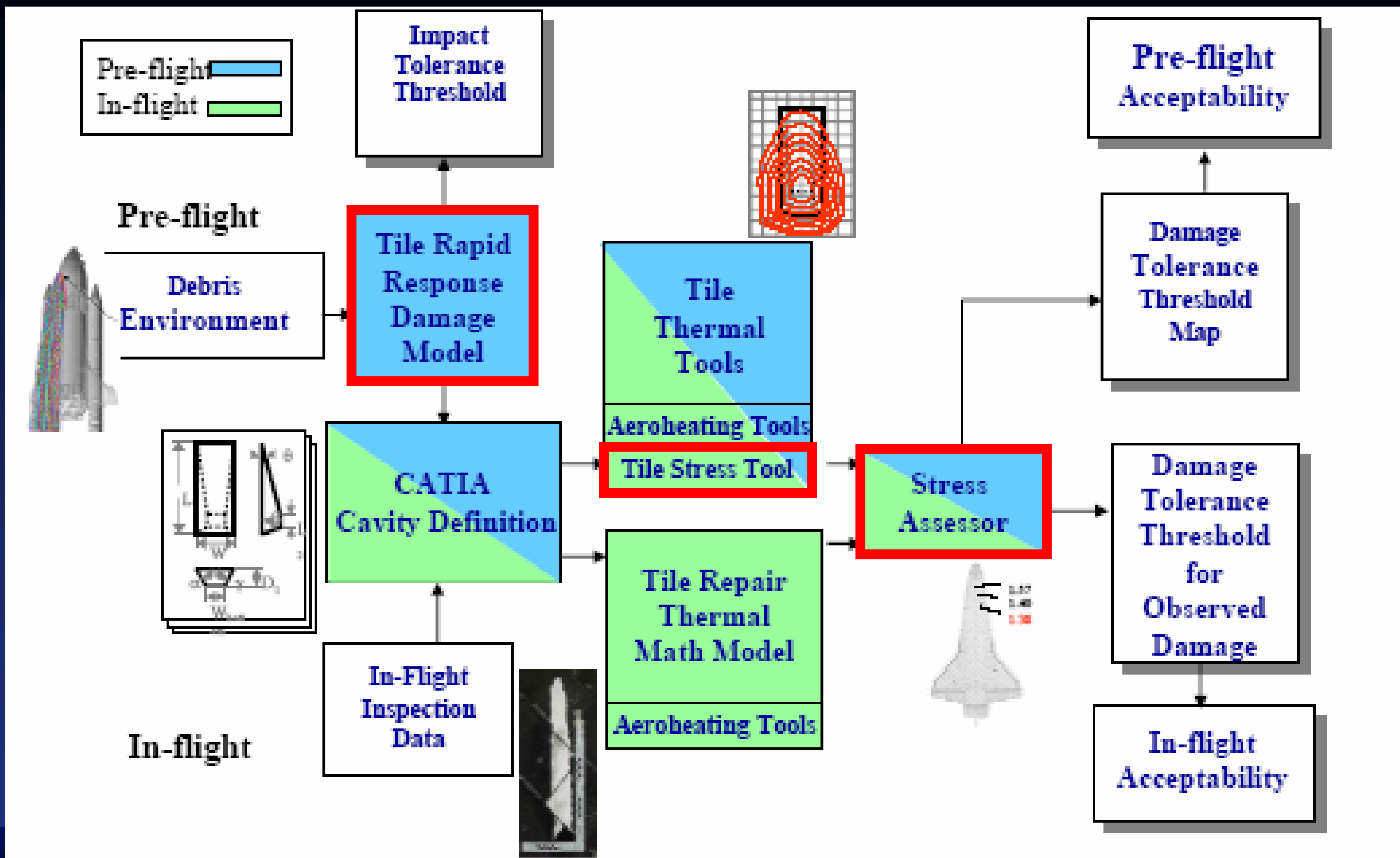
Orbiter Tile and RCC Impact Damage Assessment Tools

Challenge:

Provide a value added review of sophisticated analytical capability in a short time frame

- This suite of tools is intended to predict this…
- Then rapidly (10 sites in 24 hours) determine whether thermal and structural margin remains to reenter the orbiter in this configuration

Orbiter Tile and RCC Impact Damage Assessment Tools



Orbiter Tile and RCC Impact Damage Assessment Tools

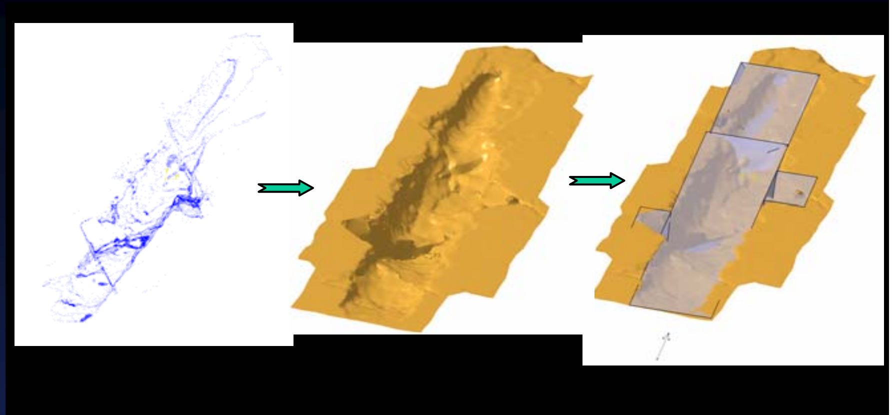
Process – Near Term

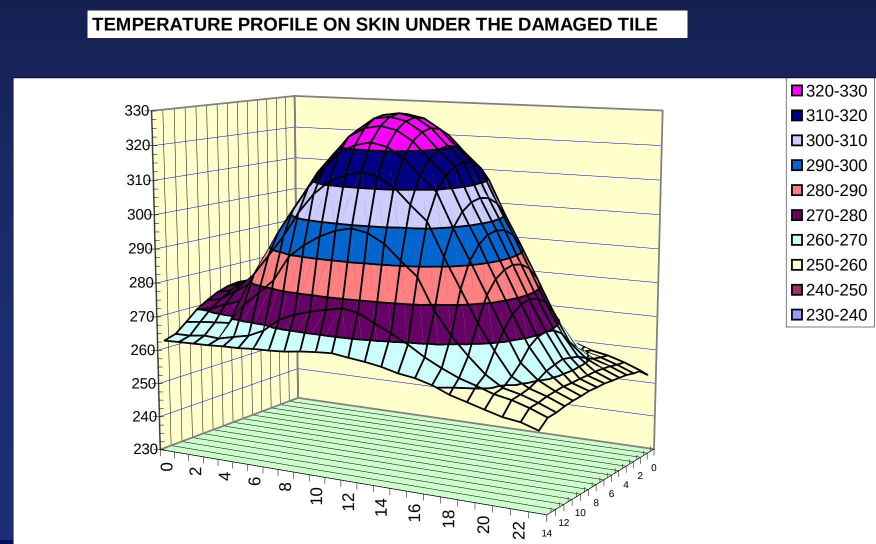
- Evaluation of tool datapacks which contain information on tool development and verification
- Participation in table top review and Q&A with model developers
- Provide official observer for mission simulation of on-orbit damage analysis
- Provide feedback on legitimacy of model limitations, identify model shortcomings, potential improvements and recommendations for additional validation testing to improve analytical results
- Ultimately, concur or non-concur on readiness of tools to support STS-114

Orbiter Tile and RCC Impact Damage Assessment Tools

Process – Longer Term

- Provide funding to bring tools in-house to NASA for parametric sensitivity studies (~$450K)
- Develop capability to conduct damage assessment independent of program & prime contractor
- Identify areas which merit additional test validation or other improvements
- Assist in the development and incorporation of upgrades





Conclusion

The NESC is a decentralized, technical organization, reporting directly to the agency chief engineer, whose goal is to provide “value added”, independent assessment

Mechanical Analysis SPRT supports the NESC by providing expertise from the centers, and outside NASA, in the solution of complex structural analysis problems

The NESC and the Mechanical SPRT, in particular, are heavily engaged in relevant return to flight issues

The continued success of NASA, the NESC and the mechanical analysis SPRT is dependant upon the continued support of engineers like you…

Safety Starts with Engineering Excellence