Design/Analysis of the JWST ISIM Bonded Joints for Survivability at Cryogenic Temperatures

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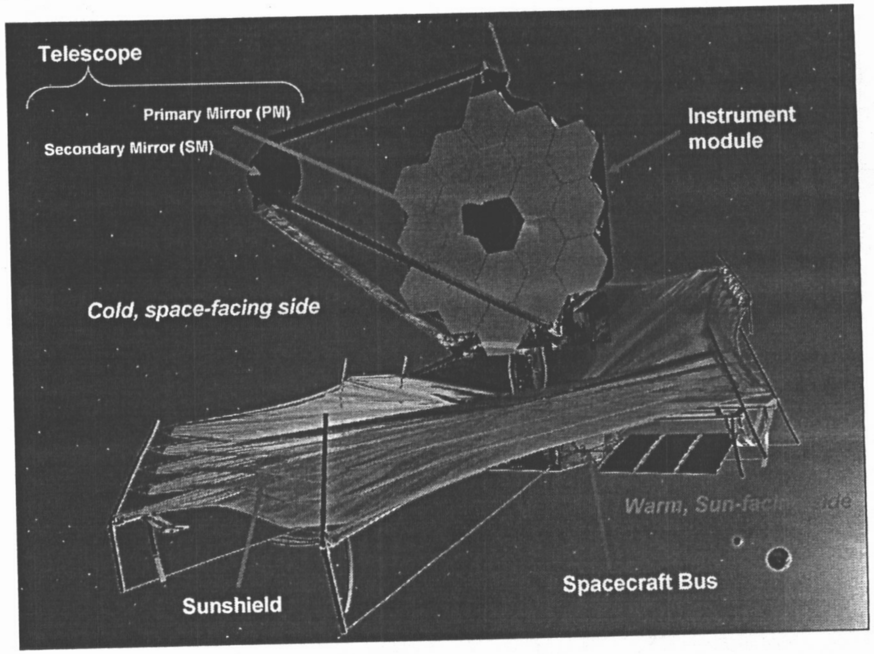
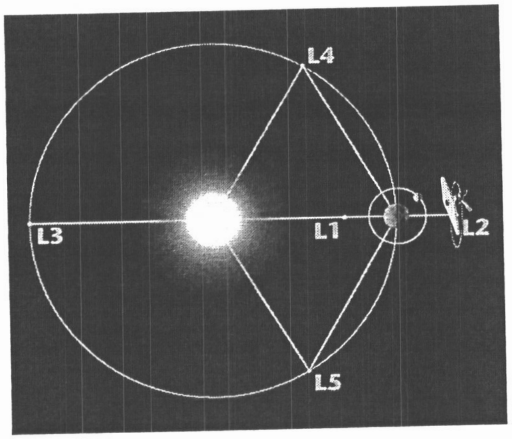
Agenda Topics

- JWST/ISIM Introduction
- Design and Analysis Challenges for ISIM Bonded Joints
- JWST/ISIM Joint Designs
- Bonded Joint Analysis
  - Finite Element Modeling
  - Failure Criteria and Margin Calculation
- Analysis/Test Correlation Procedure
- Example of Test Data and Analysis
- Summary

James Webb Space Telescope (JWST)

- Mission Objective
  - Study the origin and evolution of galaxies, stars and planetary systems
    Optimized for infrared observations (0.6 – 28 μm)
- Organization
  - Mission Lead: Goddard Space Flight Center
  - International collaboration with ESA & CSA
  - Prime Contractor: Northrop Grumman Space Technology
  - Instruments:
    - Near Infrared Camera (NIRCam) – Univ. of Arizona
    - Near Infrared Spectrograph (NIRSpec) – ESA
    - Mid-Infrared Instrument (MIRI) – JPL/ESA
    - Fine Guidance Sensor (FGS) – CSA



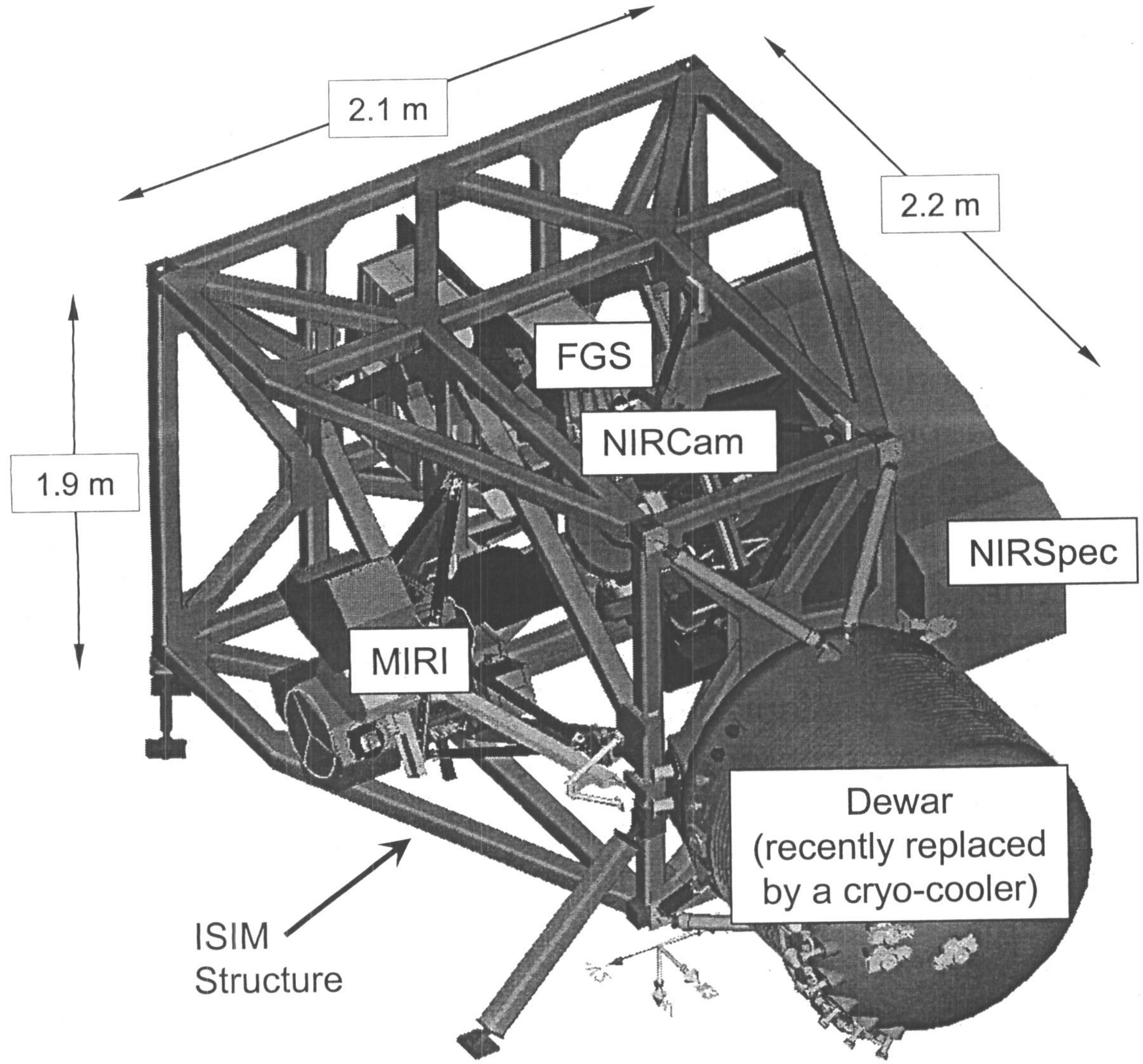


- Description
  - Deployable telescope w/ 6.5m diameter segmented adjustable primary mirror
  - Cryogenic temperature telescope and instruments for infrared performance
  - Launch in 2011 to Sun-Earth L2
  - 5-year science mission (10-year goal)

www.JWST.nasa.gov

Integrated Science Instrument Module (ISIM)

Total Mass =1140 kg



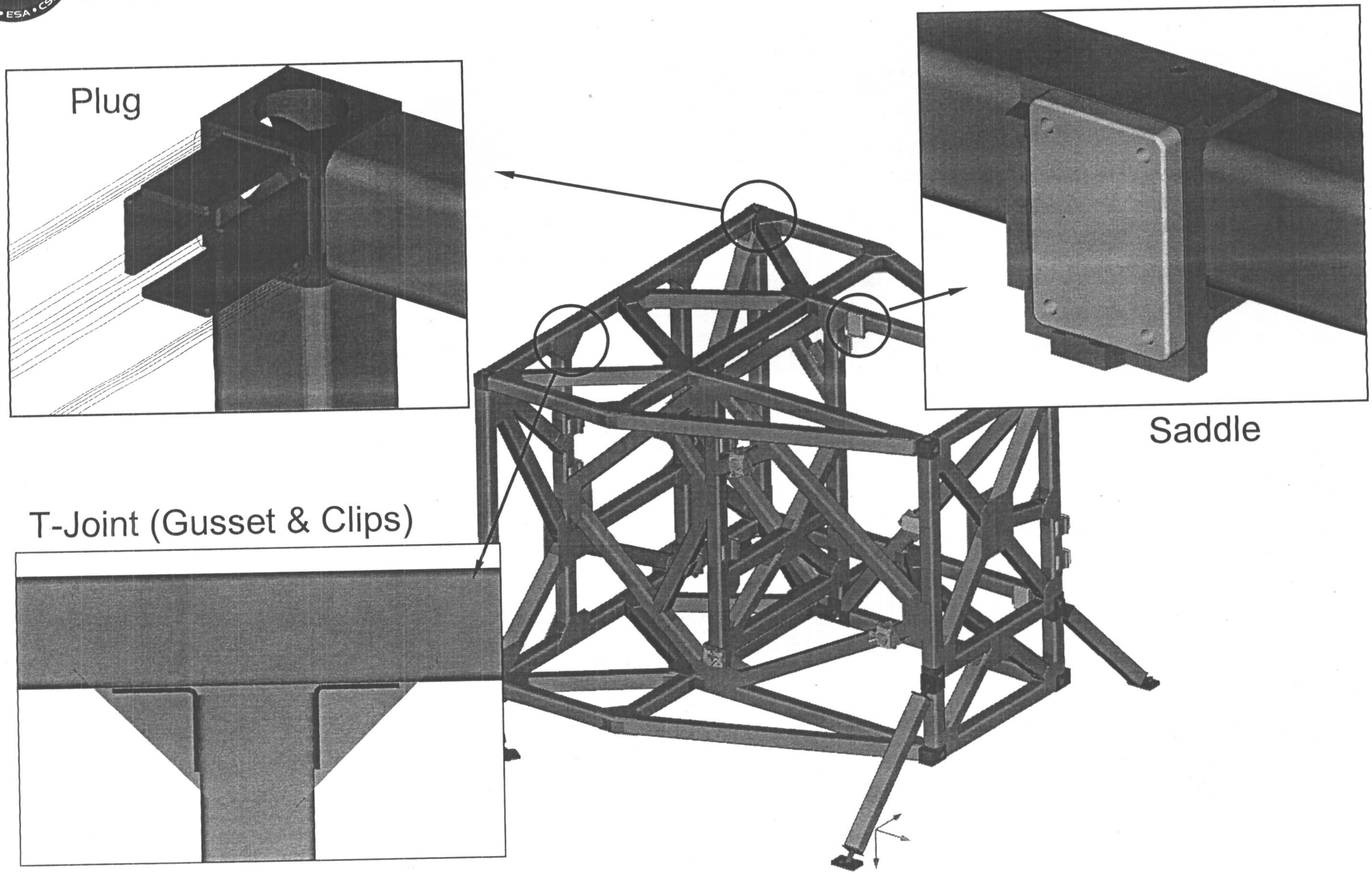
- ISIM Structure is being designed by GSFC.
- Swales Aerospace substantially contributing to ISIM design and analysis.
- ISIM Instruments are being provided by different agencies.
- ISIM Structure successfully passed PDR (Preliminary Design Review) in January 2005 and meets all design requirements.
- Detailed Design & Analysis of the Structure is in progress.
- Critical Design Review is scheduled for December 2005.

Design and Analysis Challenges

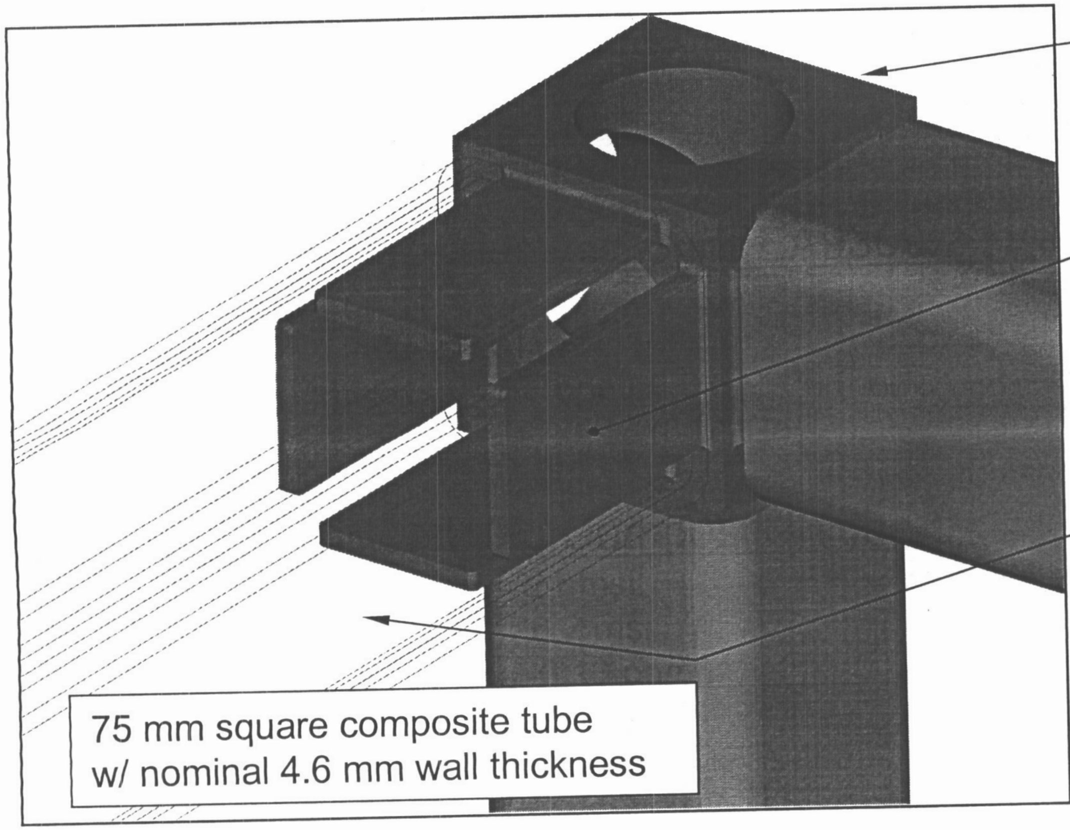
- Design Requirements
  - Metal/composite bonded joints required at a number of nodal locations on the JWST/ISIM composite truss structure to accommodate bolted instrument interfaces and flexures.
  - Survival temperature at 22K (~ – 400°F); – 271K total ΔT from RT.
  - Composite truss tube with high axial stiffness (~21 msi) and low axial CTE (~ 0 ppm/K).
  - Multiple thermal cycles throughout design life of structure. In order to survive launch loads, joints cannot degrade more than an acceptable amount.

- Design/Analysis Challenges
  - Large thermal mismatch stresses between metal fitting and composite tube at cryogenic temperature (22K).
  - Analysis and design experience is very limited for metal/composite bonded joints at temperatures below liquid nitrogen (~80K).
  - Thermo-elastic material properties and strengths for composites and adhesives at 22K are not available and difficult to test for.

ISIM Basic Joint Assemblies



Basic Plug Joint Details



Metal Fitting (Invar 36)

$E = 18.8$ msi

$\alpha = +1.5$ ppm/K

Adhesive Bond (EA9309.2 NA)

$E = 1.1$ msi

$G = 0.4$ msi

$\alpha = 47.8$ ppm/K

Fsu = 11.6 ksi (80 MPa)

Hybrid Composite Tube

$E_{axial} = 21$ msi

$E_{hoop} = 6.2$ msi

$\alpha_{axial} = -0.13$ ppm/K

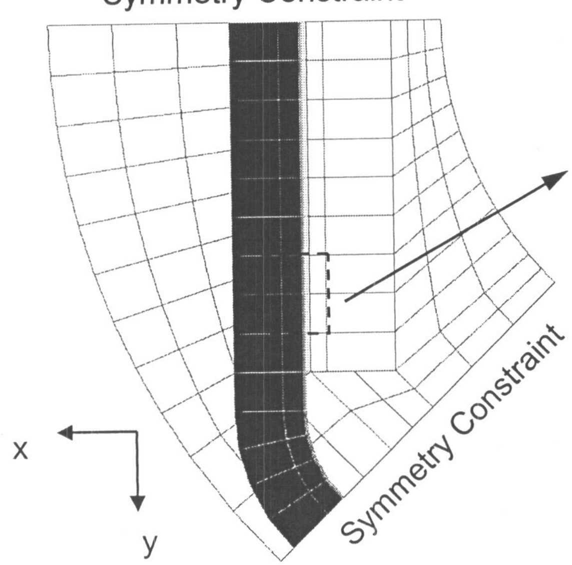
$\alpha_{hoop} = +3.7$ ppm/K

$$\left.\begin{array}{l} S_{zz} = 2.9 \text{ ksi (20 MPa)} \\ S_{zx} = S_{yz} = 5.8 \text{ ksi (40 MPa)} \end{array}\right\} \text{interlaminar strengths}$$

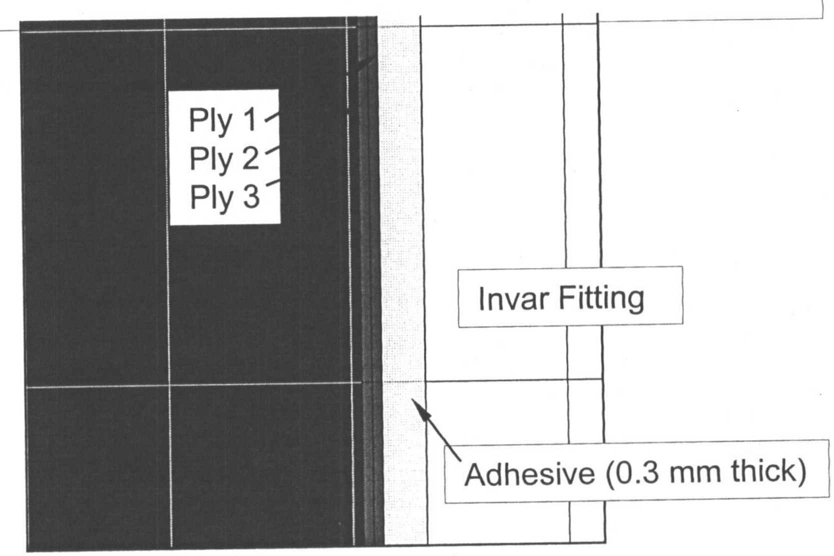
- Stiffness and strength properties are given for 22K.
- Thermal expansion properties are secant CTE from RT to 22K.

Composite Modeling and Mesh Size

- Mesh size: 2.5 mm square in-plane
- Surface plies at bonded interfaces modeled individually
- Aspect ratio $\cong 2.5/0.071 \cong 35$
- Laminate core modeled with thicker elements
- Adhesive modeled with one element through the thickness
- Same mesh size used in all joint FEMs including development test FEMs
- Stress recovery: Element centroid for interlaminar, corner for others



View A-A



Ply 1 – Explicit Props (T300/954-6 Uni Ply)
Ply 2 – Tube Smeared Props (T300/954-6 Uni Ply)
Ply 3 – Tube Smeared Props (M55J/954-6 Uni Ply)

Margin Calculations for Bonded Joint Failure

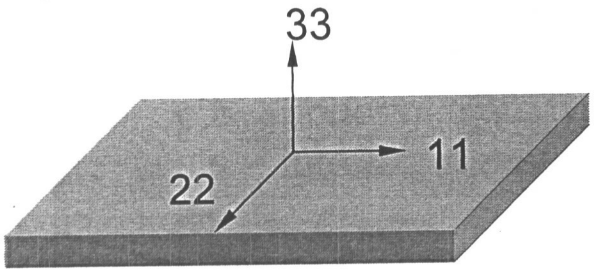
- Laminate In-Plane Failure Prediction
  - MS calculated for each primary in-plane direction of the laminate x, y, xy (shear), separately

$$MS = \frac{F_{iu}}{FS \cdot \sigma_i} - 1 \qquad i = x, y, shear$$

  - where σ_x , σ_y , τ_{xy} are limit stresses and F_{xu}, F_{yu}, F_{su} are corresponding laminate allowables.

- Interlaminar Failure Prediction
  - An interaction between peel and transverse shear components of stress is used to predict interlaminar failure of composites. More on next slide.
  - It is assumed that the failure of the adhesive is not as critical as that of the laminate in ISIM bonded joints. This will be verified by test program.

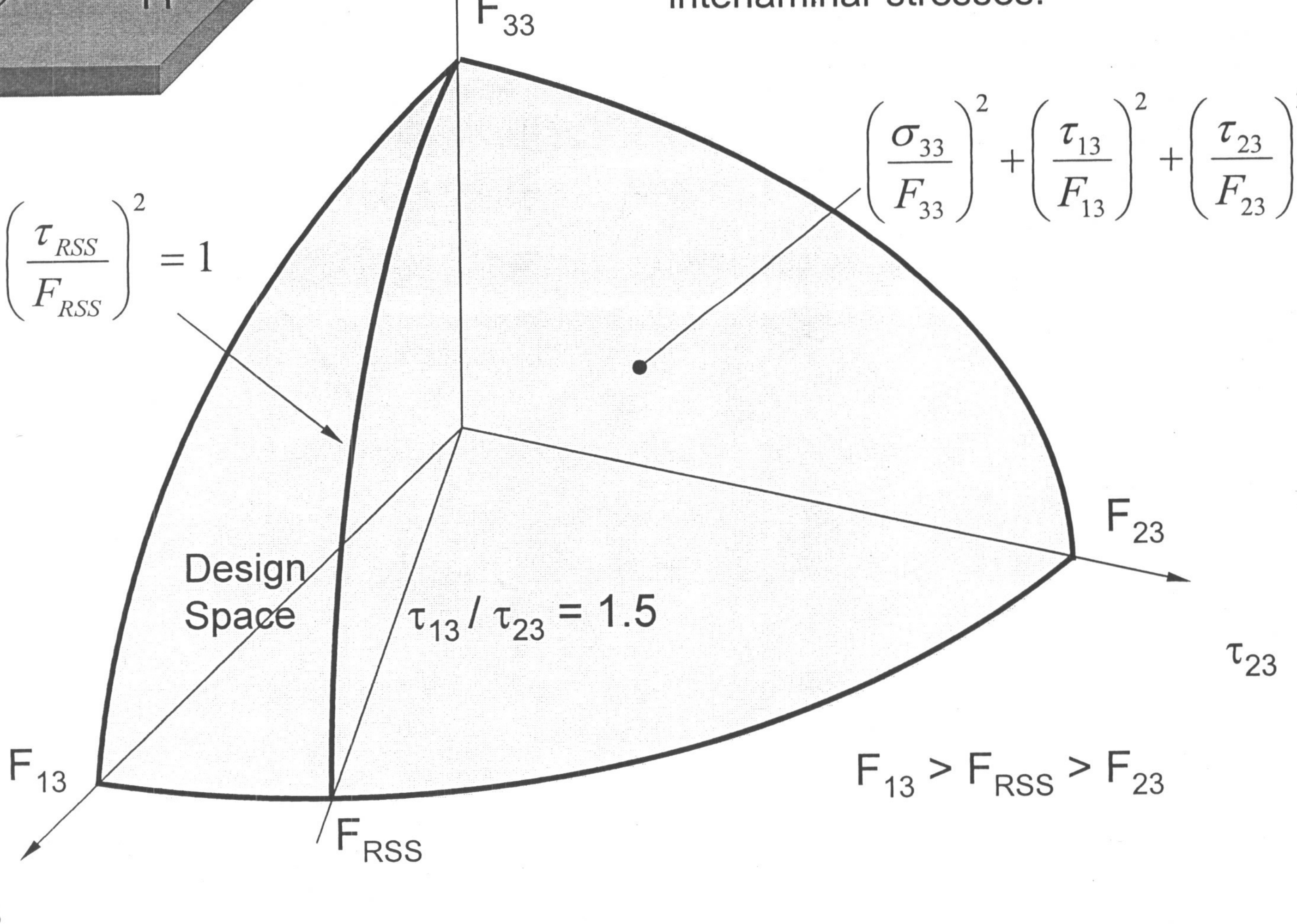
Lamina Failure Criteria – Bonded Joints



Under thermal loads, metal/composite bonded joints typically fail in composite interlaminar stresses.

$$\left(\frac{\sigma_{33}}{F_{33}}\right)^2 + \left(\frac{\tau_{13}}{F_{13}}\right)^2 + \left(\frac{\tau_{23}}{F_{23}}\right)^2 = 1$$

$$\left(\frac{\sigma_{33}}{F_{33}}\right)^2 + \left(\frac{\tau_{RSS}}{F_{RSS}}\right)^2 = 1$$



Interlaminar Failure Prediction

An empirical Interlaminar Failure Criterion is used for critical lamina:

$$\left(\frac{\sigma_{33}}{F_{33}}\right)^2 + \left(\frac{\tau_{RSS}}{F_{RSS}}\right)^2 = 1$$

where σ_{33} is peel stress, τ_{rss} is resultant transverse shear stress, and F terms are material constants dependent on interlaminar strengths, which are being determined by testing.

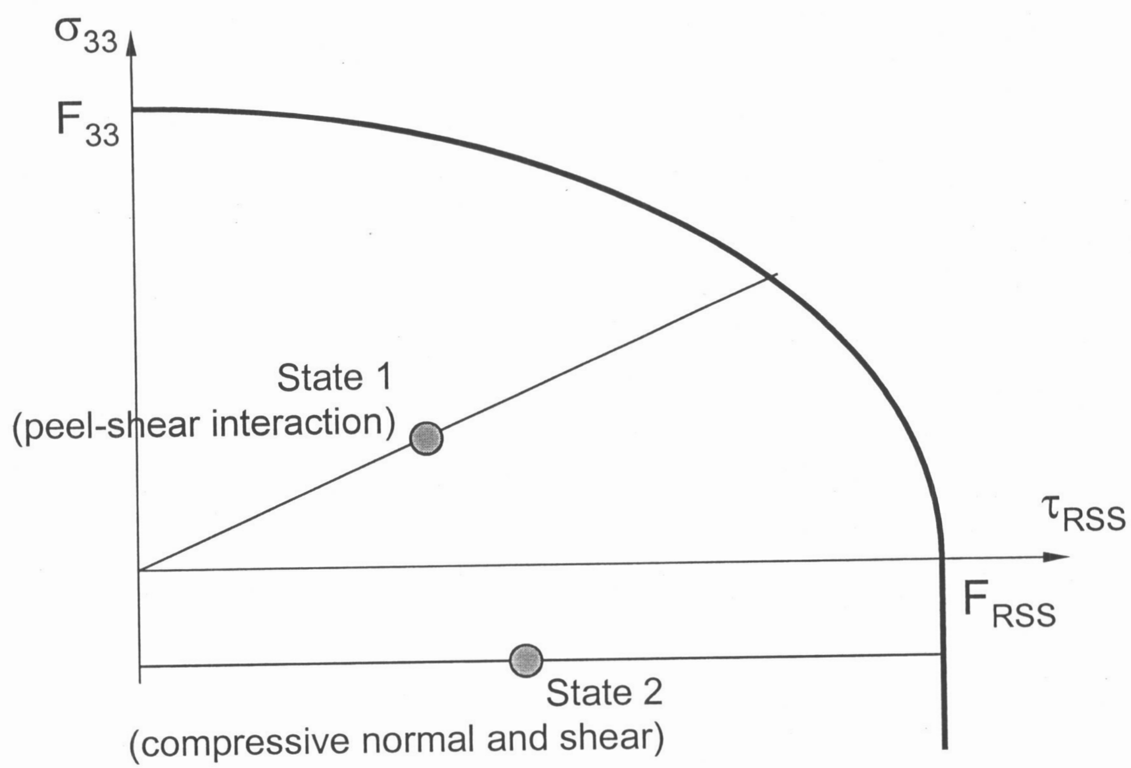
<u>Margin Calculations</u>

Stress State 1

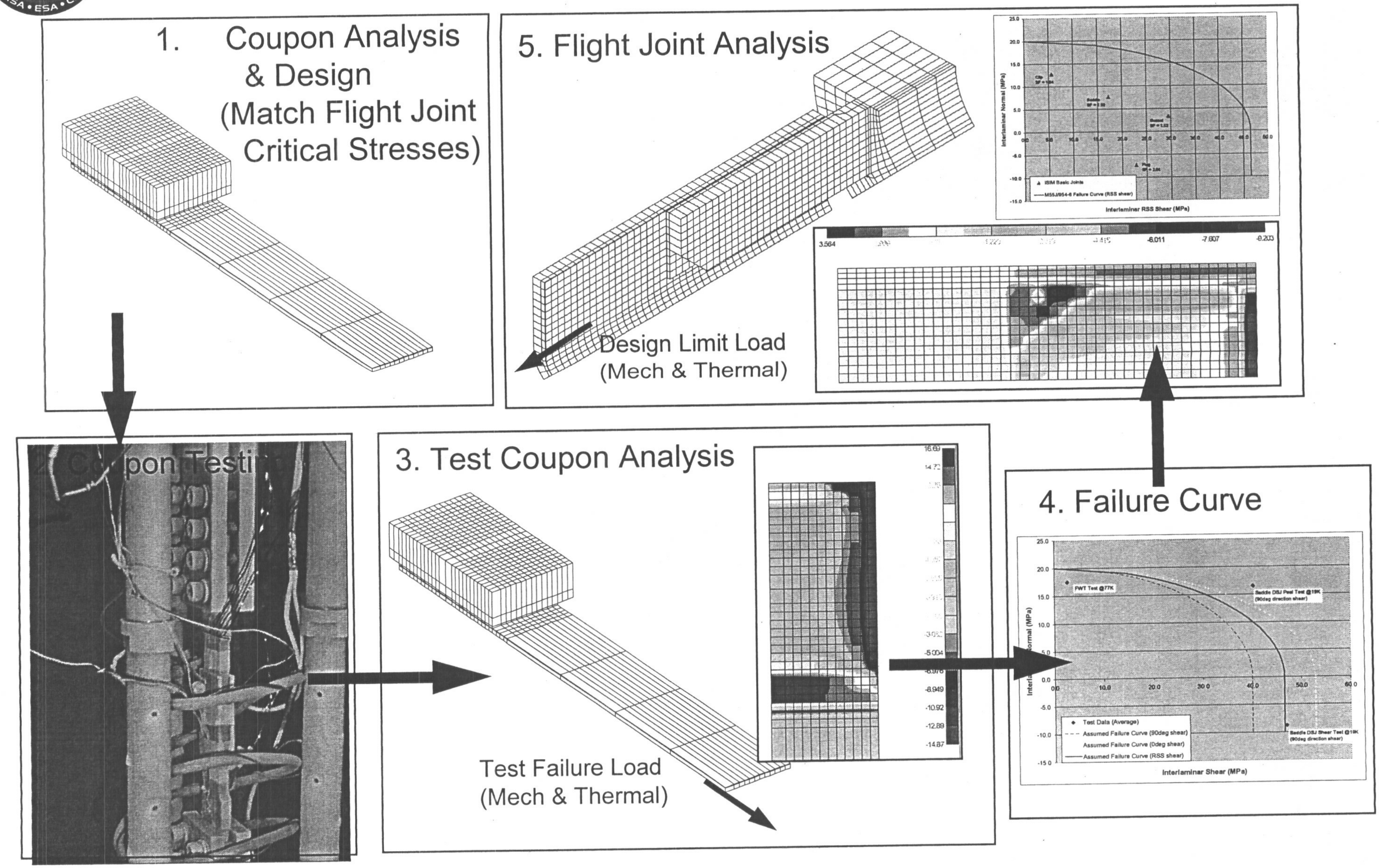
$$MS = \frac{1}{FS \cdot \sqrt{\left(\frac{\sigma_{33}}{F_{33}}\right)^2 + \left(\frac{\tau_{RSS}}{F_{RSS}}\right)^2}} - 1$$

Stress State 2

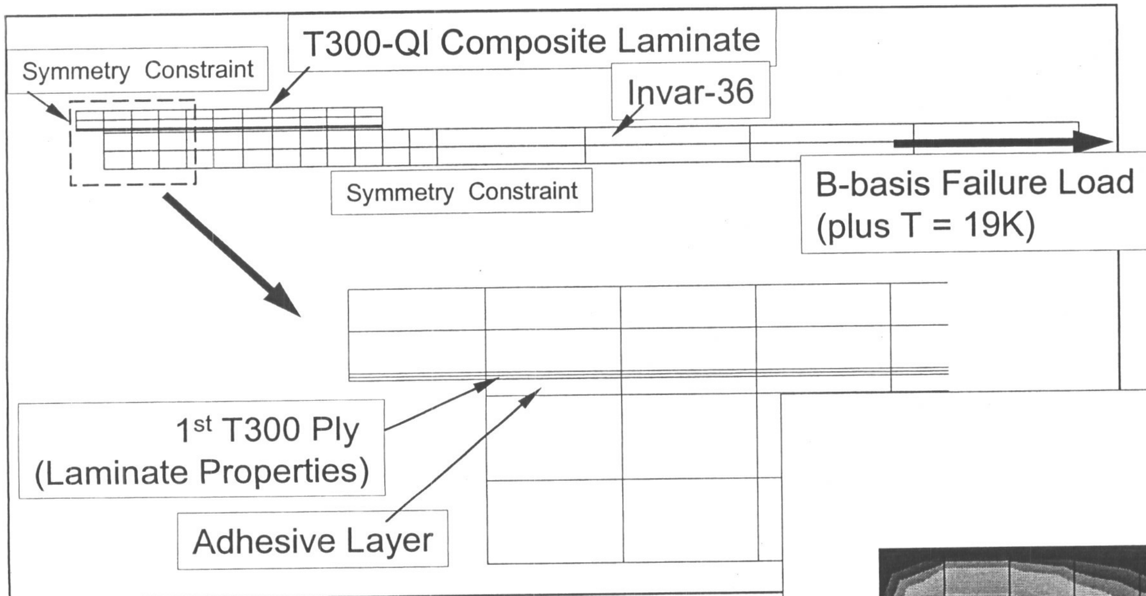
$$MS = \frac{F_{RSS}}{FS \cdot \tau_{RSS}} - 1$$



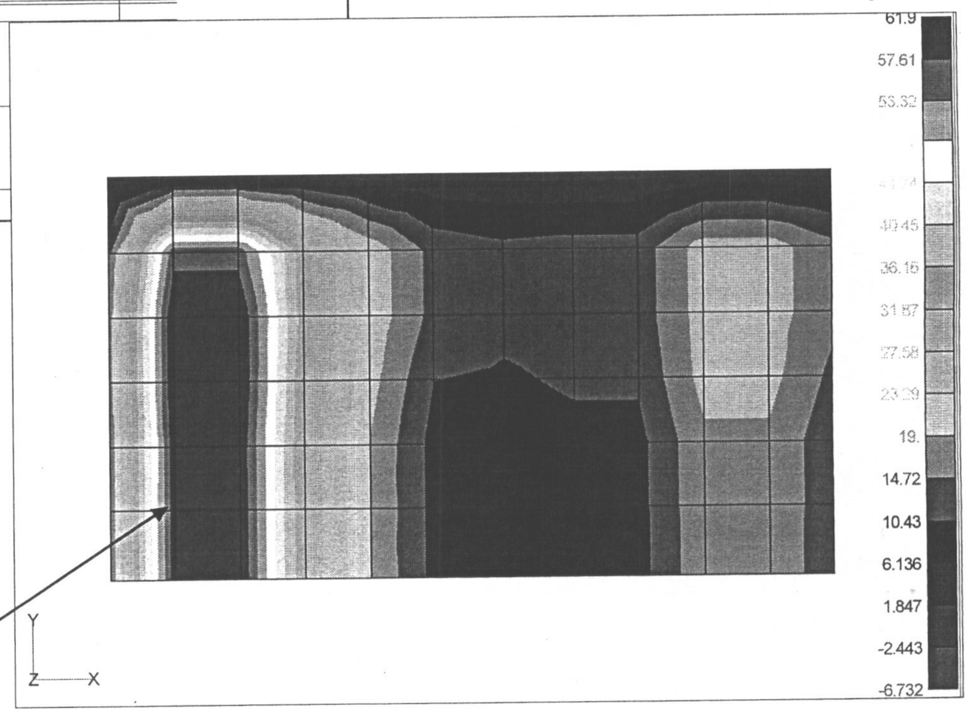
Bonded Joint Analysis/Test Correlation Procedure



Example: T300-QI Gusset Shear Coupon

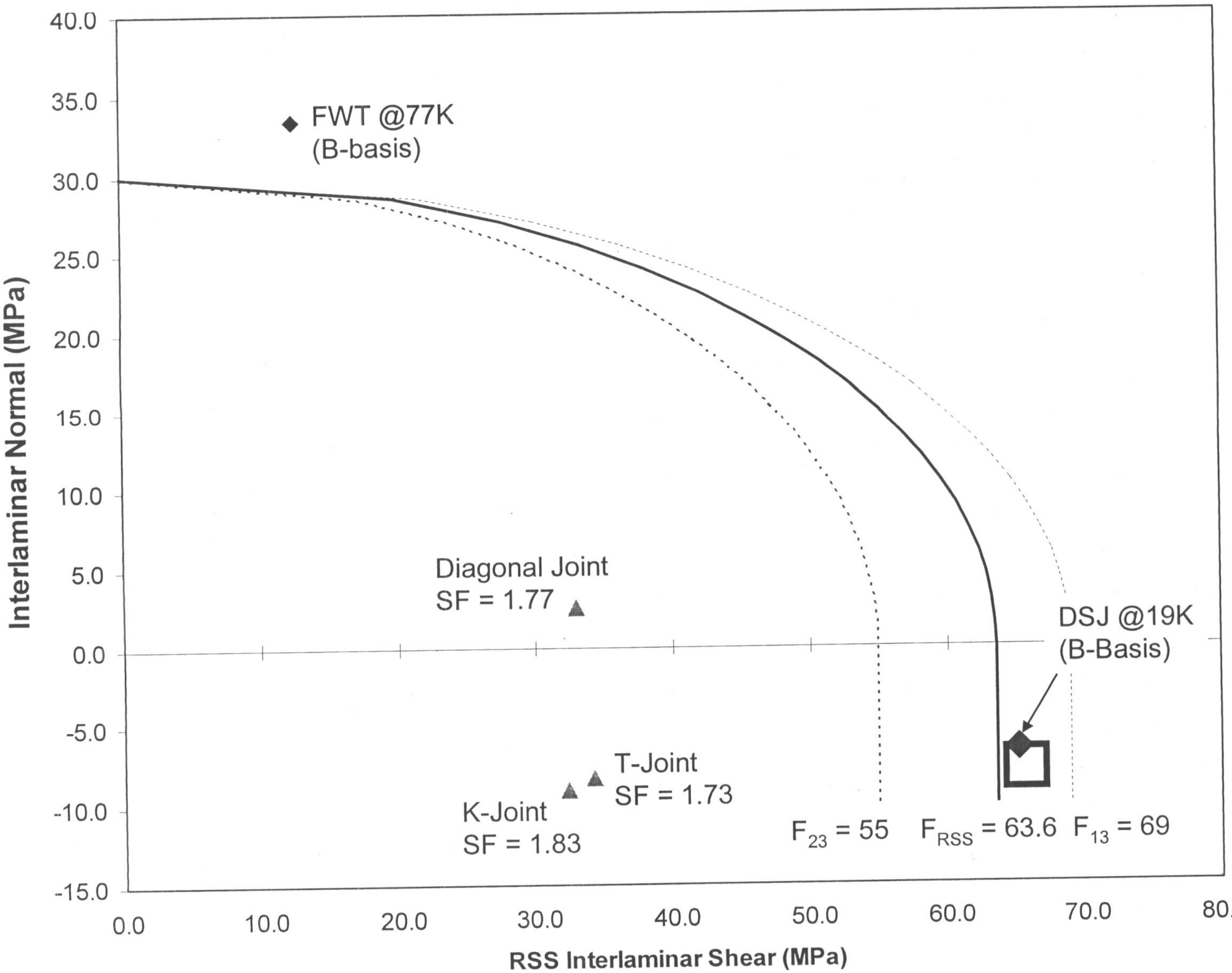


tau-13 contour plot



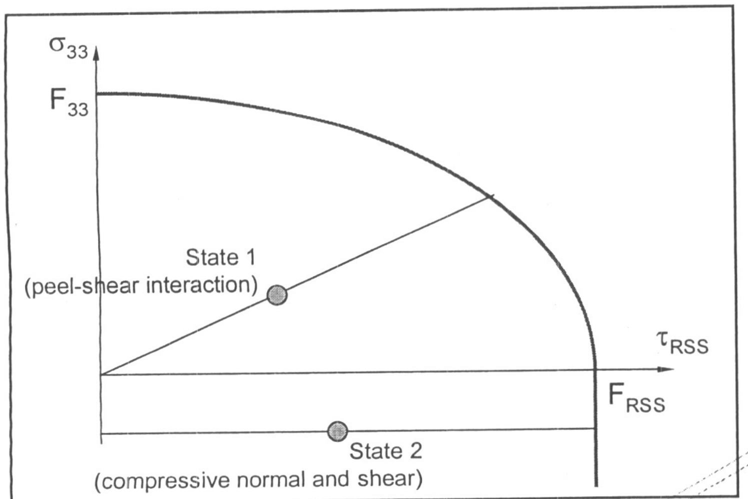
Elm #	sigma-3 (MPa)	tau-13 (MPa)	tau-23 (MPa)	RSS Shear (MPa)	SF
255	-7.2	62.2	17.6	64.6	0.98
277	-10.9	60.8	7.9	61.3	1.04
211	-11.5	60.8	-2.5	60.8	1.05
266	-13.4	59.1	2.5	59.2	1.08
212	-9.0	56.0	13.7	57.6	1.10
258	3.5	31.9	15.5	35.5	1.76
224	-2.1	33.4	6.2	33.9	1.87
280	1.3	30.6	8.0	31.6	2.00
223	0.5	30.8	-3.7	31.0	2.05

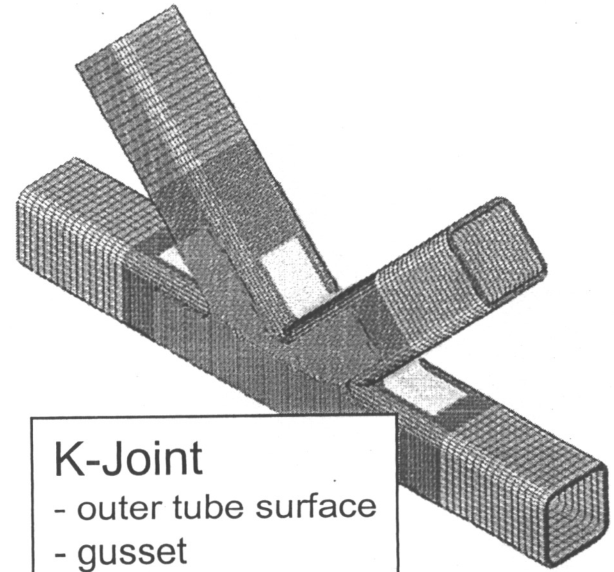
Example: T300-QI Gusset Failure Curve at Cryo



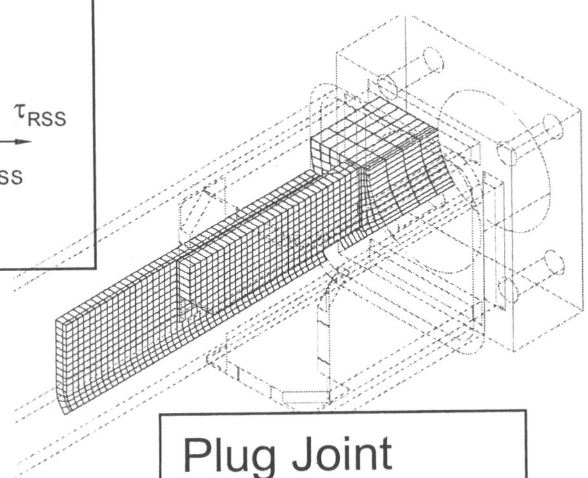
Bond I/F Types and Curves

- Three unique composite interfaces are designed in the structure:
    1. Tube inner surface (hybrid w/ additional T300/954-6 outer ply)
    2. Tube outer surface (hybrid)
    3. Gusset (T300-QI)
- Test program includes coupon testing for establishing six unique interlaminar failure curves, one for each composite interface at cold survival temperature and at room temperature.

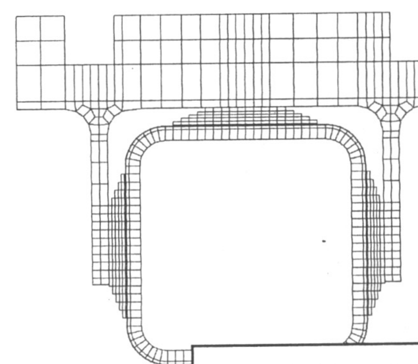




K-Joint
- outer tube surface
- gusset



Plug Joint
- Inner tube surface



Saddle Joint
- outer tube surface

Summary

- Material characterization testing and joint development testing are in progress. Joint development testing includes flat wise tension and double strap joint coupon tests at room and cryogenic temperatures. Test results will be critical for analysis correlation and the final design/analysis of the ISIM metal/composite bonded joints.
- A joint demonstration test program is underway and will include thermal survivability testing of basic joints including a plug joint.
- An evaluation of strength degradation due to multiple thermal cycles will also be included in the joint development test program.
- After all testing and post-test analysis is complete, the analytical tools will exist for final design and analysis of the JWST/ISIM flight joints. The joints will be designed for positive strength margins and optimized for mass and stiffness.