National Aeronautics and Space Administration

SITPS Analysis and Sizing on RALV Orbiter

Hypersonics Project

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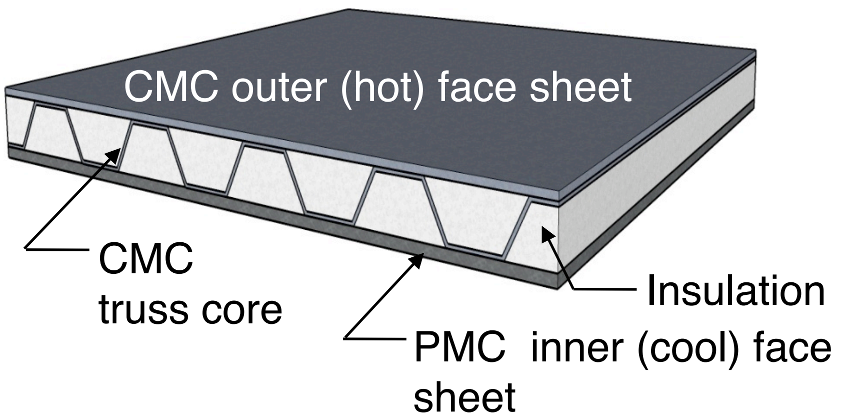
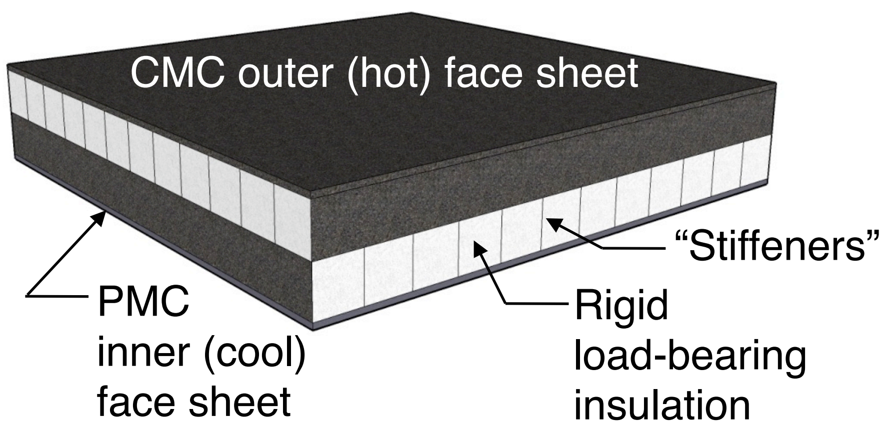
Outline

- Background: What is SITPS?
  Structurally-Integrated Thermal Protection System
- Structural Sizing
- Thermal Sizing
- Concluding Remarks and Future Work

Structurally-Integrated Thermal Protection Systems

The thermal protection system is load-carrying structure





CMC = Ceramic Matrix Composite
PMC = Polymer Matrix Composite

Potential Payoffs:

- Lighter vehicle weight by eliminating significant amount of primary structure
- More durable than external insulation
- Large panel sizes are possible
  - Fewer parts than stand-off TPS (heat shields)
  - Fewer gaps and seals

Vehicle-Level Design Challenges:

- Thermal growth
- Panel closeouts, joints, and attachments

Fabrication Challenges:

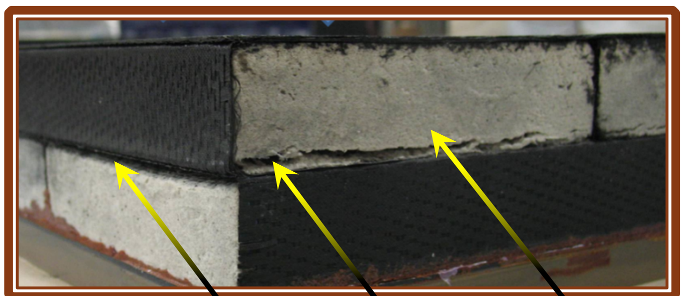
- Bonding for high temperature applications
- Bonding of different materials
- Fabricating large parts with complex geometries

SITPS Technology Development

Fabrication Demonstration Article 1

- 1-inch X 1-inch AETB-16 insulation bars
- SiC/SiC outer face sheet and over-wrap
- 0.1-inch thick PMC inner face sheet
- Thermal characterization & structural tests

Fabrication Demonstration Article 2



- 4-inch X 1-inch AETB-8 insulation bars
- SiC/SiC outer face sheet and over-wrap
- 0.04883-inch thick PMC inner face sheet (sized to match strength of outer face sheet)

AETB cracks and separation from SiC/SiC during application of PMC face sheet

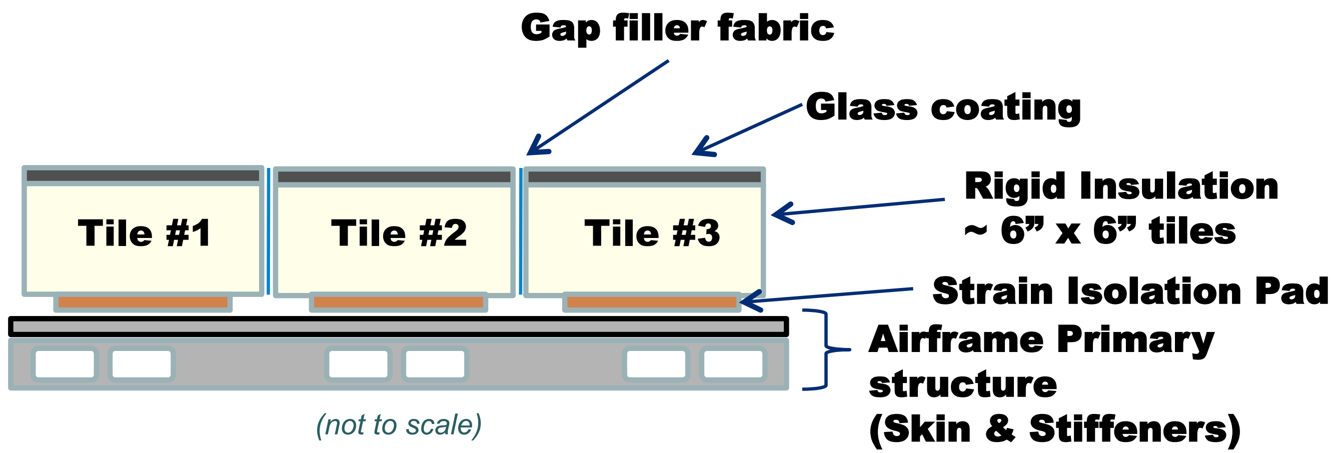
Fabrication Demonstration Article 3

- 2-inch X 1-inch AETB-12 insulation bars
- SiC/SiC outer face sheet and over-wrap
- 0.04883-inch thick PMC inner face sheet

SiC/SiC = Silicon Carbide Fibers in a Silicon Carbide Matrix

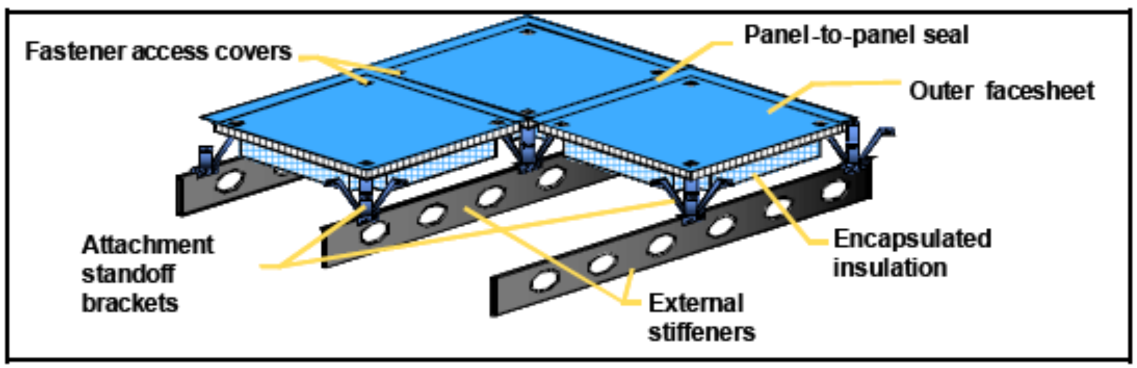
Conventional TPS: Tile and Stand-Off Panel

Space Shuttle & X-37



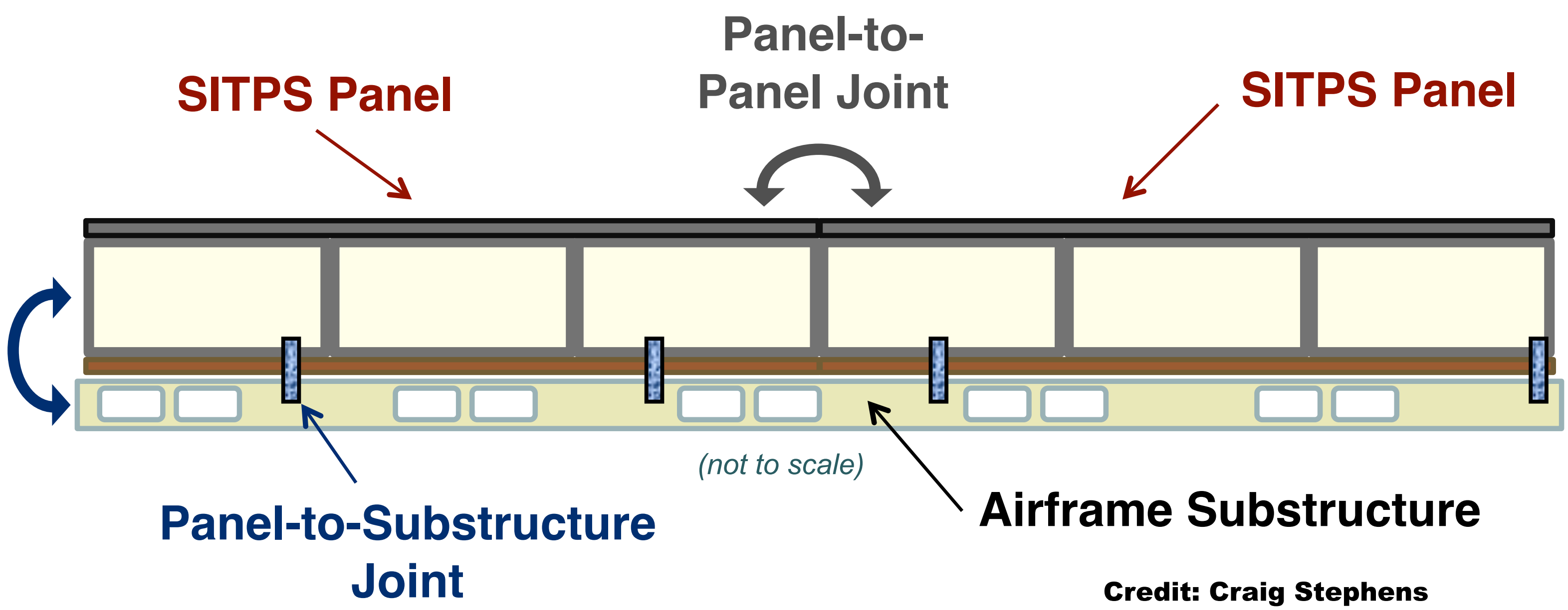
(not to scale)

X-33



- Each tile or panel is independent of its neighbors
- Aero pressure load transferred to airframe primary structure
- Inertial (vehicle) loads are carried by airframe primary structure

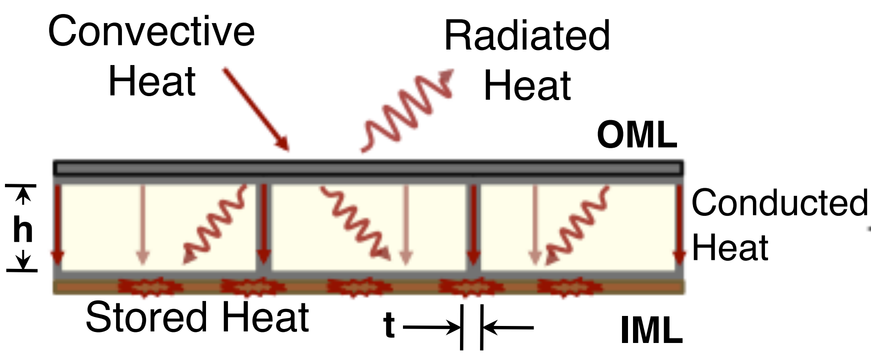
Distinguishing Features of SITPS



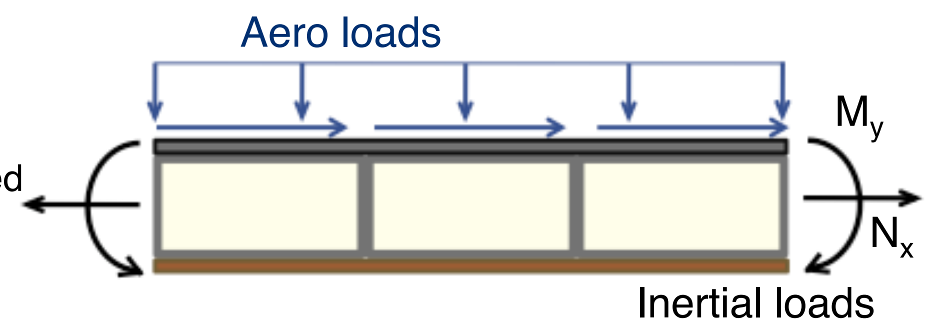
- Panels are joined to each other and act as a unit
- Inertial, aero pressure and shear loads are shared by panels and airframe substructure which together form the primary structure

Design Challenge: Resolving the Conflict

Thermal Loads



Structural Loads



To improve thermal performance	Approach	Impact on structural performance
Minimize Heat Shorts	Decrease the number	May decrease structural efficiency, i.e., <u>load-carrying capacity</u> weight
	Decrease the thickness	
Maximize Insulating Capability	Increase height	

Combined Thermal and Structural Sizing is Required!

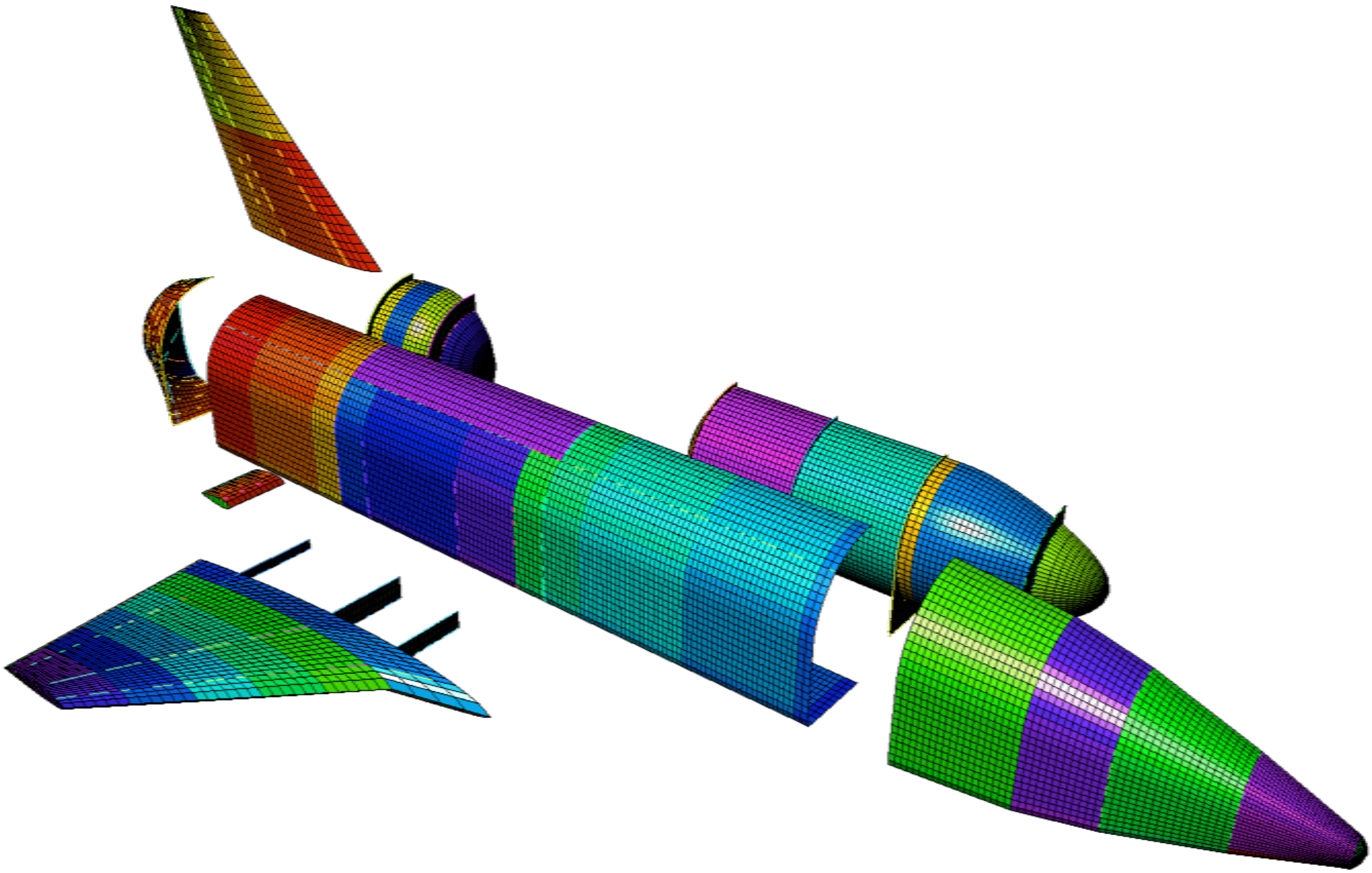
SITPS Analysis and Sizing

- Existing methods and tools for vehicle-level sizing are based on conventional structure/TPS concepts, and therefore inadequate for SITPS

- Mass estimation relationships (MER's) for conventional structure/TPS concepts were used in system studies

- To verify MER's, independent higher fidelity structural sizing of conventional structure and thermal sizing of SITPS was performed
  - Thermal loads were not considered for structural sizing
  - Structural loads were not considered for thermal sizing

Orbiter Structural Sizing



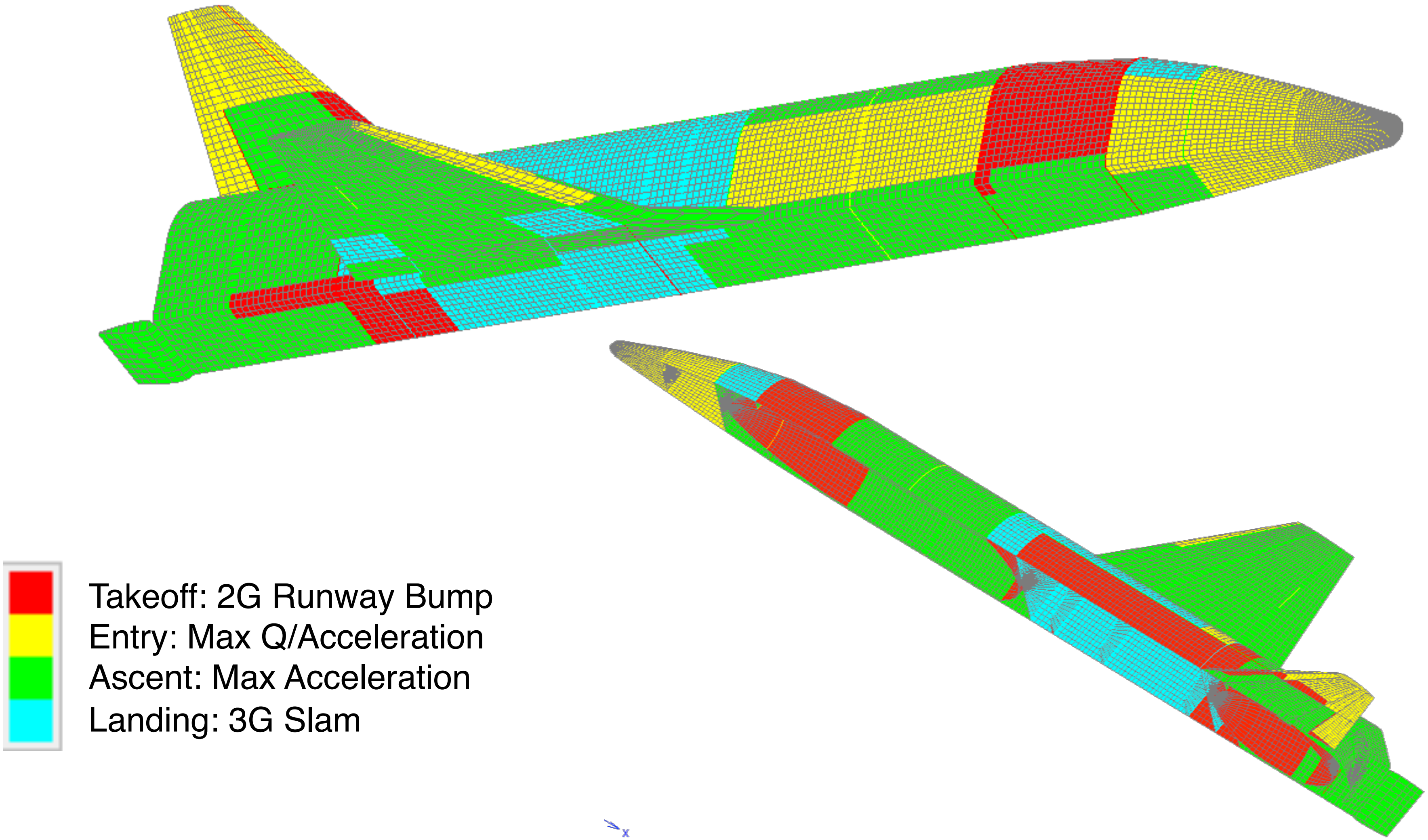
Mechanical Load Cases Considered

- Takeoff: 2G Runway Bump
  - Full tanks, no aero (surface pressure), no thrust, 2G vertical, 0.5G axial, payload
- Ascent: Max Acceleration
  - Immediately after separation
  - Full tanks, mapped aero, thrust, inertia, payload
- Entry: Max Dynamic Pressure/Max Acceleration
  - Empty tanks, mapped aero, no thrust, inertia, payload
- Landing: 3G slam
  - Simplified and combined case
  - Empty tanks, no aero, no thrust, payload, 3G vertical on both forward and aft gear points

Structural Sizing Approach

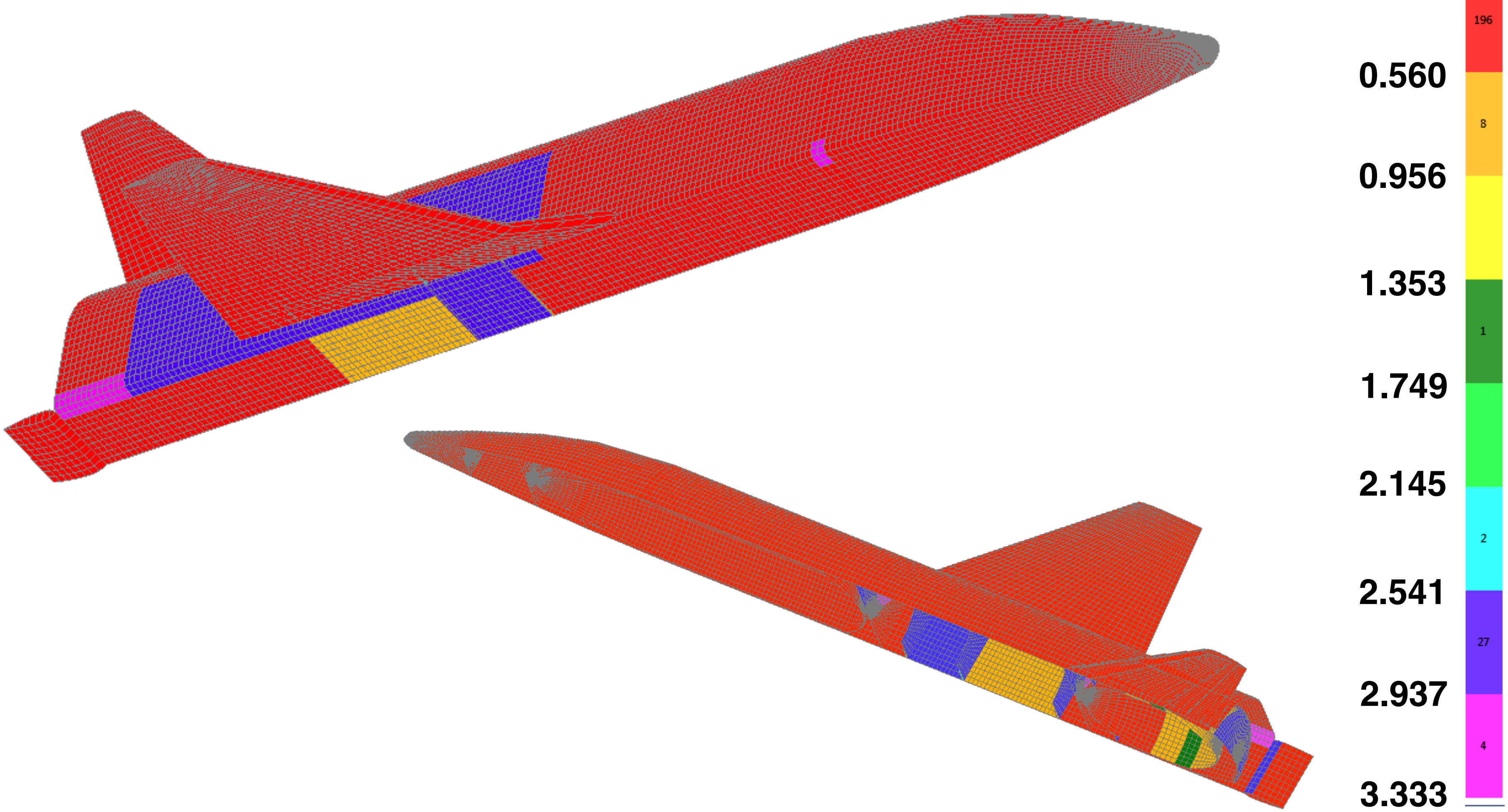
- Mechanical load cases applied to model and analyzed in NASTRAN to compute internal loads
- Components sized in HyperSizer to support computed loads
- Non-optimum structural factor of 1.5 applied mass to represent build-ups, tolerances, fasteners, and joints
- Three structural concepts, used for all components, were analyzed:
  - Solid metal panels (Al 2219 or Al-Li 2195) – Upper Bound
  - Stringer stiffened metal panels (Al 2219 or Al-Li 2195)
  - Honeycomb sandwich panels: C/Ep Composite face sheets with aluminum core (IM7/977-3 and Hexcel Al 5052)

Load Cases Governing Structural Sizing



Weight Distribution

Sandwich Panel Concept: C/Ep Face Sheets, Al honeycomb core



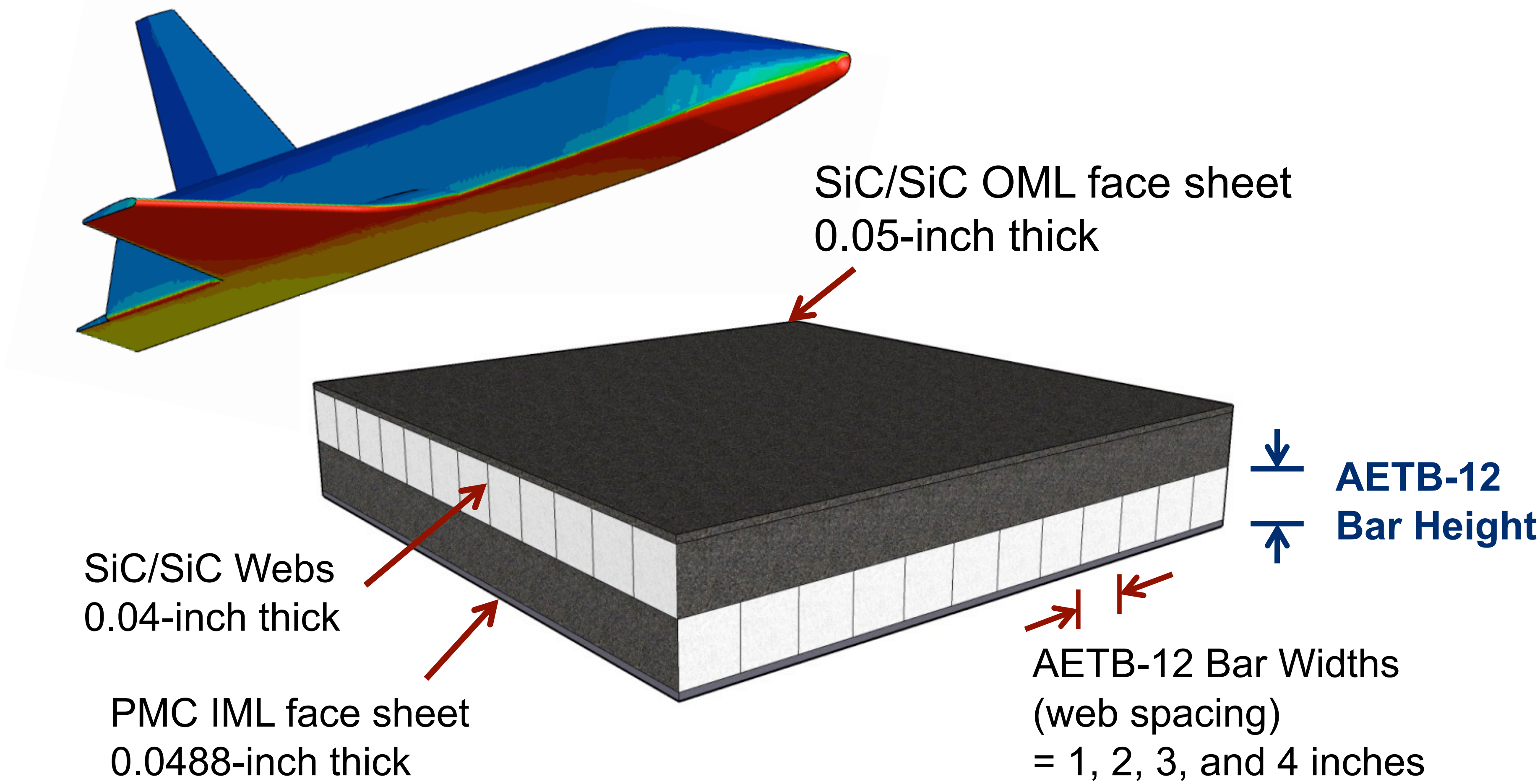
Structural Weight Summary

Structural Component		MER's	Concept		
			Solid	Stiffened	Sandwich
		Mass (lb_m)			
Aerodynamic Surfaces	Wing	7106	15208	7178	2719
	Vertical Tail	1628	2442	1150	635
	Body Flap	1620	1212	1036	305
Body	Primary	19504	27321	21750	15148
	LH_2 Tank	4879	6899	7320	1336
	LOX Tank	2211	1879	2207	1135

Total Half-Vehicle Mass	36947	54961	40641	21278

MER's = Mass Estimating Relationships

Orbiter TPS Sizing

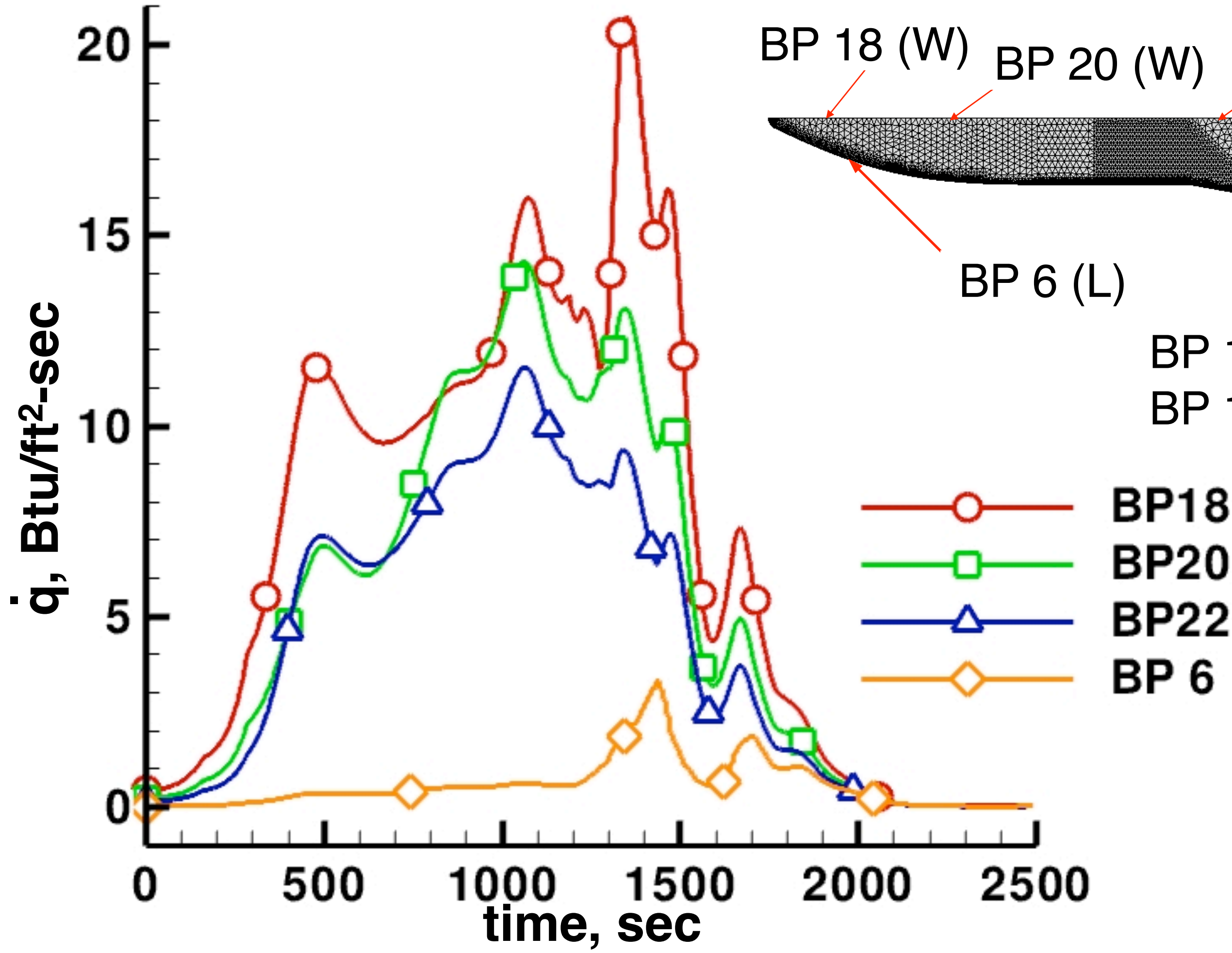


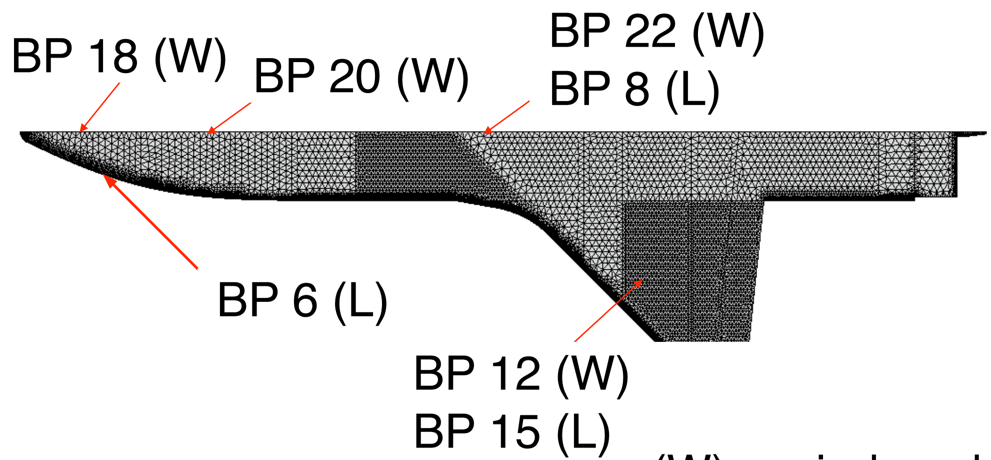
AETB-12 bar height sized to meet PMC material temperature limit

Orbiter Entry Heating at Select Body Points

Includes additional 25% margin

Data Provided by Jeff Bowles, NASA ARC



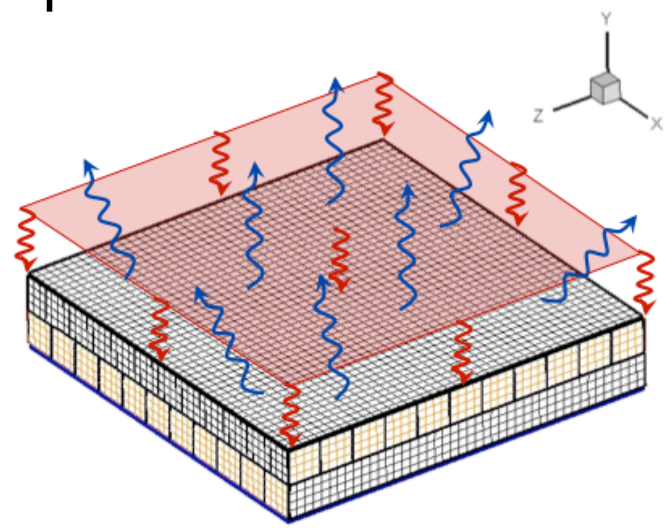


(W) = windward
(L) = leeward

BP	Location
12,15	Wing 25% Chord
18	Fuselage 5% Length
6	Fuselage 10% Length
20	Fuselage 20% Length
22, 8	Fuselage 50% Length

Orbiter Thermal Sizing Approach

- Thermal analysis performed with Abaqus* for various bar heights and widths

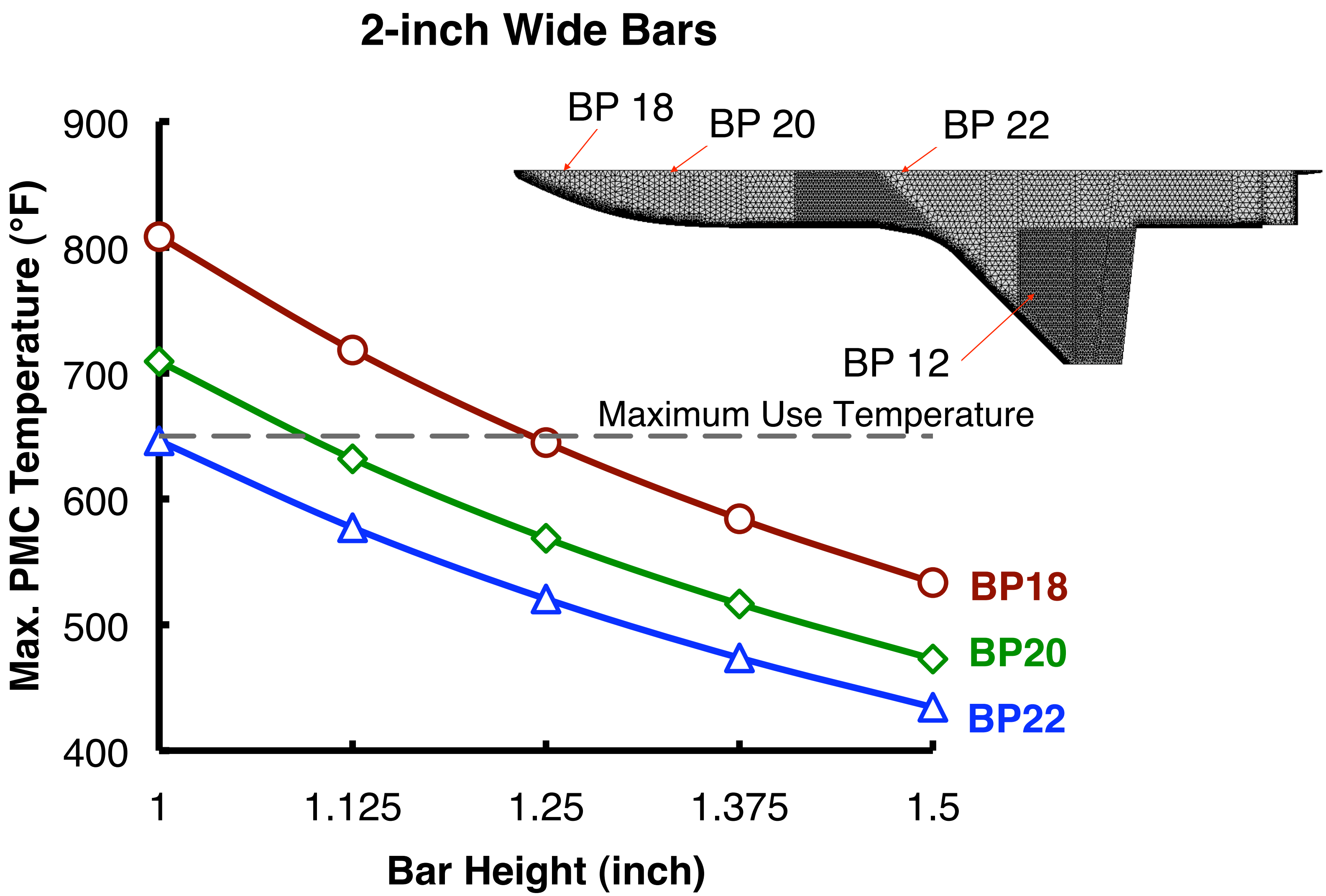


- Boundary conditions
  - Spatially-uniform $q = C_f(t)\,(T_{rec}(t)\text{-}T_{surf}(t))$
  - Radiation to space
  - Adiabatic sides and bottom

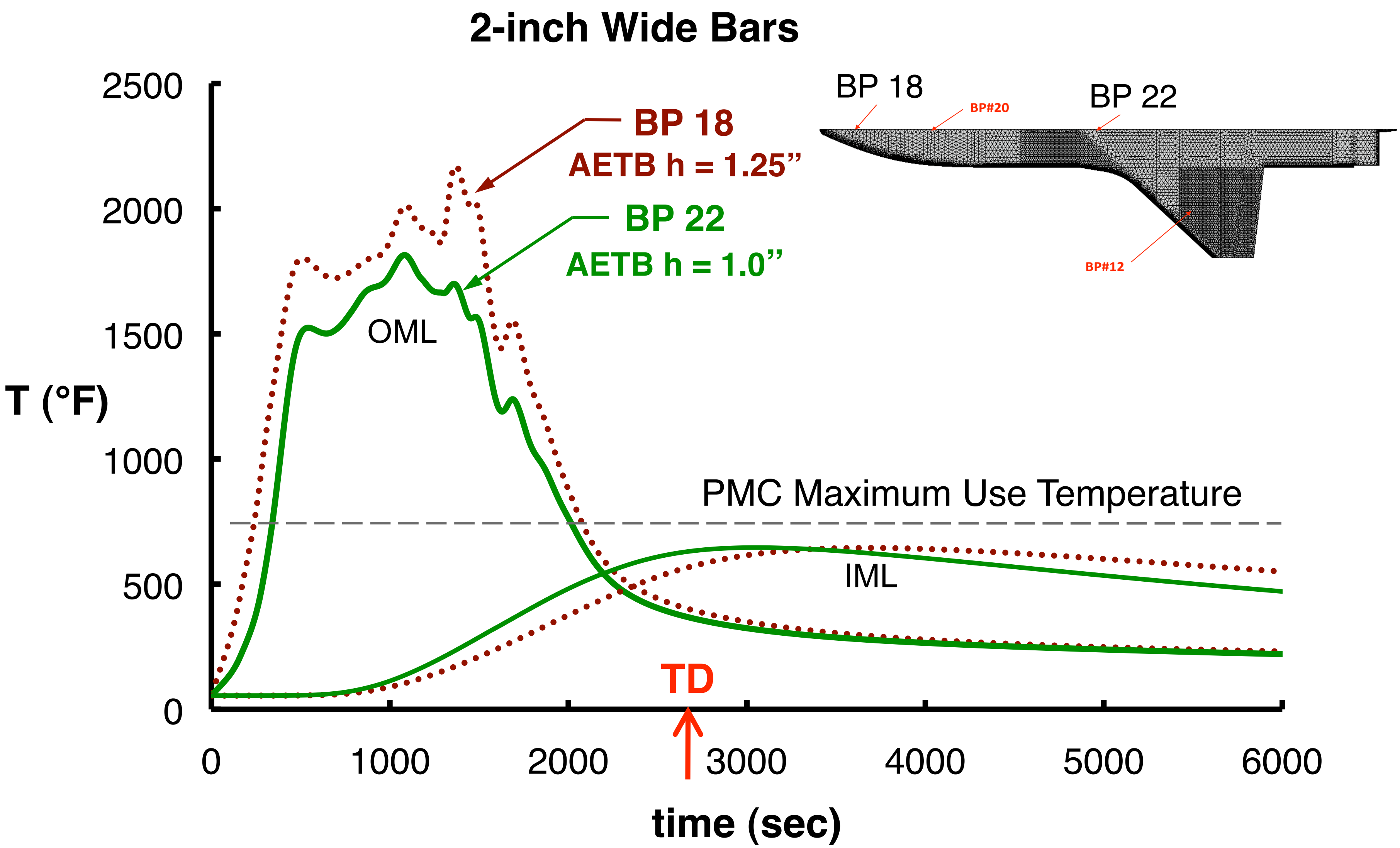
- Maximum-use temperature constraint for the materials
  - PMC ≤ 650°F
  - SiC/SiC and AETB temperature limits are automatically satisfied

*validated with thermal characterization experiments

Thermal Analysis Results for Windward Surface

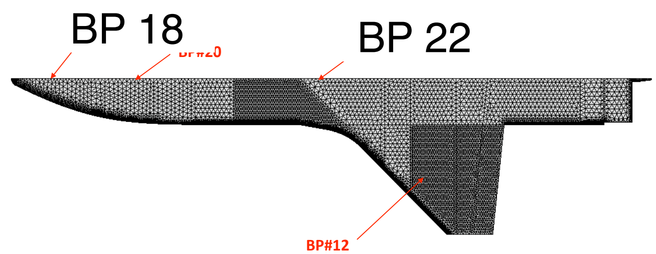


Temperature History for Sized Panels



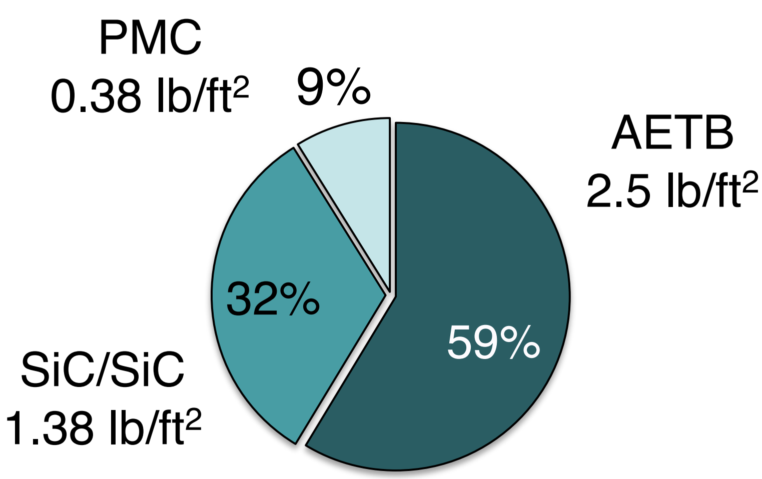
Weight Breakdown for Sized Panels

2-inch Wide Bars



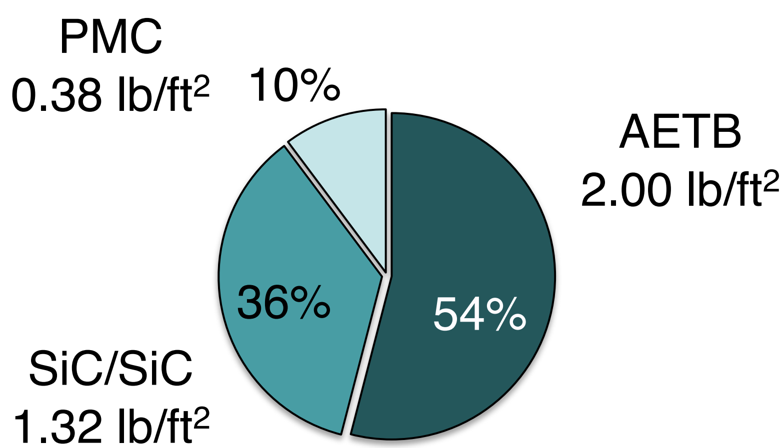
BP 18 (1.25-inch high bars)

Areal Weight: 4.26 lb/ft^2

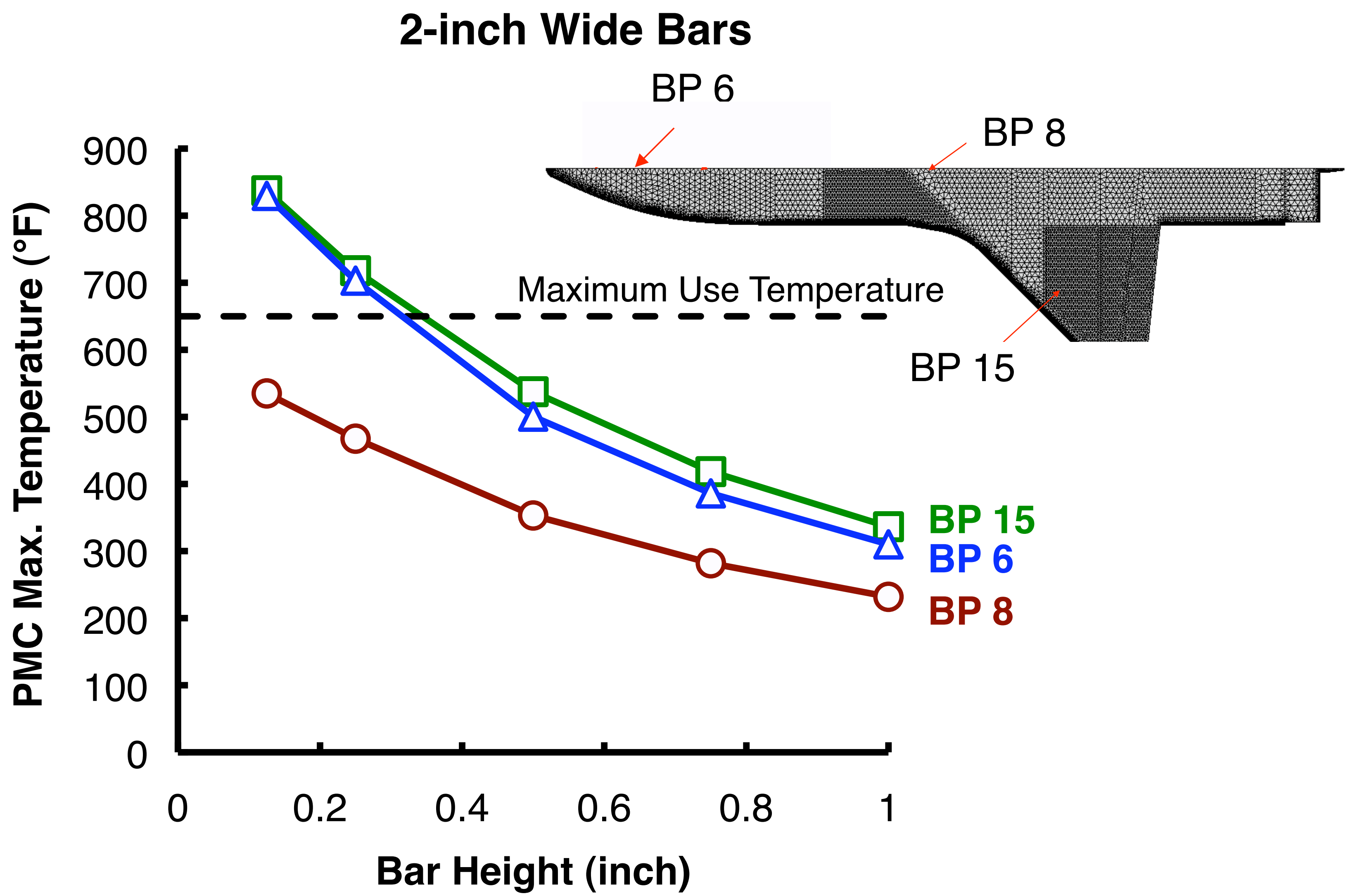


BP 22 (1-inch high bars)

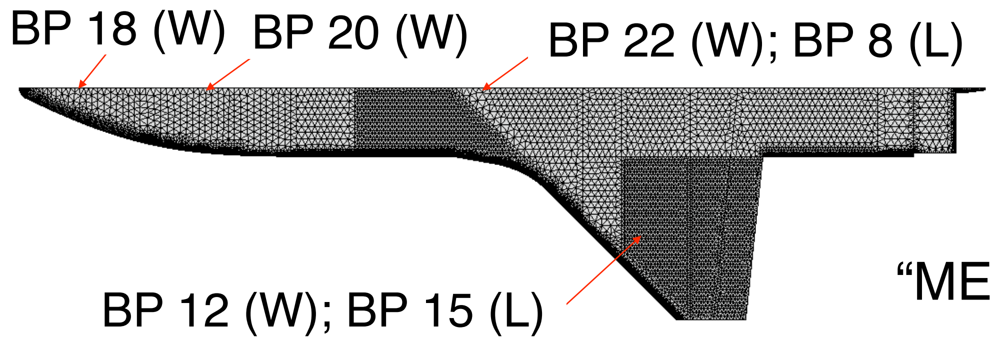
Areal Weight: 3.70 lb/ft^2



Thermal Analysis Results for Leeward Surface



Thermal Sizing Summary



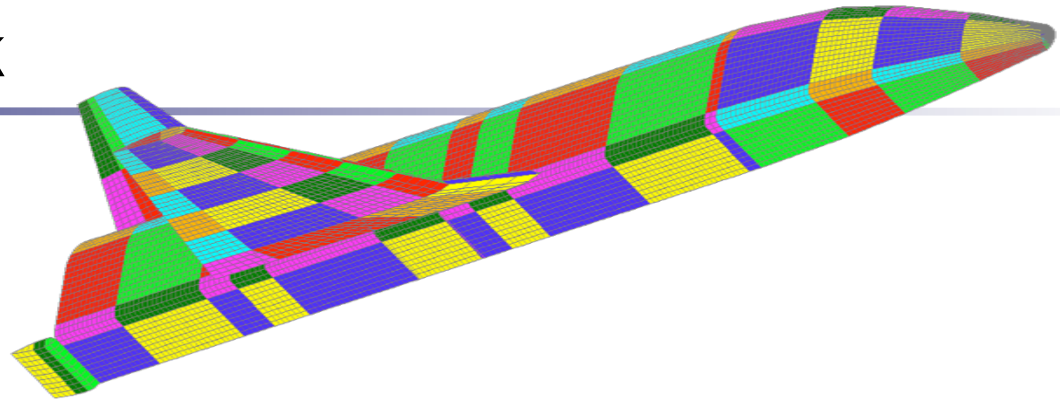
“MER” = 3 lb/ft^2

Surface	Body Point	Bar Width (inch)							
		1	2	3	4	1	2	3	4
		AETB Bar Height (inch)				Areal Weight (lb/ft^2)			
Wind	12	1.302	1.200	1.158	1.164	4.68	4.14	3.96	3.92
	18	1.311	1.241	1.199	1.186	4.71	4.24	4.05	3.97
	20	1.186	1.094	1.055	1.056	4.40	3.91	3.73	3.69
	22	1.056	1.000	1.000	1.000	4.07	3.70	3.62	3.58
Lee	6	0.367	0.316	0.296	0.283	2.37	2.16	2.10	2.06
	8	0.125	0.125	0.125	0.125	1.77	1.74	1.73	1.72
	15	0.401	0.344	0.323	0.309	2.45	2.23	2.15	2.11

Concluding Remarks

- Simple mass estimation relationships for RALV Orbiter were verified with higher-fidelity thermal and structural sizing methods applied <u>independently</u>
- Integrated thermal and structural methods are required to accurately size SITPS concepts
- Accurate SITPS sizing is required to estimate vehicle weight and trade SITPS against conventional structure/TPS

Future Work



NRA with Collier Engineering

- Integrated thermal-structural sizing of SITPS with Hypersizer
  - SITPS concept added to available suite of concepts
    - Structural analysis methods verified with high-fidelity FEM
    - Thermal analysis methods validated with experiment
  - FEM and structural loads delivered
  - Full-vehicle aerothermal loads are in progress
- RALV Orbiter trade study for SITPS and conventional TPS

In-House

- Alternate SITPS concepts
- Develop design tools required for SITPS

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