THERMAL-STRUCTURAL ANALYSIS OF STRUCTURALLY-INTEGRATED THERMAL PROTECTION SYSTEMS

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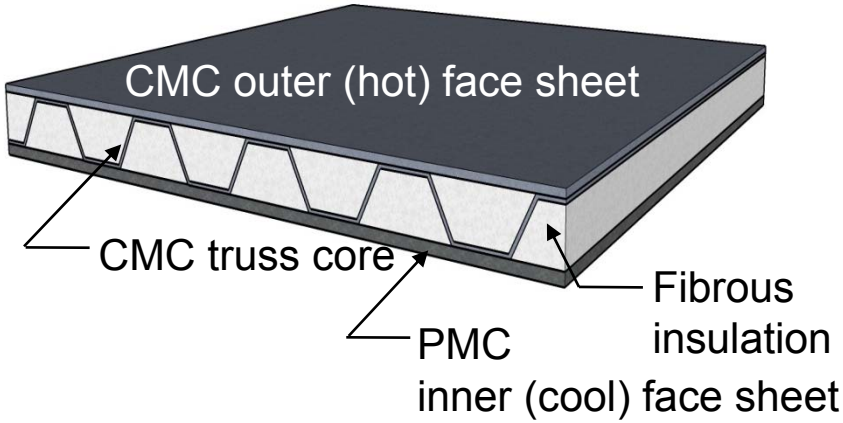
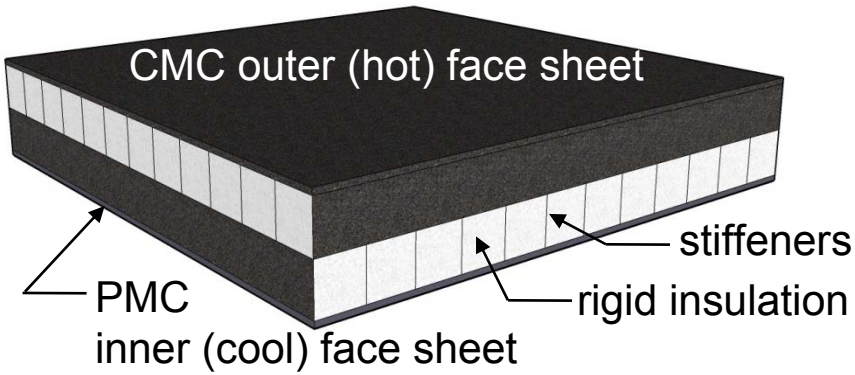
OUTLINE

- Background
- Structurally-Integrated TPS Fabrication Demonstration
- Thermal Analysis
- Structural Analysis
- Concluding Remarks
- Future Work

STRUCTURALLY-INTEGRATED THERMAL PROTECTION SYSTEM (SITPS) CONCEPTS

Thermal protection is integrated with load carrying structure



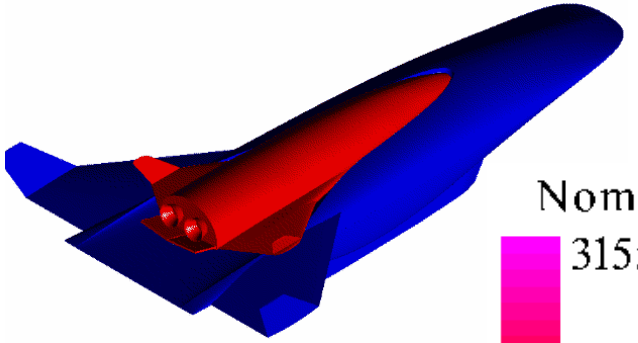


Potential Payoffs:
- More durable than external insulation
- Less weight

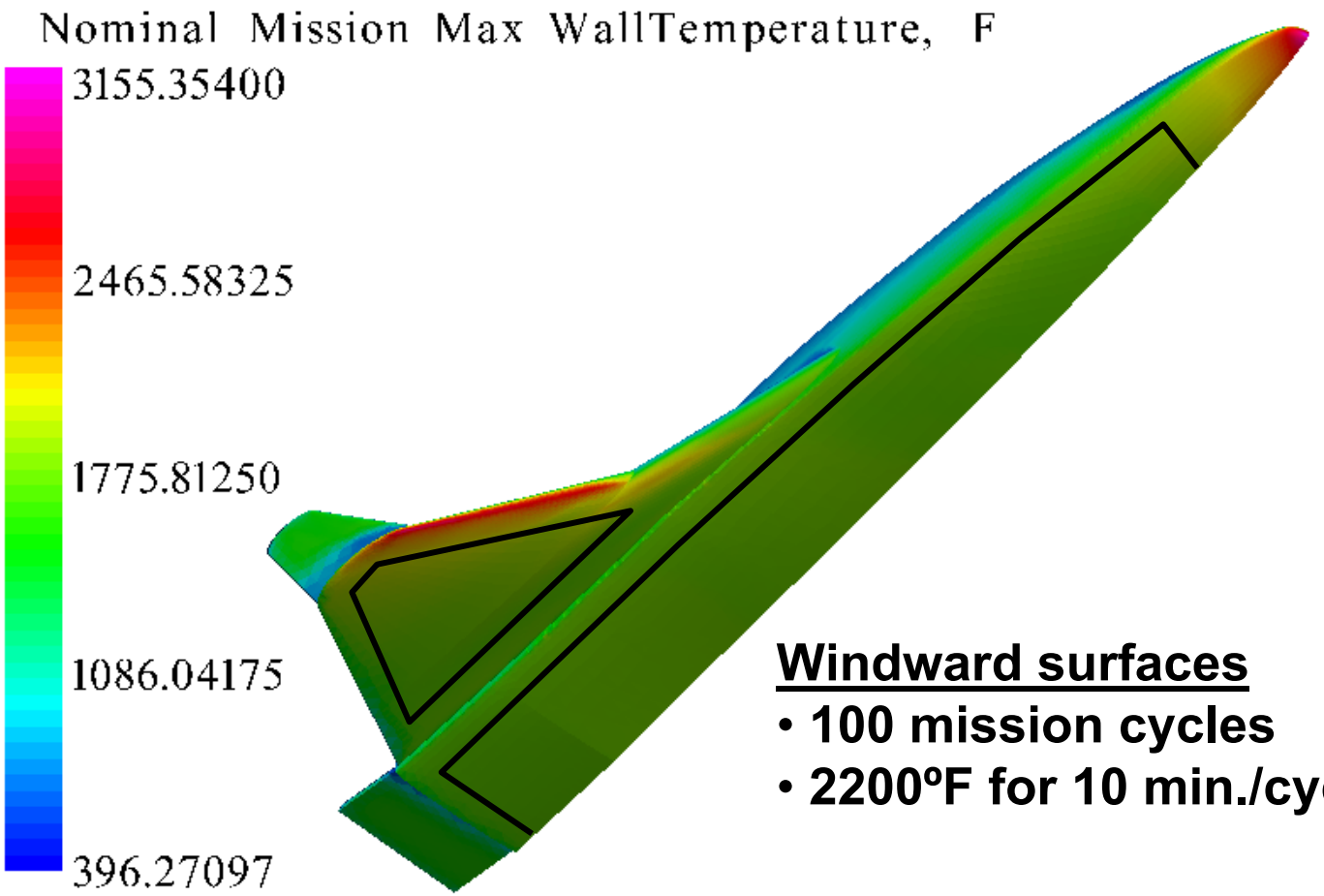
Design Challenges:
- Heat shorts from hot to cool surfaces
- Thermal growth mismatch between different materials
- Panel closeouts and joints

Fabrication Challenges:
- Bonding for high temperature applications
- Bonding of different materials
- Fabricating large parts with complex geometries

APPLICATION: HIGHLY RELIABLE REUSABLE LAUNCH SYSTEMS (HRRLS)



Upper Stage Re-entry

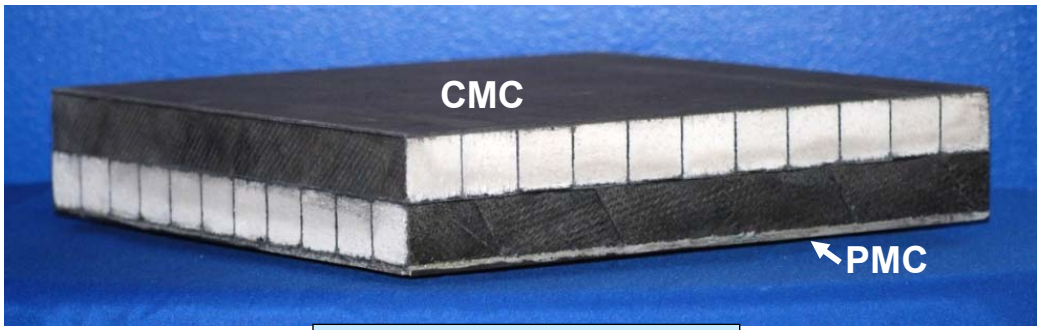


<u>Windward surfaces</u>

- **100 mission cycles**
- **2200ºF for 10 min./cycle**

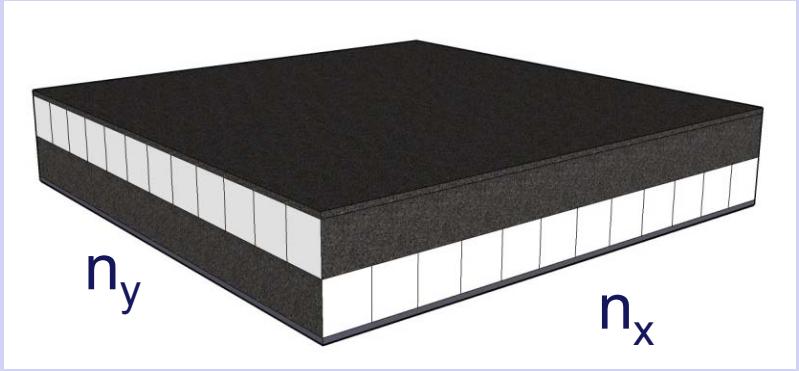
FABRICATION DEMONSTRATION
COI CERAMICS

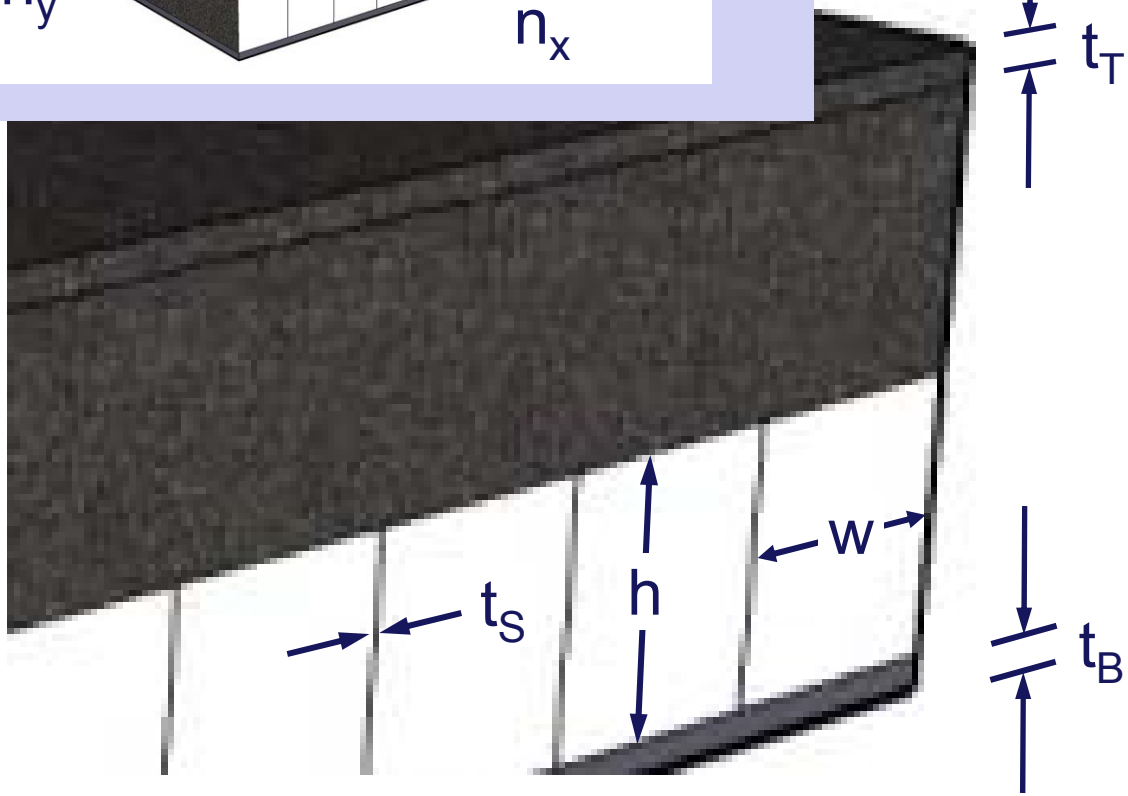
- Rigid insulation bars are spiral-wrapped with impregnated ceramic-fiber cloth
- Wrapped bars are stacked in a 0º/ 90º configuration
- Layers of impregnated ceramic- fiber cloth are stacked on top
- Stack-up is co-cured and trimmed
- PMC bottom face sheet is bonded to panel



Final TPS Panel

PARAMETERIZED PANEL GEOMETRY FOR THERMAL-STRUCTURAL OPTIMIZATION





As Built

$n_x = n_y$	11
h = w	1.0
t_S	0.01
t_T	0.1
t_B	0.1

Total thickness
$= 2h + 2t_S + t_T + t_B$

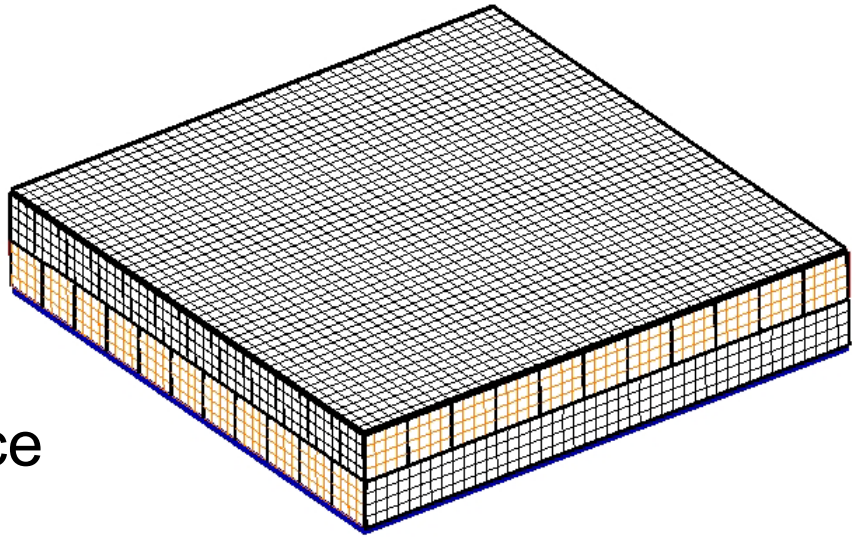
Panel dimensions
11.5 x 11.5

All dimensions in inches

FINITE ELEMENT ANALYSIS

- **Materials**
  - SiC/SiC top face sheet
  - SiC/SiC wrap
  - AETB-8 bars
  - IM7/977 PMC bottom face sheet

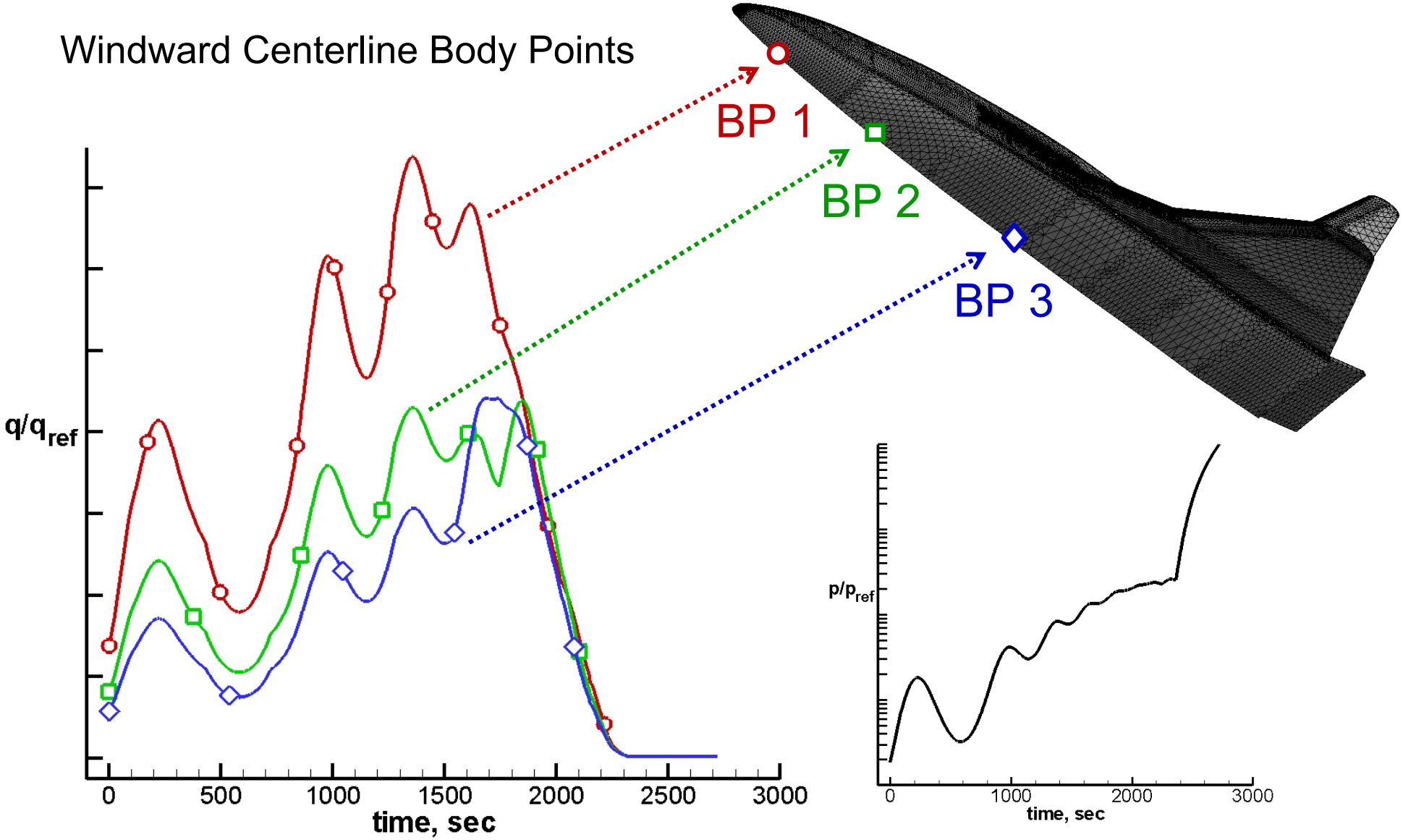
FE mesh for SITPS panel



- **Abaqus™ FE Code**
  - 5808 shell elements for face sheets
  - 4224 shell elements for “struts”
  - 15488 solid (hex) elements for insulation

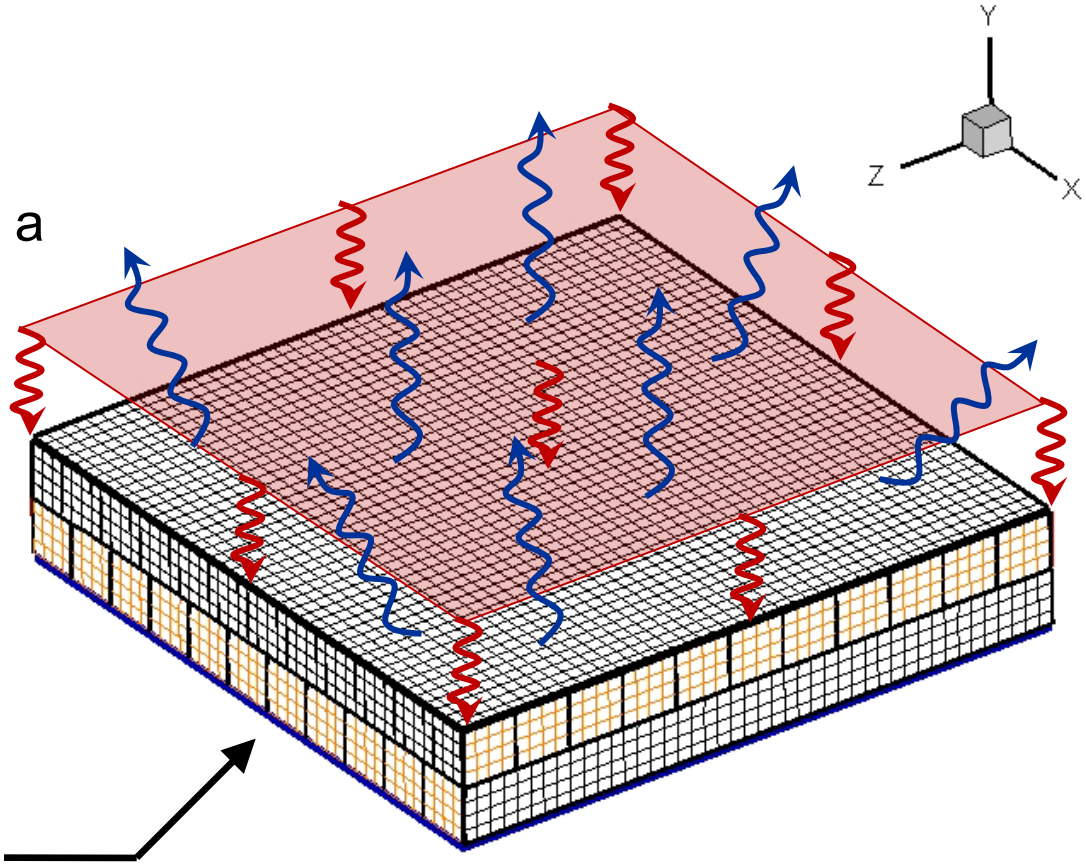
UPPER STAGE RE-ENTRY ENVIRONMENT

Windward Centerline Body Points



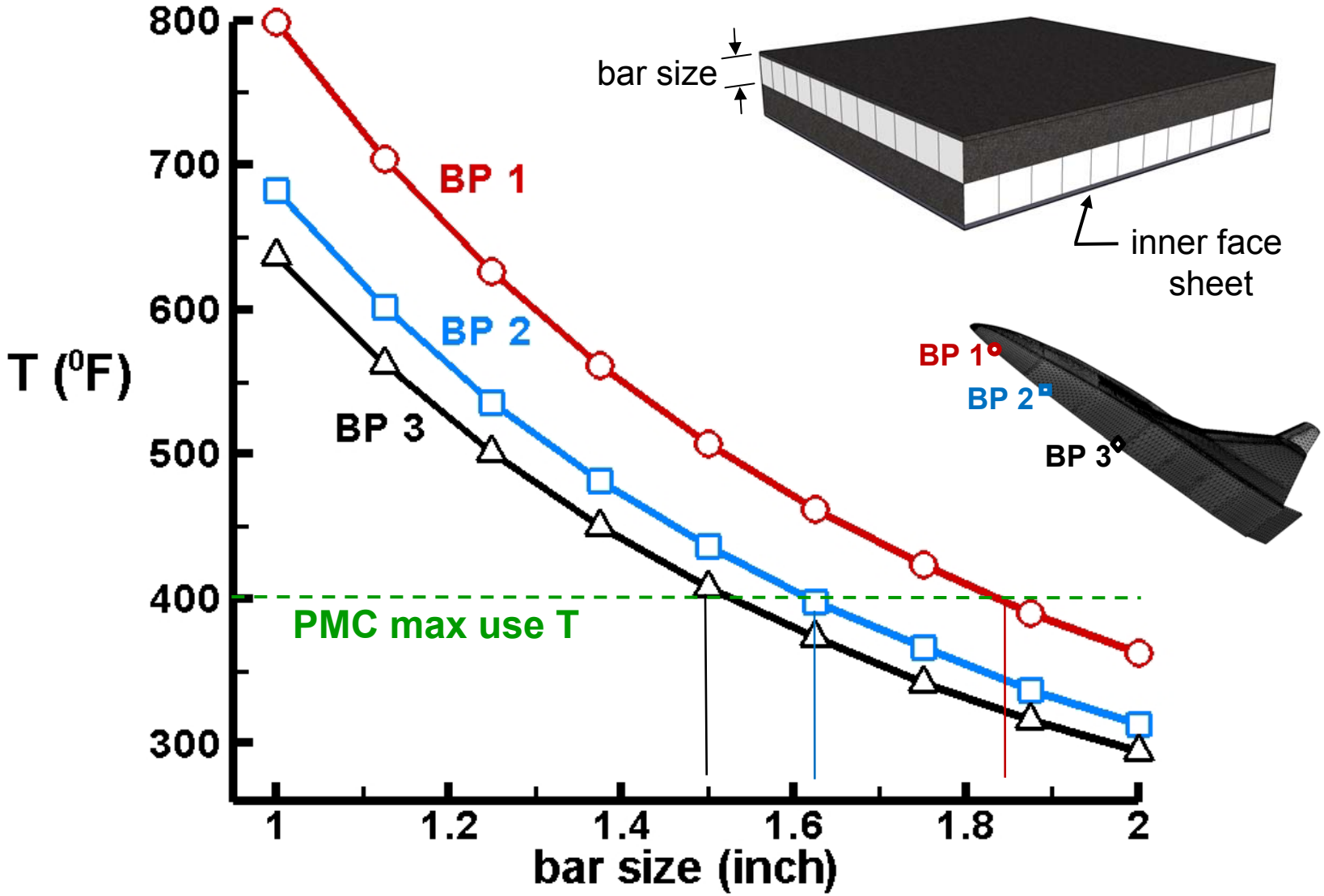
THERMAL ANALYSIS AND SIZING

- **Boundary Conditions**
  - Uniform $\dot{q}(t)$ corresponding to a particular body point (BP)
  - Radiation to space
  - Insulated sides and bottom



- **Material Temperature Limit Criteria**
  - PMC and bond line ≤ 400ºF
  - AETB & SiC/SiC limits are satisfied for all BPs

THERMAL SIZING RESULTS:
Maximum Inner Face Sheet Temperature



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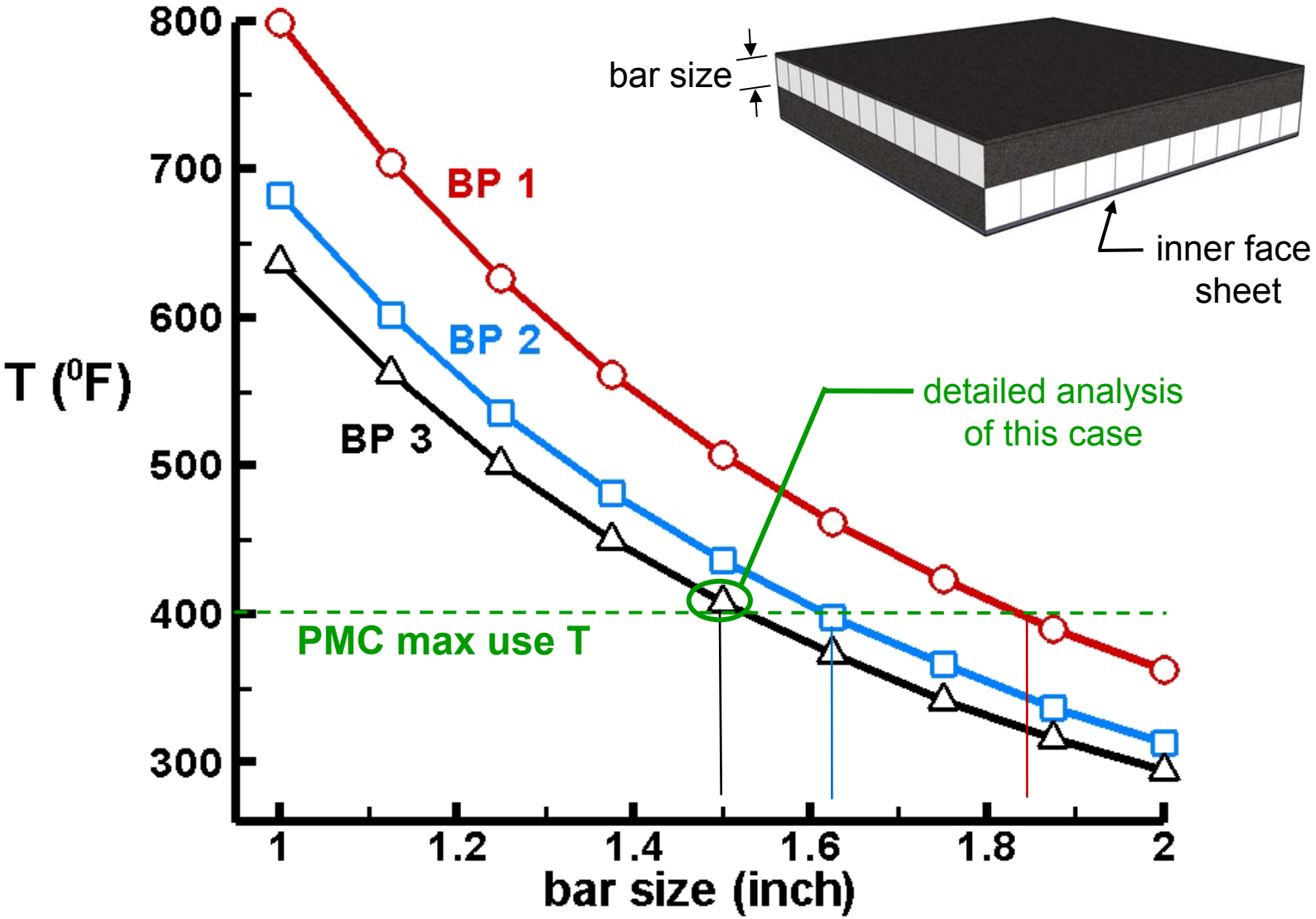
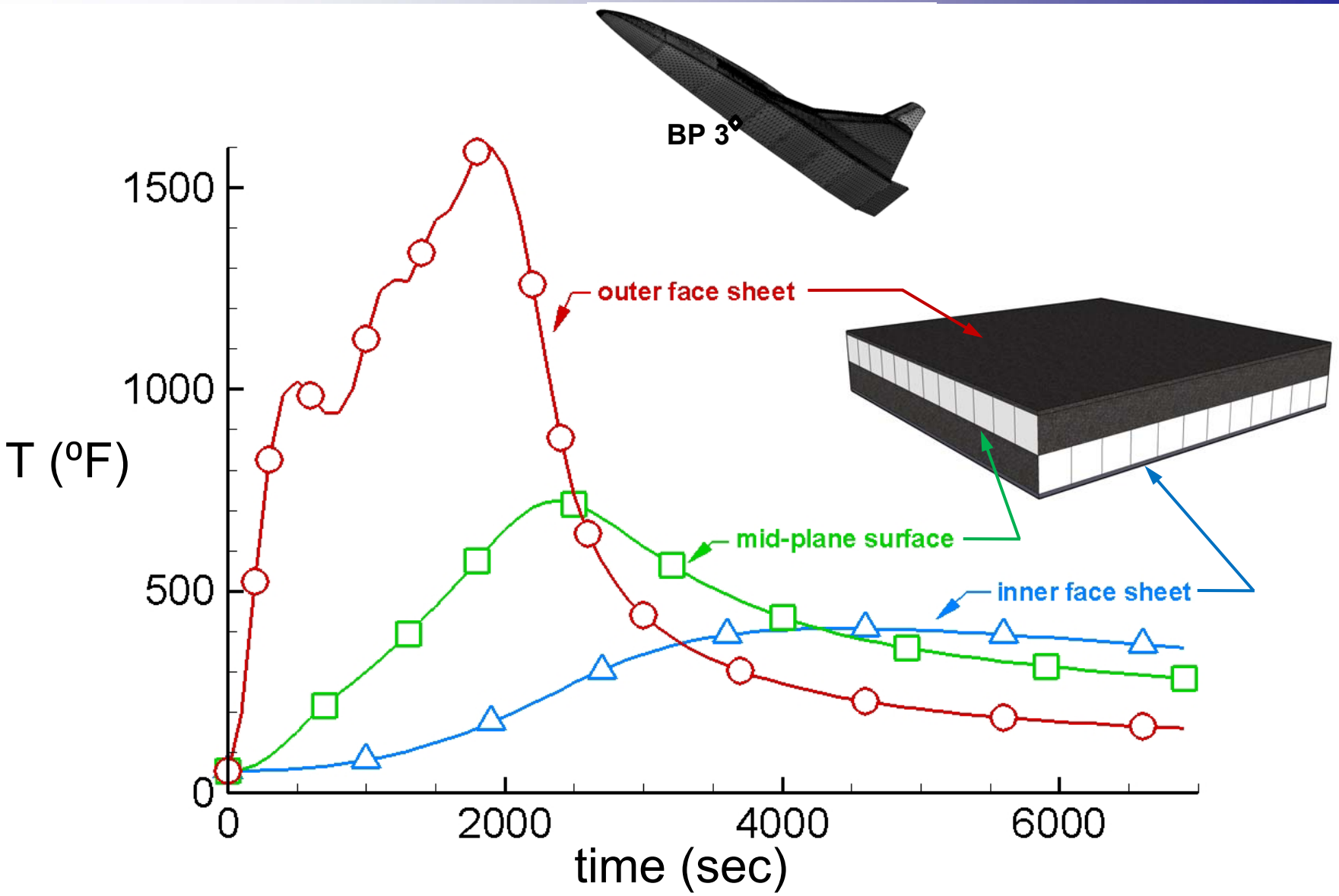
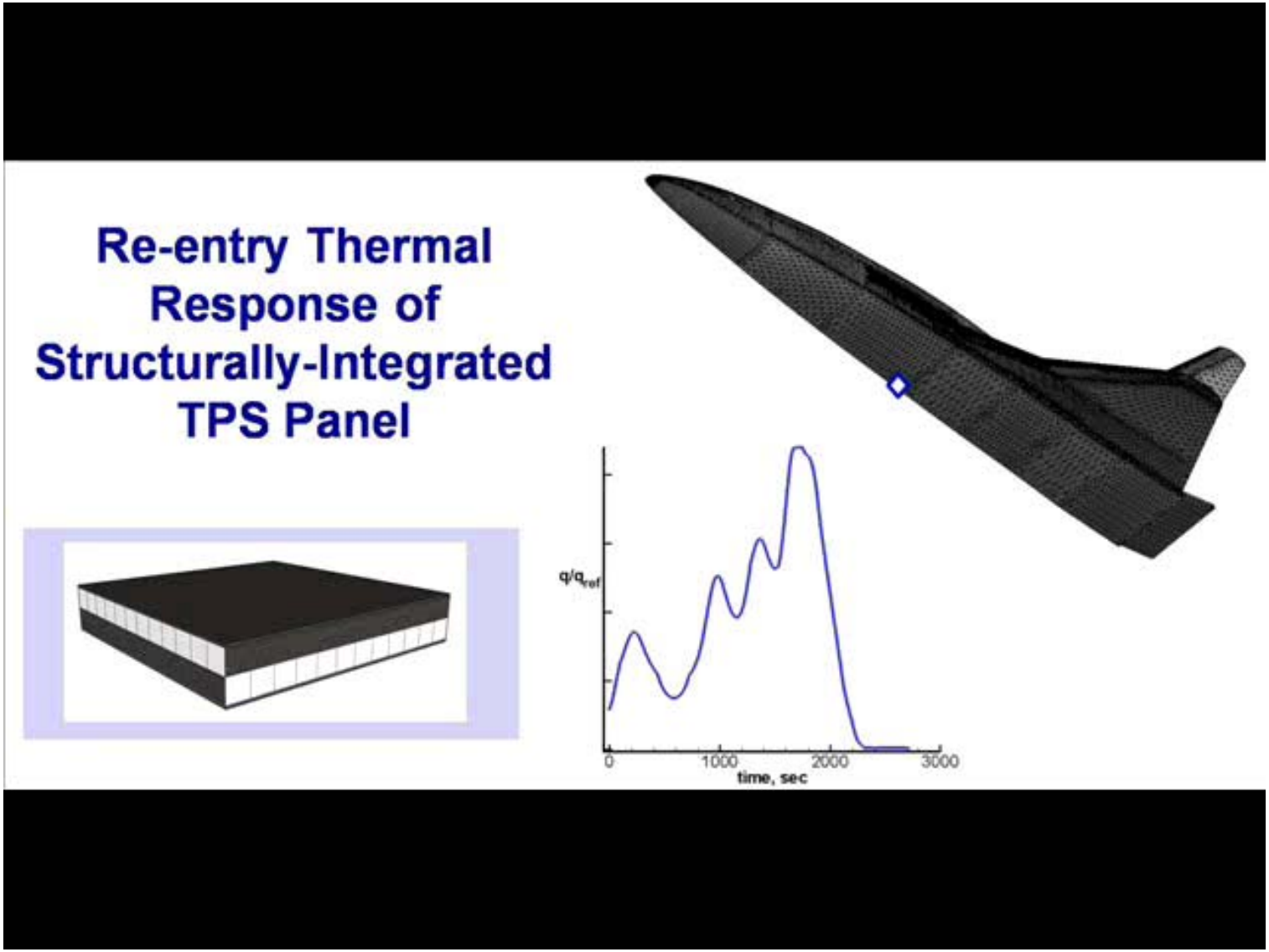


THERMAL RESPONSE FOR BODY POINT 3

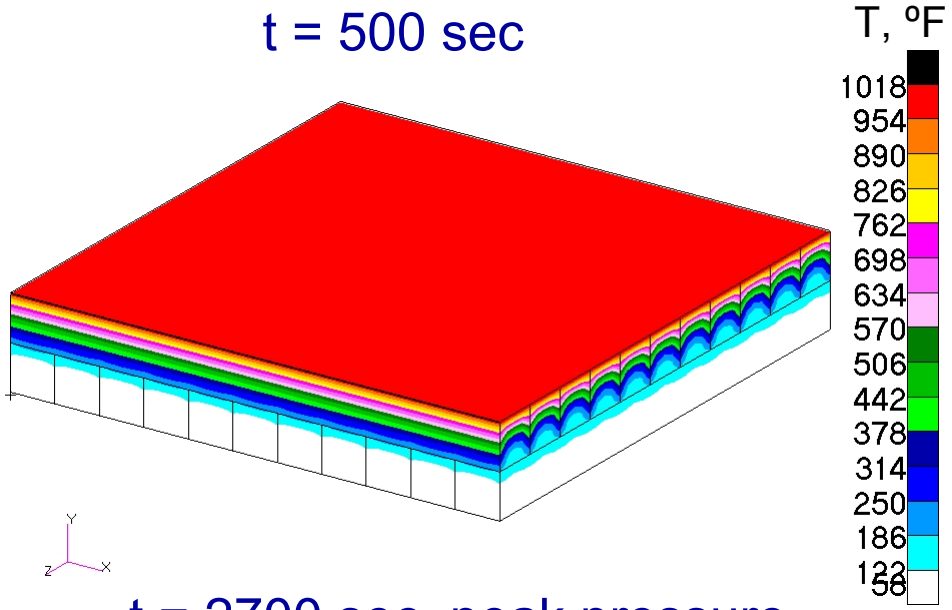


THERMAL RESPONSE MOVIE

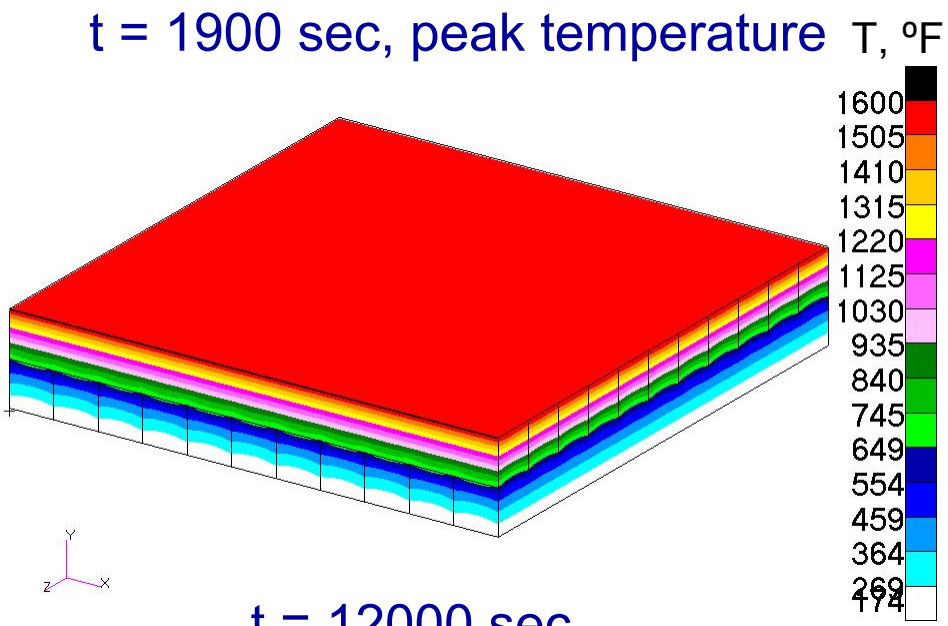


THERMAL RESPONSE FOR BODY POINT 3

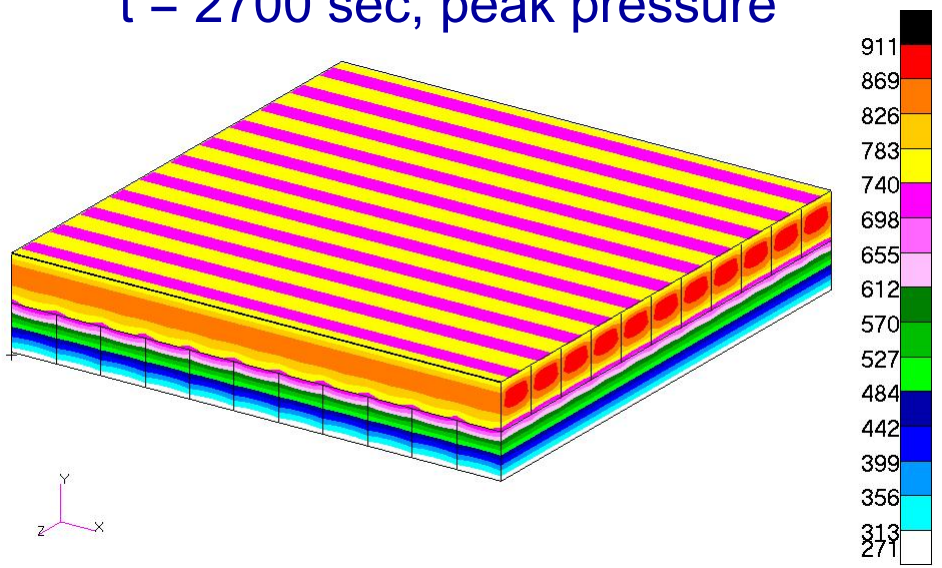
t = 500 sec



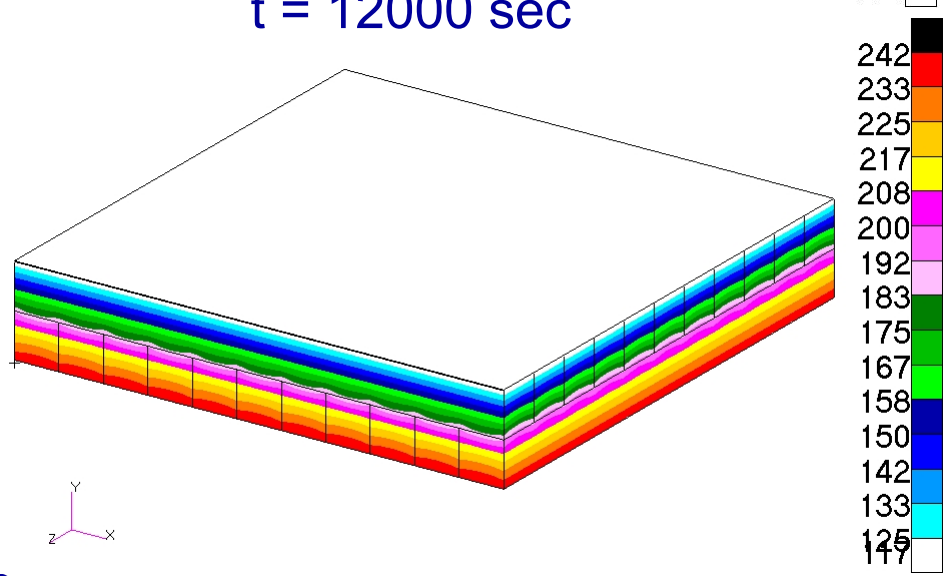
t = 1900 sec, peak temperature



t = 2700 sec, peak pressure



t = 12000 sec



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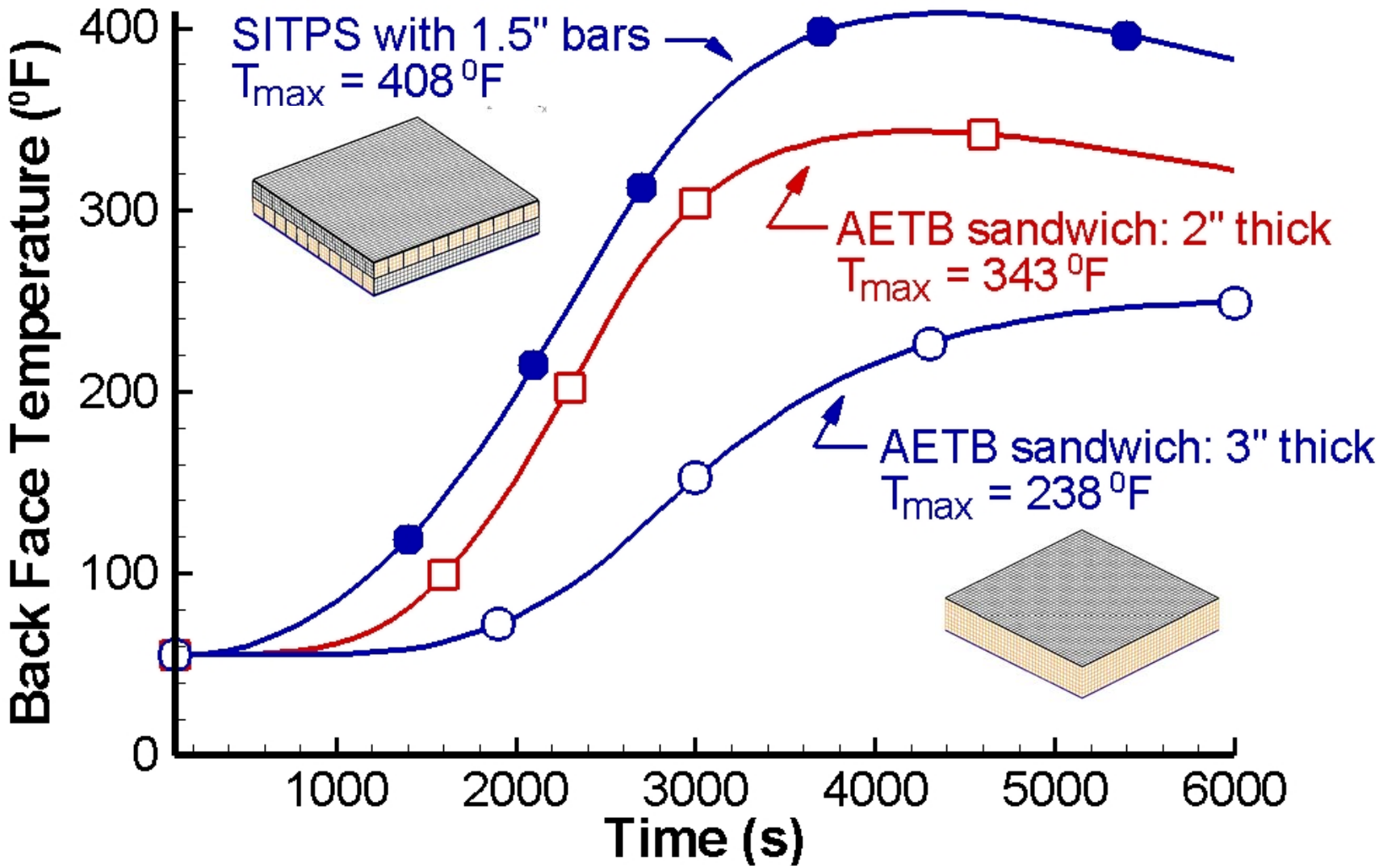
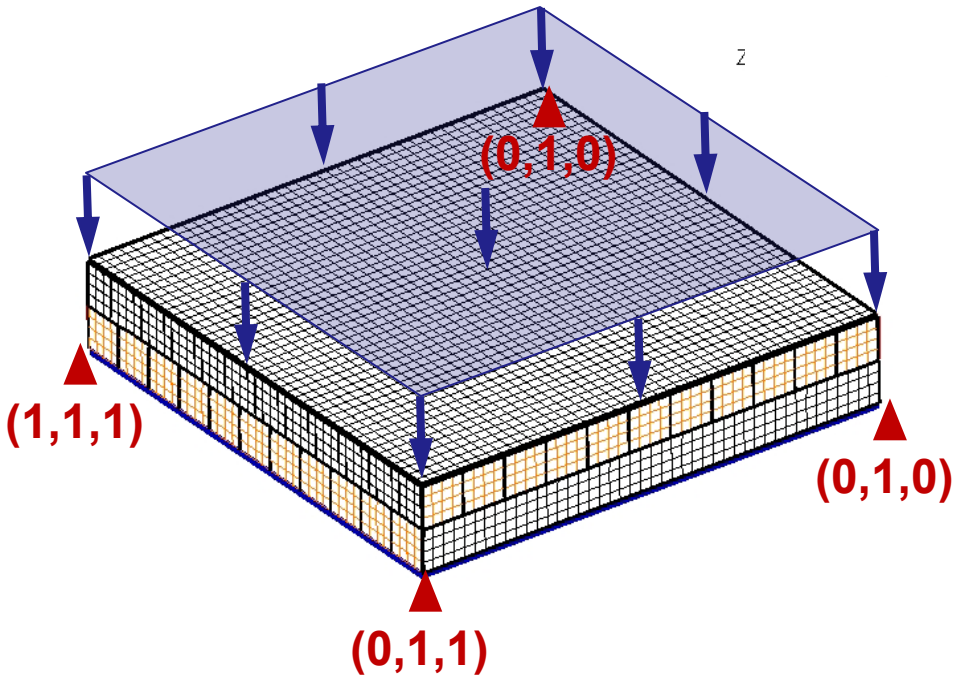
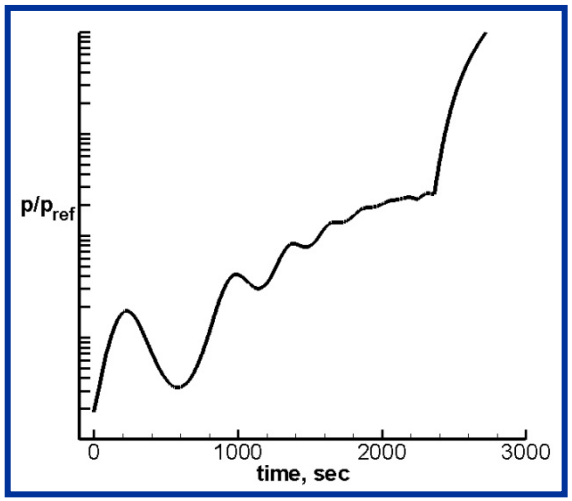
EFFECT OF HEAT SHORTS



LOADS FOR STRUCTURAL ANALYSIS

- **Loads and Boundary Conditions**
  - Uniform p(t) corresponding to aerodynamic loads
  - Temperature distribution T(x,t) at specific time slices
  - Minimally constrained corners
    (u,v,w): 0 = free, 1 = fixed

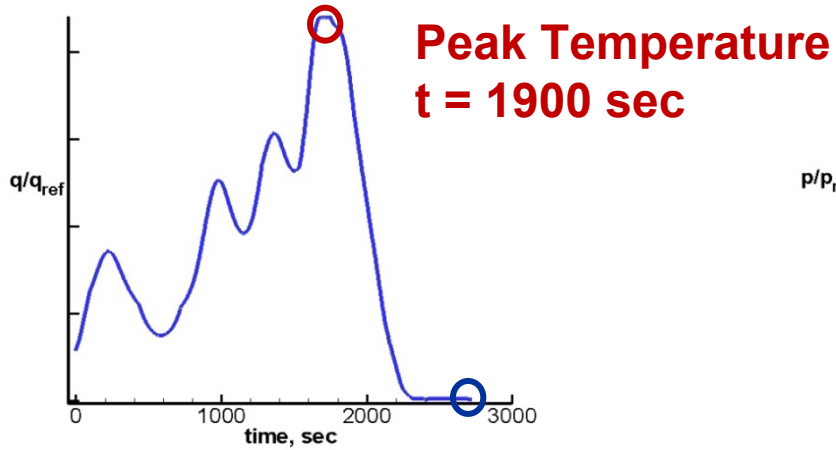


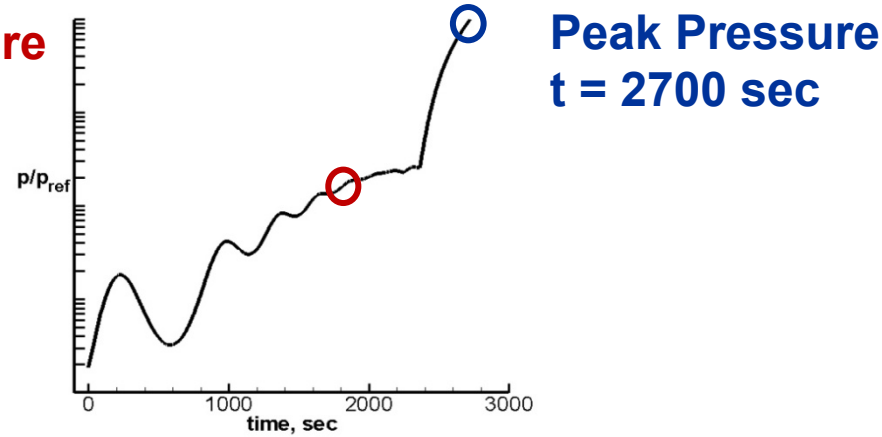


"Failure" Criteria
- Stress & strain allowables
- Bondline strength
- Buckling

CONSIDERATIONS FOR SELECTING TIME SLICES FOR STRUCTURAL ANALYSIS

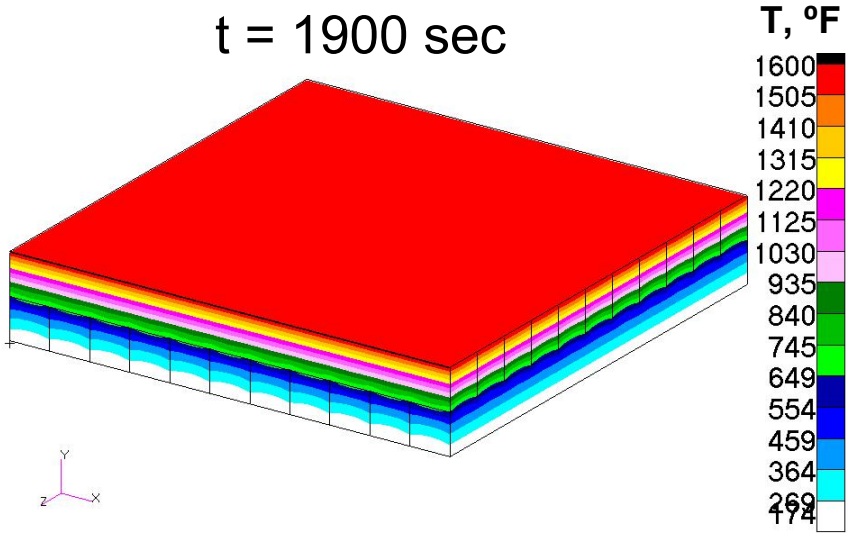
- Thermal stress
  - Driven by temperature gradients
  - Highly dependent on boundary conditions
- Mechanical properties are temperature dependent
- Peak heating occurs when pressure loads are low
- Structural sizing is usually driven by other loads, e.g. abort maneuvers, landing
- Detailed stress analysis of panels should be based on running loads obtained from full vehicle model
- Loads at two times were selected



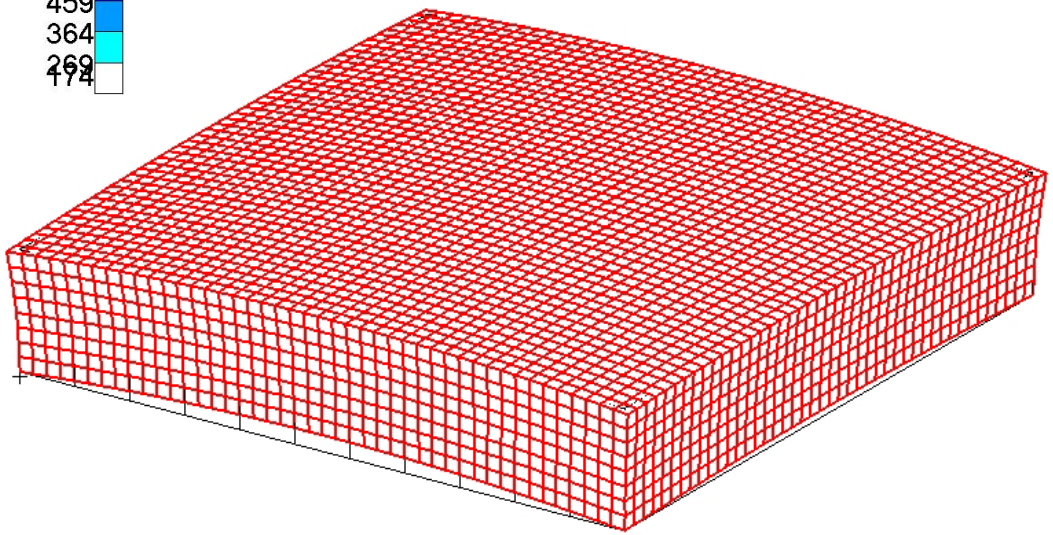


STRUCTURAL RESPONSE AT PEAK TEMPERATURE

t = 1900 sec

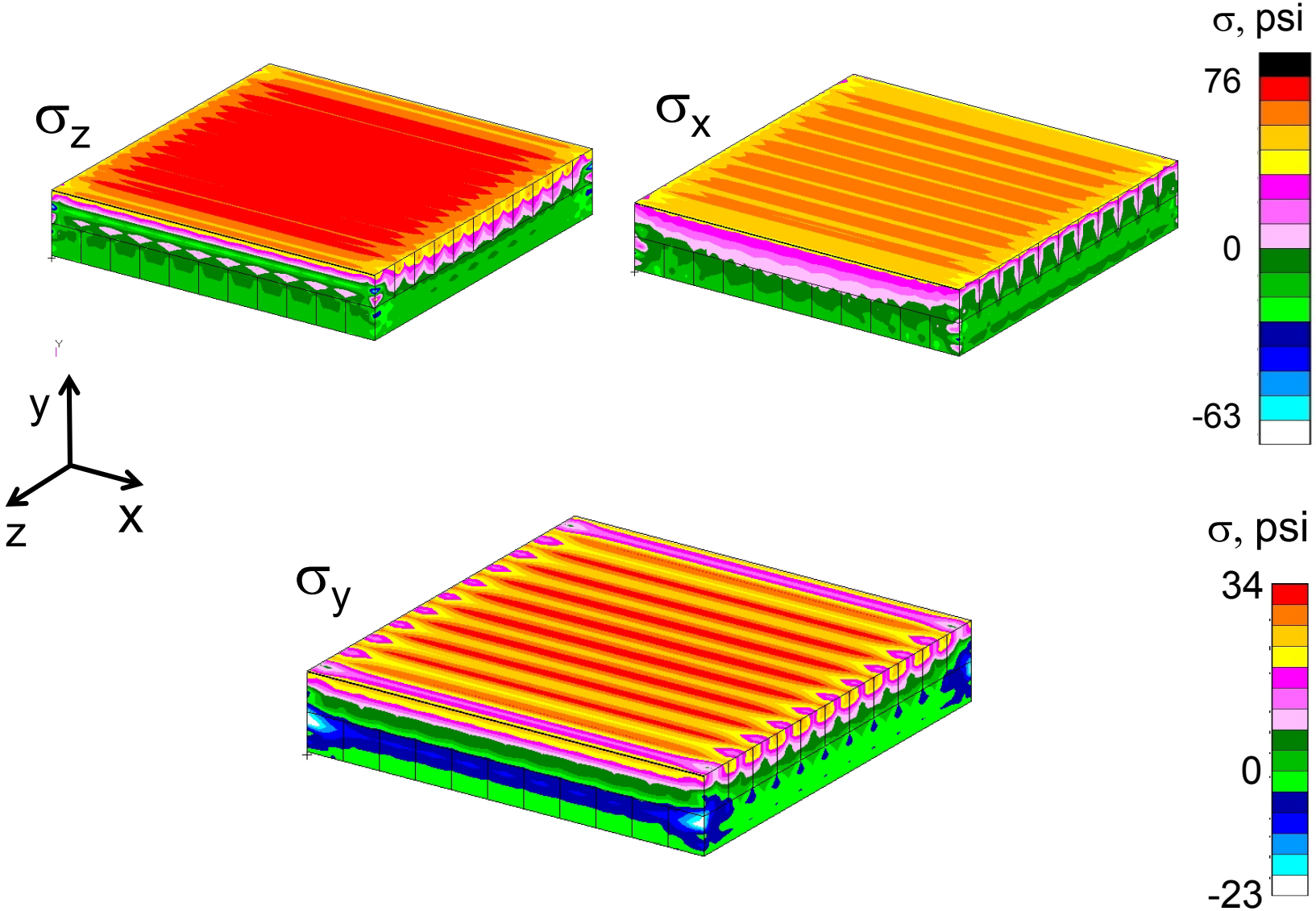


Deformation
(magnified x10)

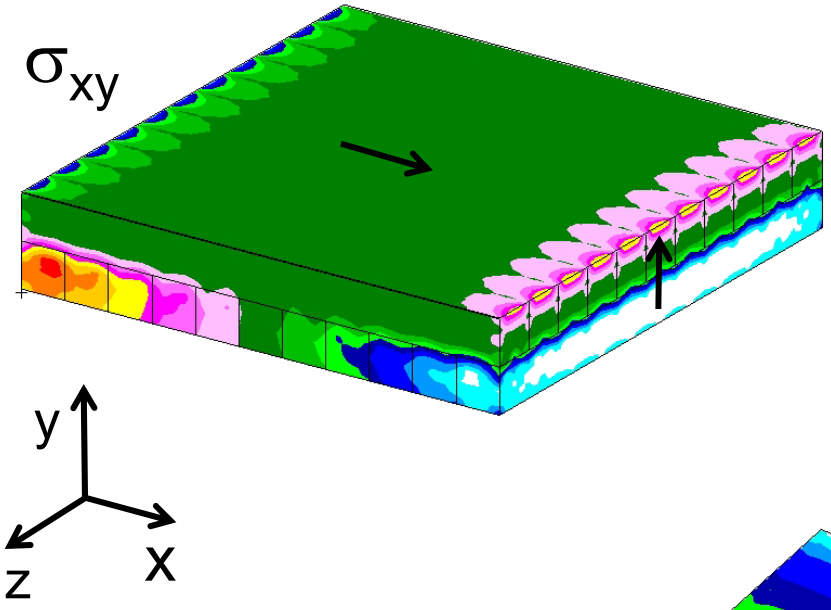


maximum deflection at center = 0.061 inch

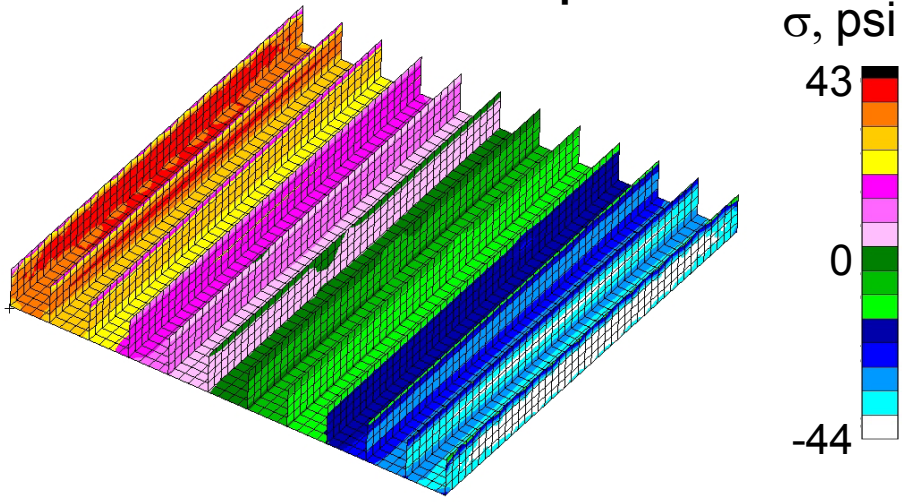
NORMAL STRESS AT PEAK TEMPERATURE

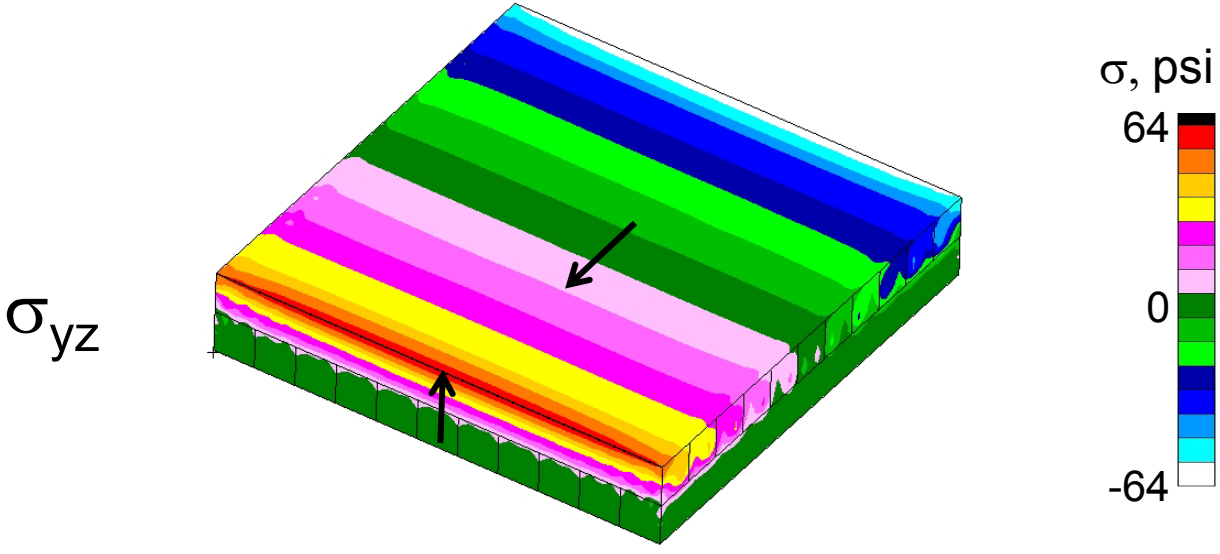


SHEAR STRESS AT PEAK TEMPERATURE



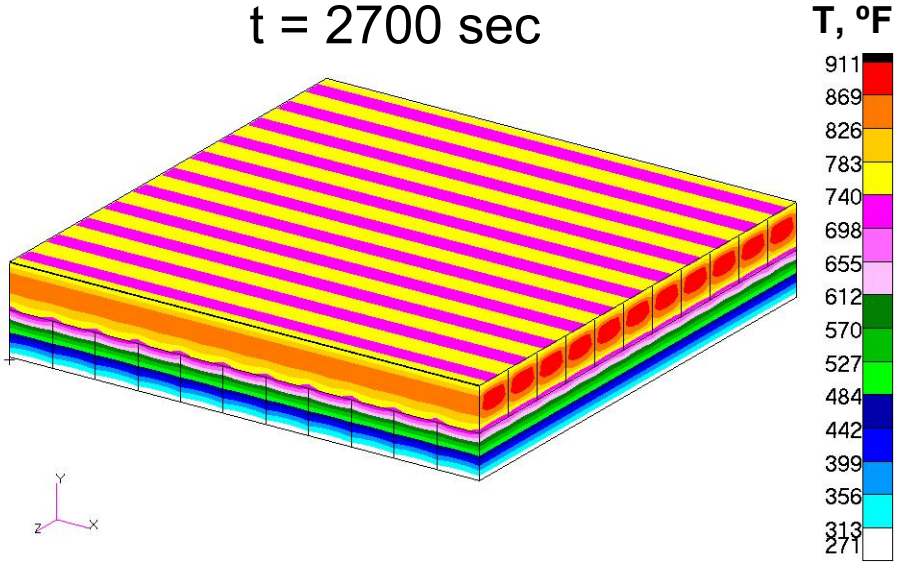
Bottom struts and plate



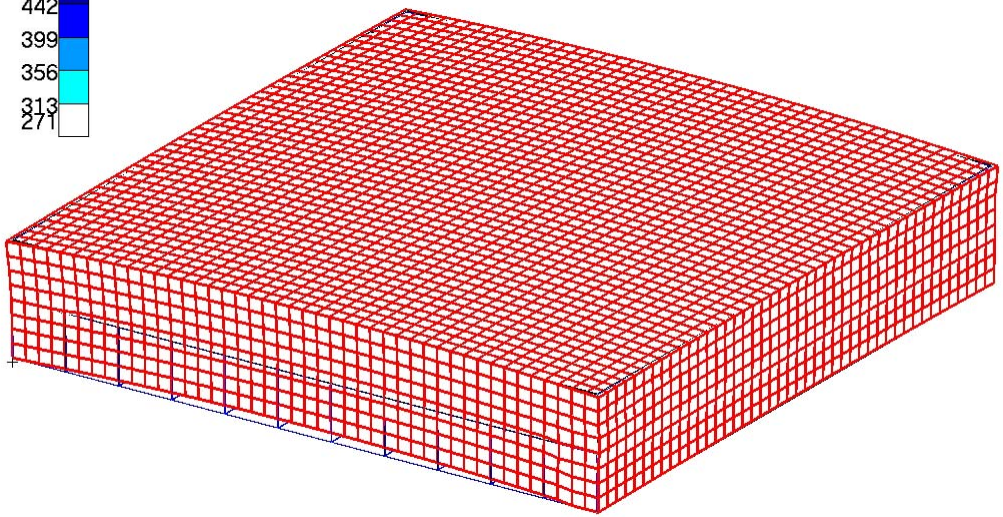


STRUCTURAL RESPONSE AT PEAK PRESSURE

t = 2700 sec

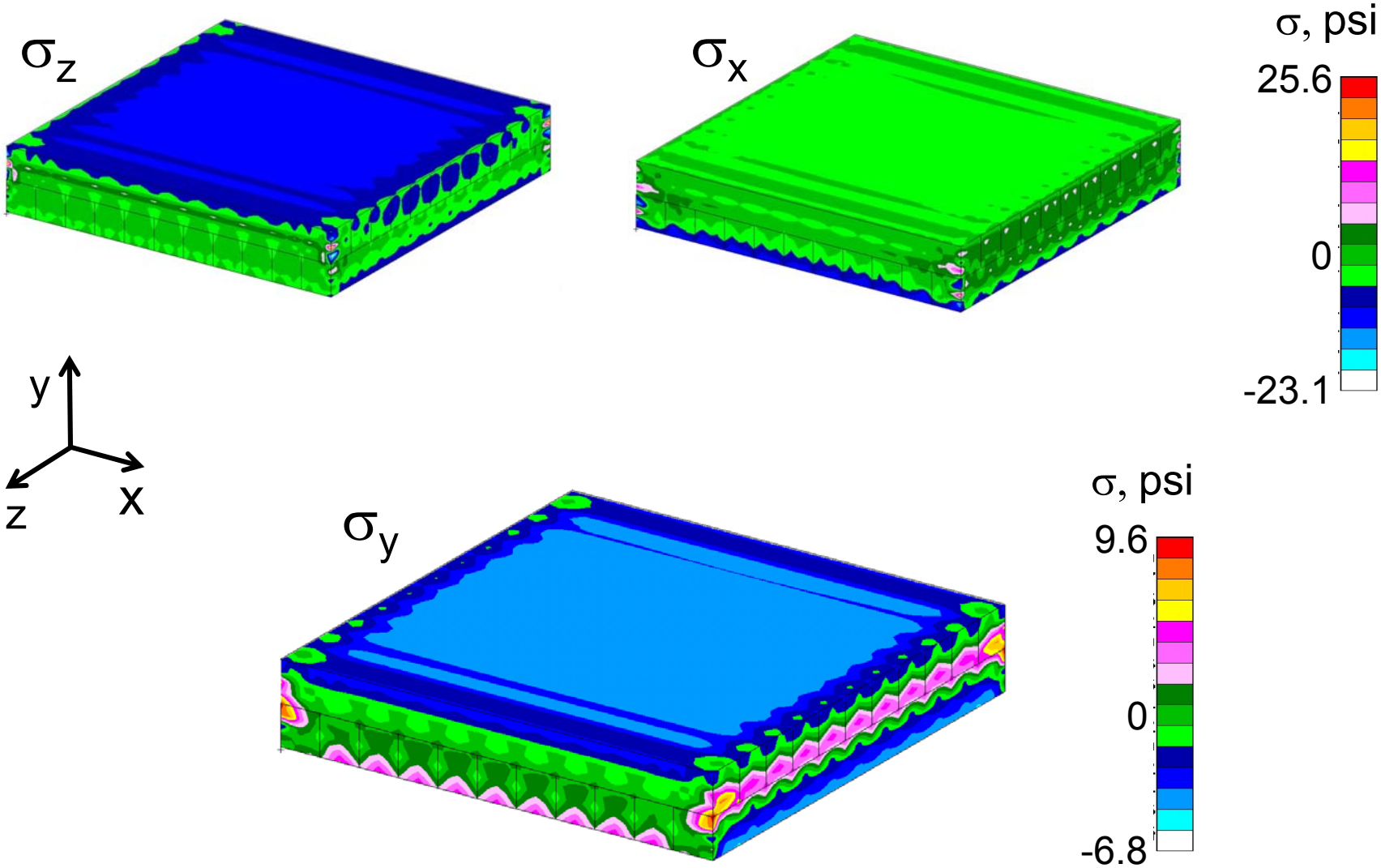


Deformation
(magnified x10)

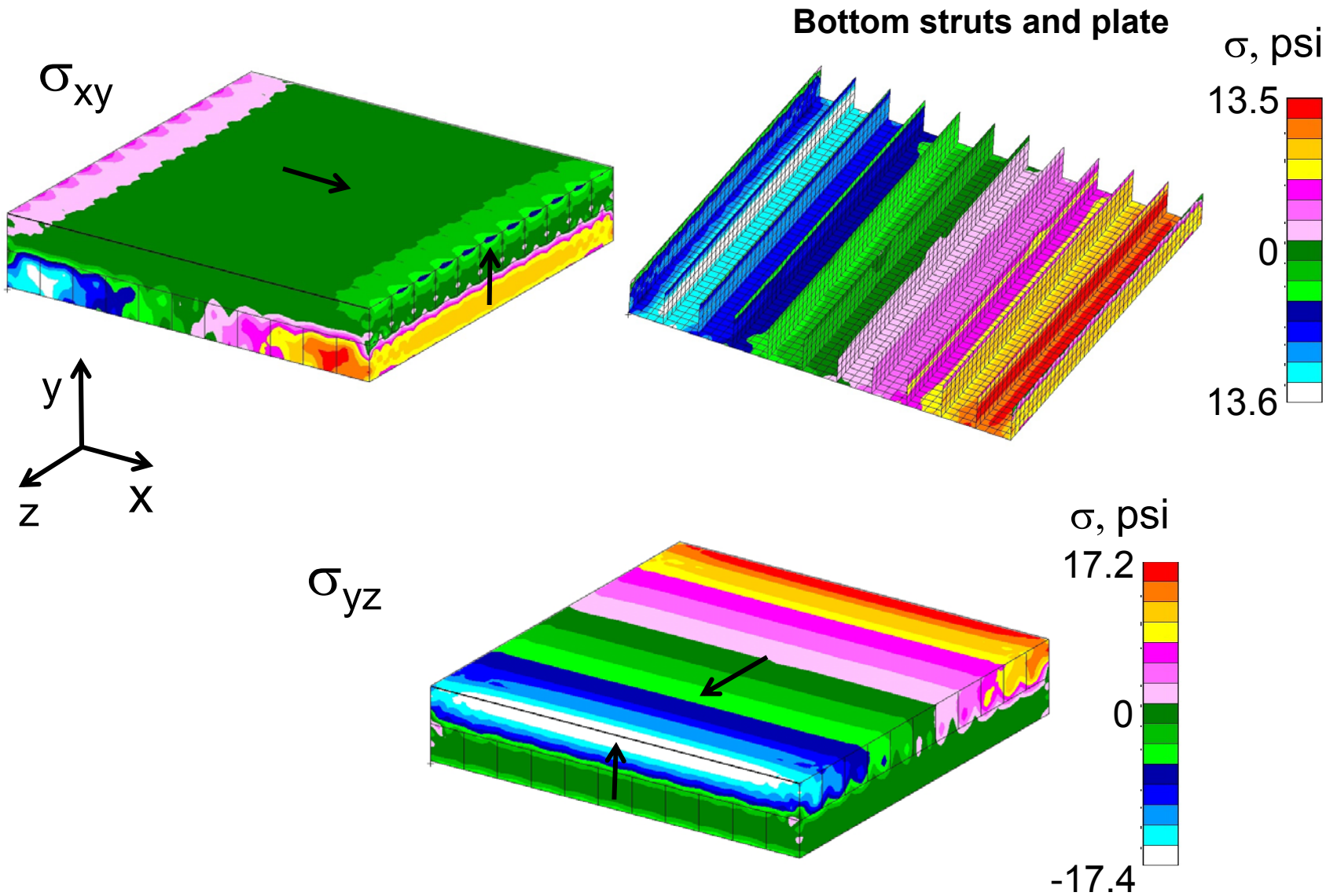


maximum deflection at center = 0.031 inch

NORMAL STRESS AT PEAK PRESSURE



SHEAR STRESS AT PEAK PRESSURE



CONCLUDING REMARKS

- The SITPS concept was sized for HRRLS upper stage re-entry heating, resulting in overall thickness of ~3, 3.25, and 3.7 inches at 10, 25, and 50% of vehicle length

- Thermal-stress analysis of the panel with baseline dimensions indicates that the concept is viable at the panel scale

- More load cases and realistic boundary conditions are required

FUTURE WORK

Near Term (≤ 1 year)

- **Thermal and structural analysis of a larger panel**
  - 20” x 40” with closeouts to be fabricated by COIC
  - Vehicle-size portion of windward fuselage
- **Structural sizing when other load cases have been defined**
- **Identification of potential failure mechanisms and subcomponent tests to establish failure criteria**

- **Pre- and post-test analysis of thermal performance tests of fabrication demonstration panel**

Longer Term

- **Panel joints and attachments**
- **Manufacture of large-scale curved panels**