ZONAIR for RLV/TPS Design and Analysis

From SHABP to ZONAIR

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ZONA TECHNOLOGY

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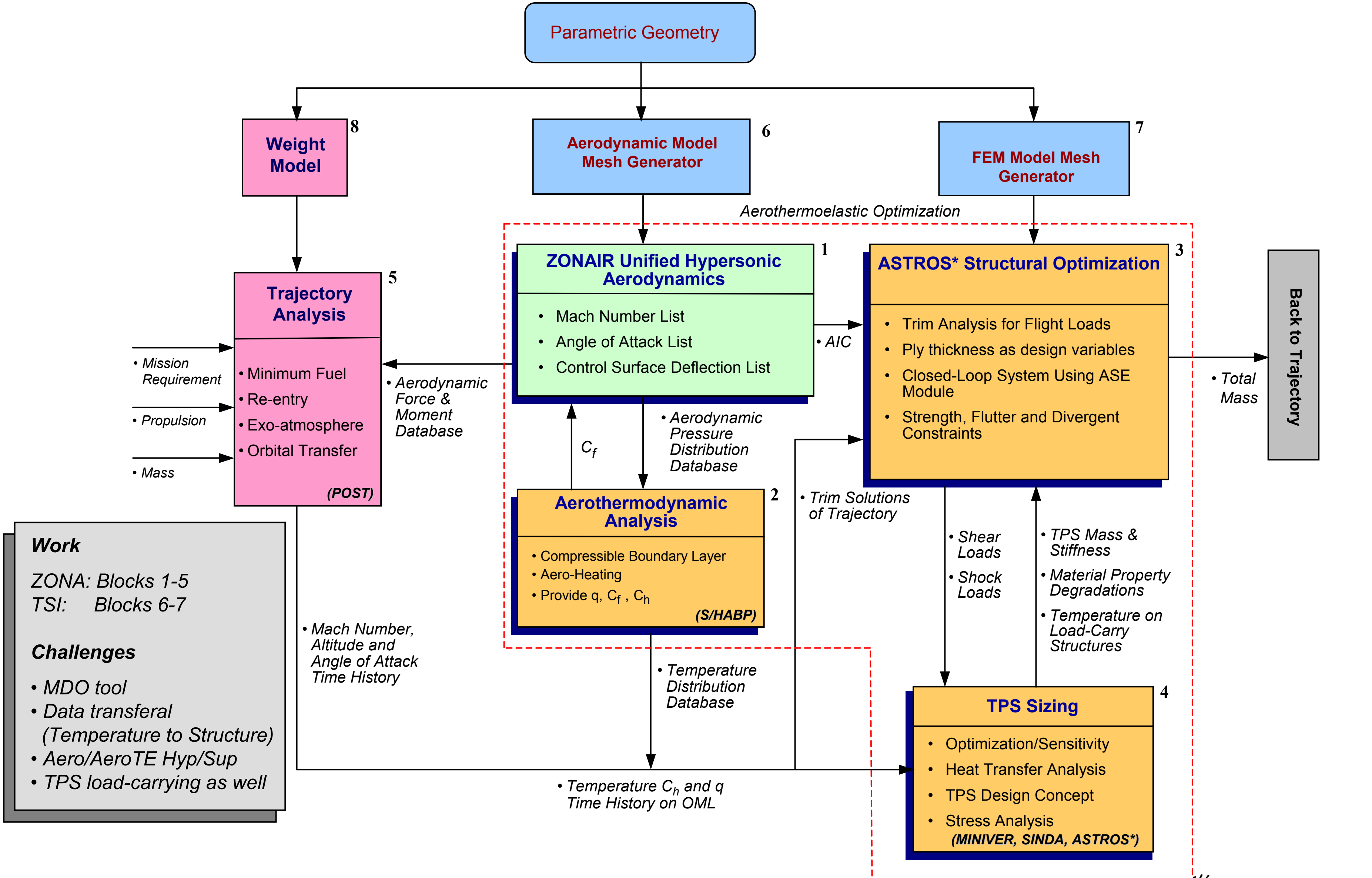
ZONAIR in HYAAT

HYpersonic Aerodynamic Aerothermoelastics for TPS program



ZONAIR vs S/HABP

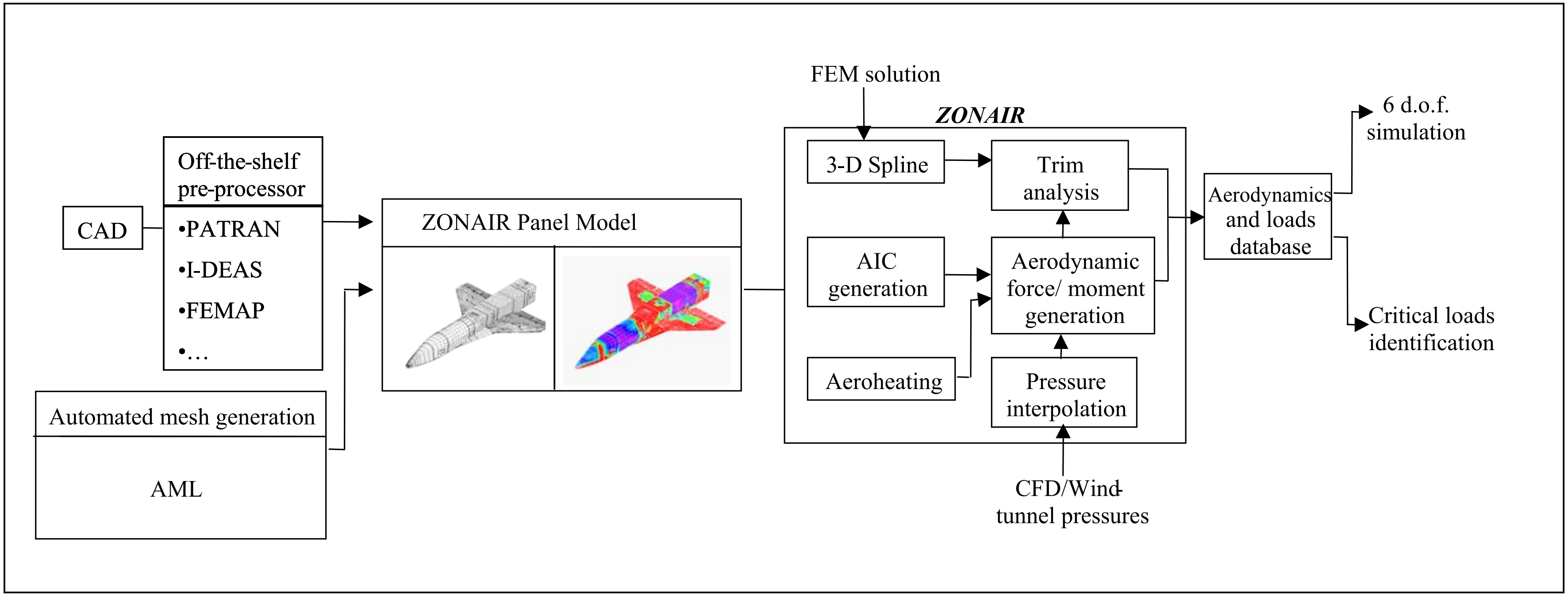
Method	ZONAIR ∈ HYAAT	S/HABP ∈ SHVD
Inviscid	Potential + Perturbed Ehler	Analytical/ Empirical
Streamline	- ZSTREAM - Finite Element Based - Mach no Dependent	- Quanstream - Mach no Dependent
Viscous & Thermal	Zoby's convective heating equations	Zoby's convective heating equations
Mach Range	Unified Subsonic/Supersonic/ Hypersonic	Supersonic/Hypersonic
Interference	Multi-Body/Ground Effect Aerodynamics	-
AML Mesh	√	√
Blunt Nose	√	√

ZONAIR Capability vs Other Aerodynamic Codes

ZONAIR is a versatile tool for rapid aerodynamic database generation
- **Aerodynamic AIC matrix readily coupled with FEM**
- **Force/moment coefficients**
- **Multi-body interference aerodynamics**
- **Accurate aerodynamics for aeroheating prediction**

Code	Method	Computational Efficiency	Streamline Solution for Aeroheating	Hypersonic/ Supersonic/ Subsonic Mach No.	AIC for Structural FEM	Geometry High Fidelity	High AOA	2 Body Aero Interference
CFD3D	Euler/N-S	30 hrs/ X-34	Yes	All	No	Yes	Yes	Yes
PANAIR	Potential	20 min/ X-34	No	Supersonic/ Subsonic	No	Yes	No	Yes
ZONAIR	**Potential + PEF**	**20 min/ X-34**	**Yes**	**All**	**Yes**	**Linear-Order Panel**	**Yes**	**Yes**
ZAERO	Potential + PEF	10 min/ X-34	Yes	All	Yes	Constant Order Panel	No	Yes
APAS	Potential + Empirical	<10 min	Newtonian S.L.	Empirical for hypersonics	No	Low-Order Panel	No	Yes
MINIVER	Analytical/ Empirical	<<10 min	No	No subsonics	No	No	No	No
DATCOM	Analytical/ Empirical	<< 10 min	No	All	No	No	Yes	No
AP98	Analytical/ Empirical	<< 10 min	No	All	No	No	Yes	No

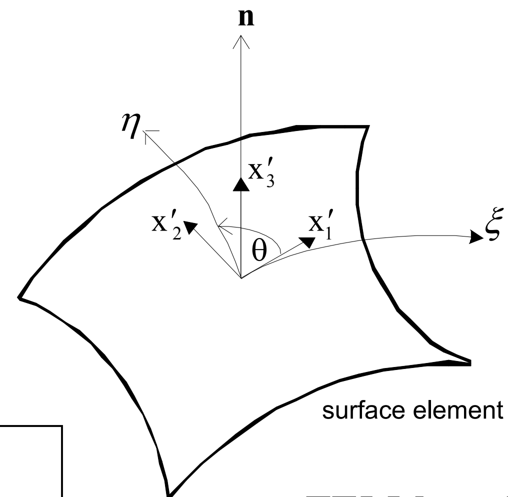
ZONAIR and Interfacing Capability w/ other Softwares



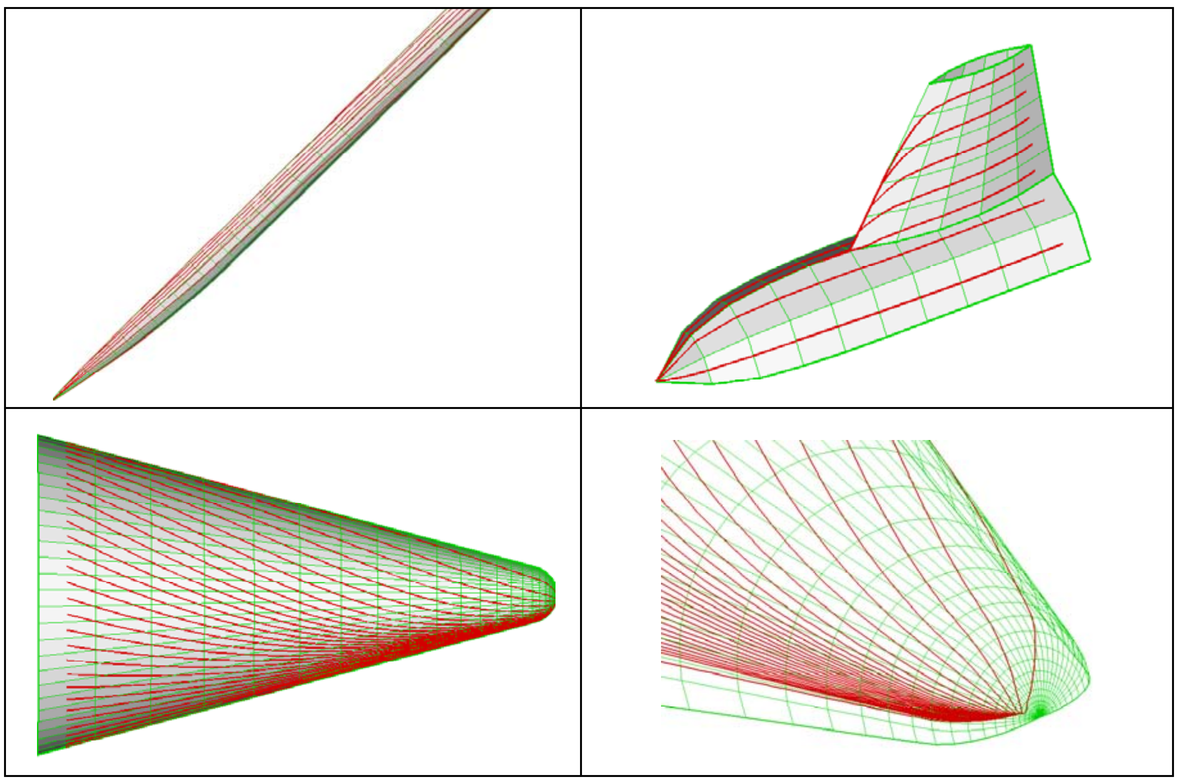
- Unified high-order subsonic/supersonic/hypersonic panel methodology
- Aerodynamic influence coefficient (AIC) matrix for rapid data retrieval
- Unstructured surface panel scheme compatible to the finite element method
- Rapid panel model generation using COTS/FEM pre- and post-processors
- Accurate streamline solution with axisymmetric analogy for aerothermodynamics
- Trim module for flexible loads and aeroheating module for TPS design/analysis
- Multibody interference/separation aerodynamics
- Pressure interpolation scheme for transonic flexible loads generation
- Aerodynamic database for 6 DOF simulation and critical loads identification

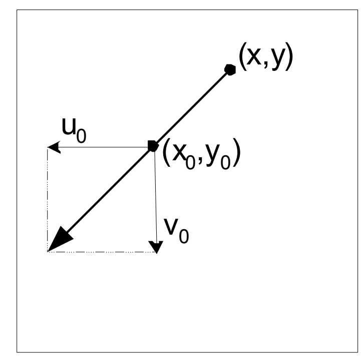
ZSTREAM for Stream Line Solution

- Aeroheating analysis requires inviscid flow streamlines
- QUADSTREAM in SHABP is not robust for quadrilateral panels and is Mach number independent
- ZSTREAM is finite-element-based derived from ZONAIR surface velocities



FEM-based





Marching from position (x_o, y_o) to (x, y)

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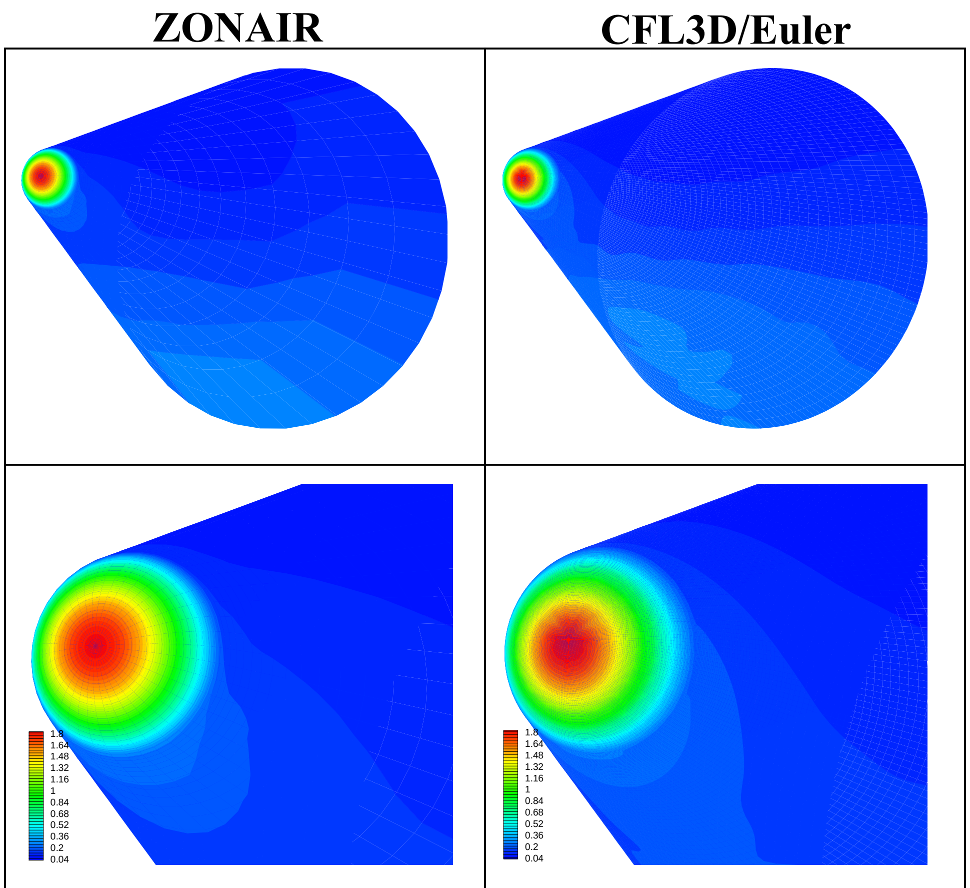
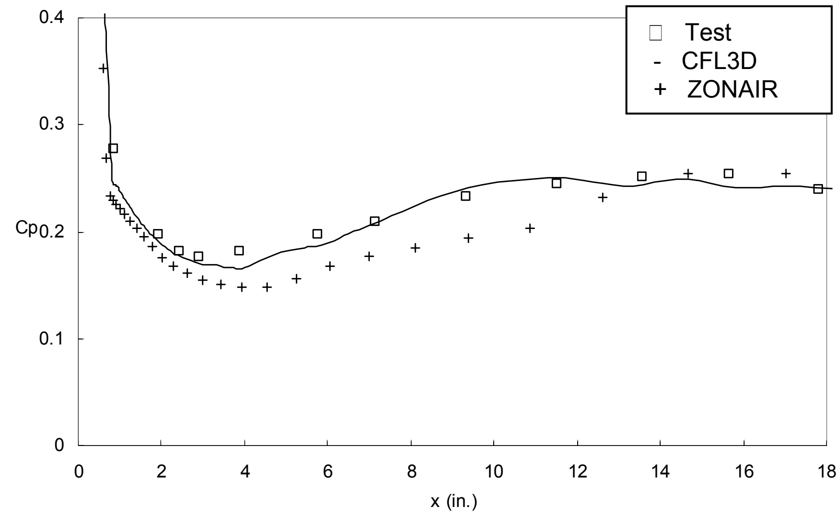
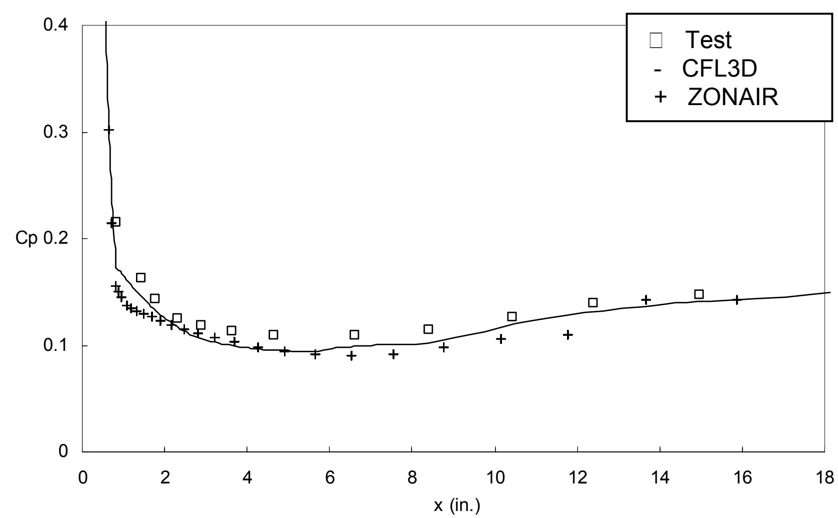
15º Blunt Cone: Aerodynamics

M = 10.6, α = 5º



Inviscid Surface Pressure Distribution





Inviscid Surface Pressure Distribution

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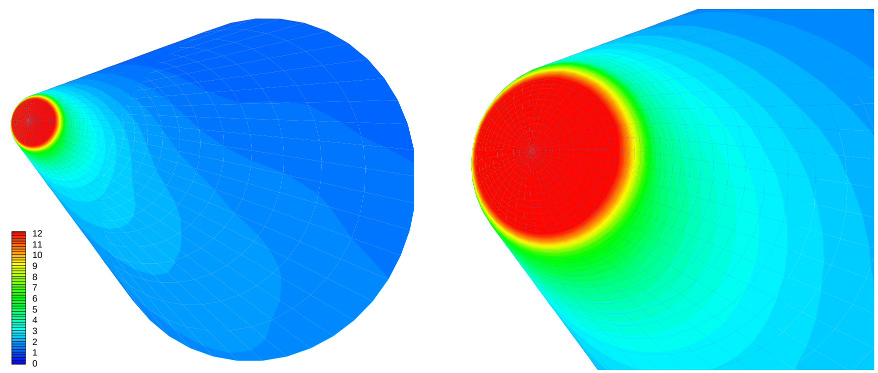
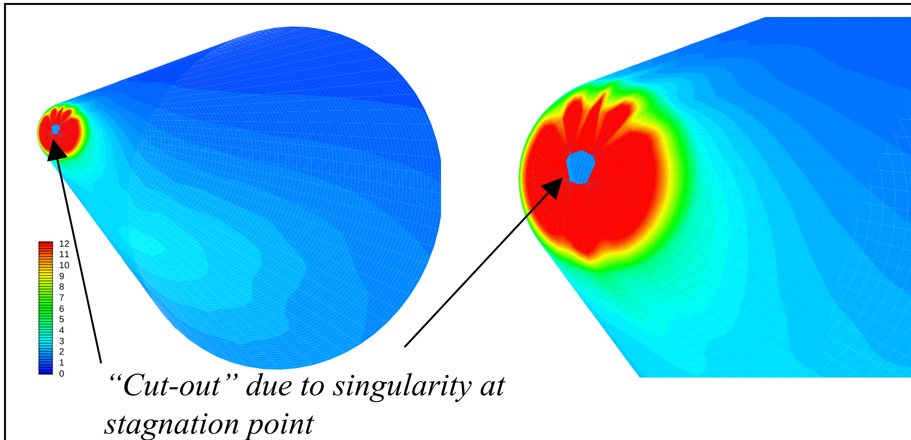
Laminar Heat Rate: 15º Blunt Cone

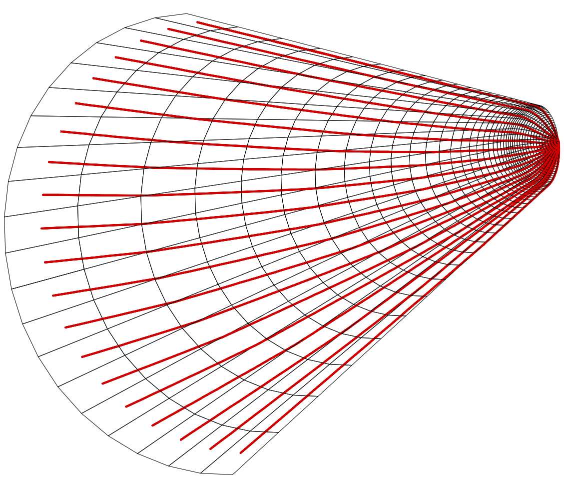
$M_\infty = 10.6$, $\alpha = 5°$, $P_\infty = 2.66\ lb/ft^2$, $T_\infty = 89.971°R$, $T_W = 540°R$

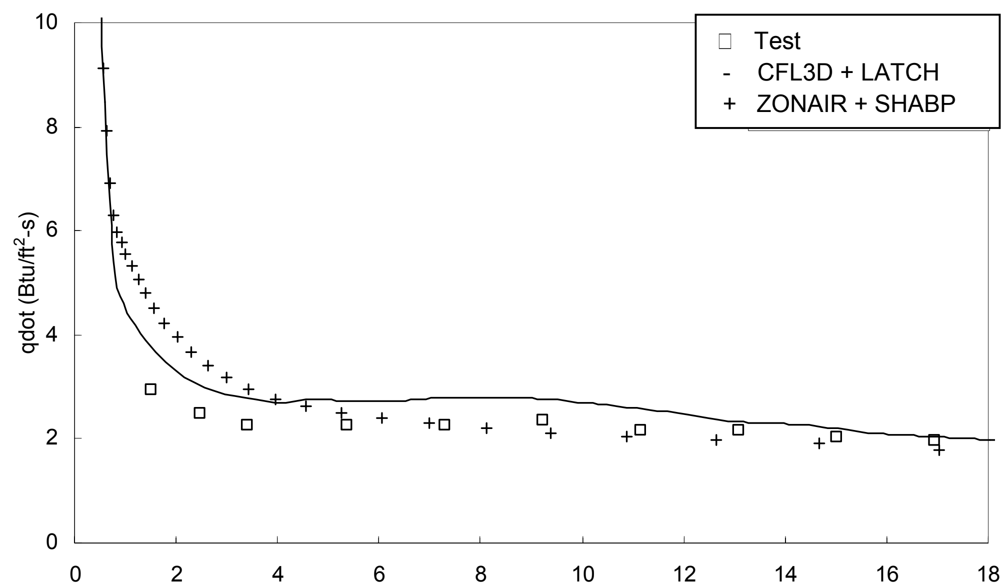


ZONAIR + SHABP



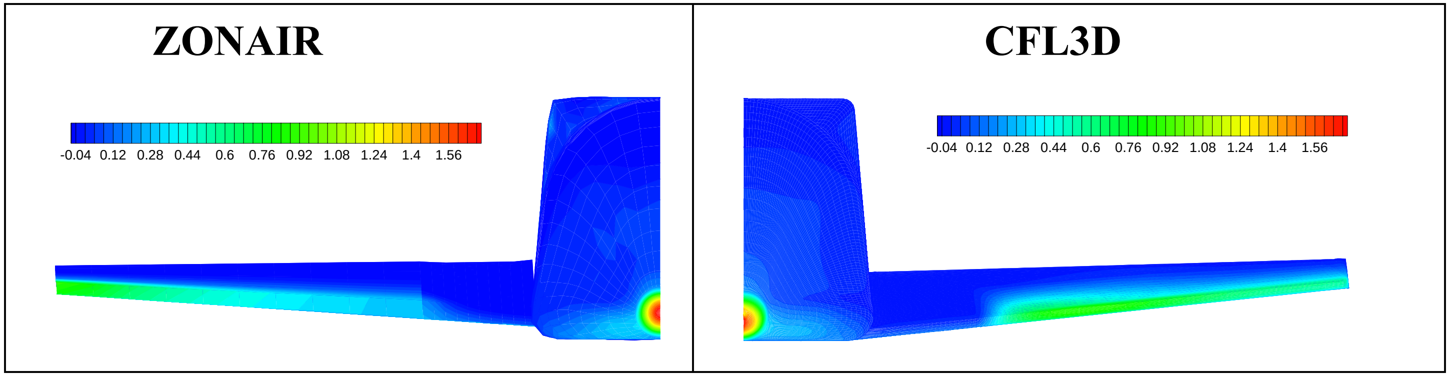
CFL3D/Euler + LATCH





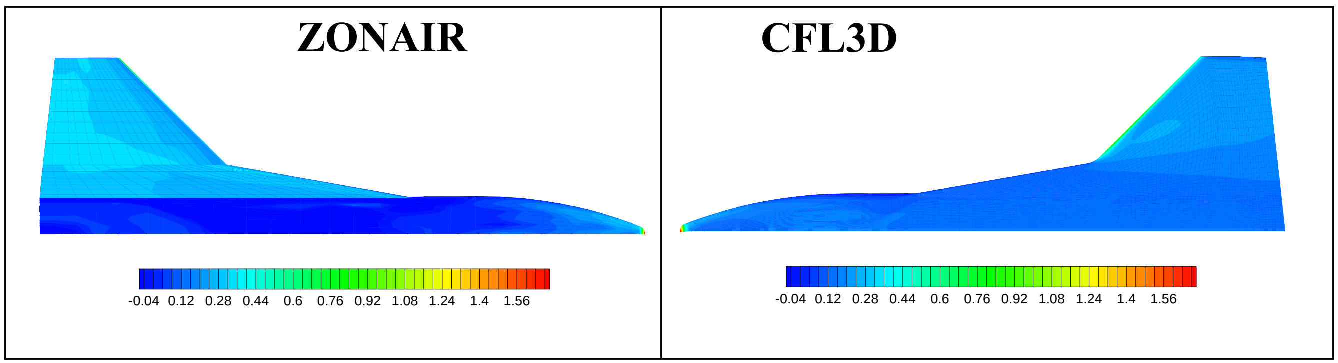
X-34 Wing-Body: Aerodynamics

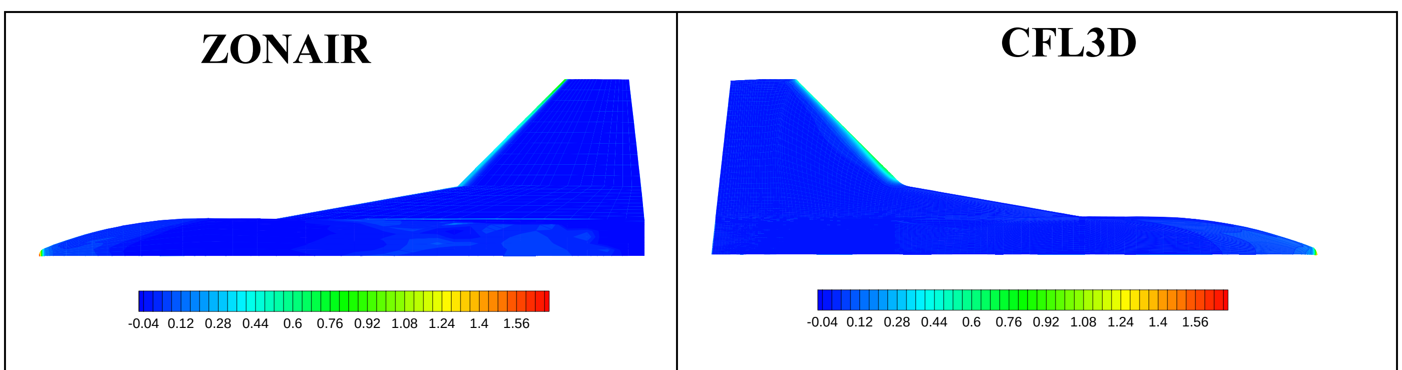
$M_\infty = 6.0,\ \alpha = 15.22°$



Front View

Wind-Side



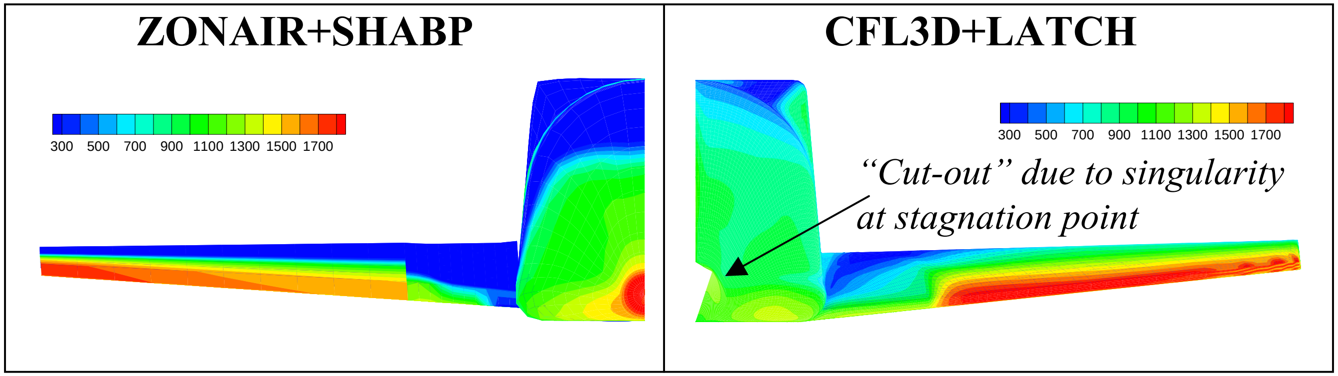


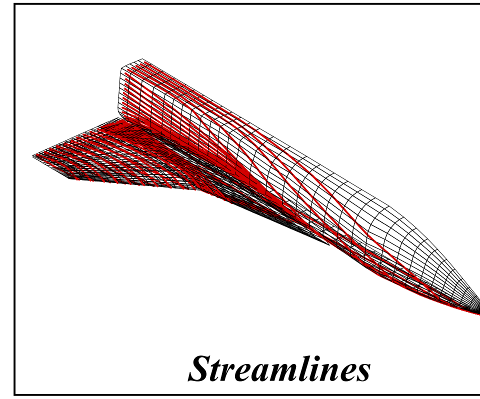
Lee-Side

Aeroheating of X-34

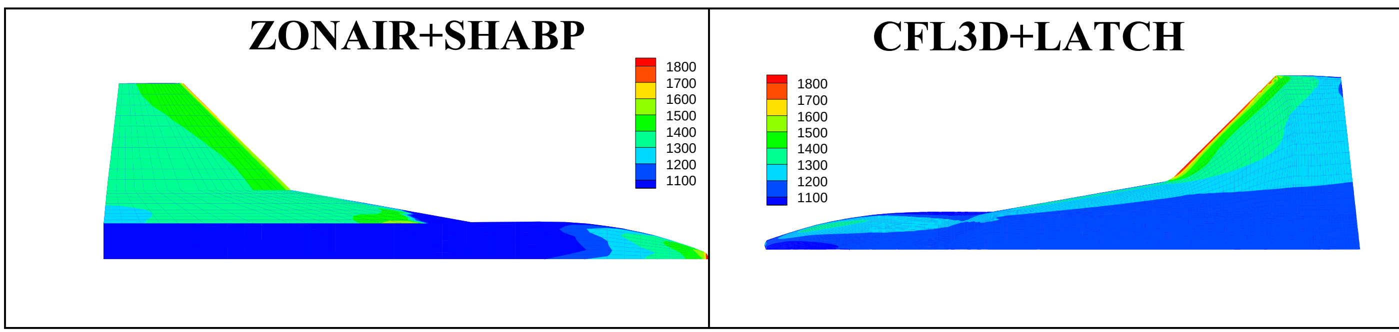
$M_\infty = 6.0$, $\alpha = 15.22^o$, $h = 112$ Kft., Hot Wall, Emissivity = 0.8, Turbulent

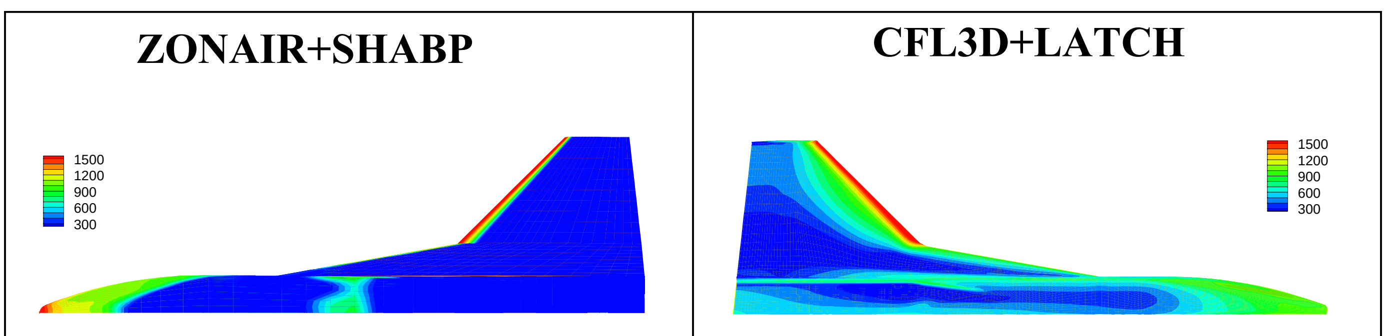
Front View





Wind-Side





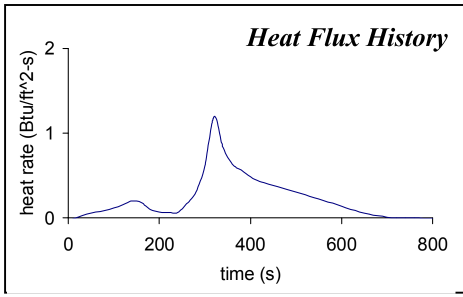
Lee-Side

ZONA TECHNOLOGY

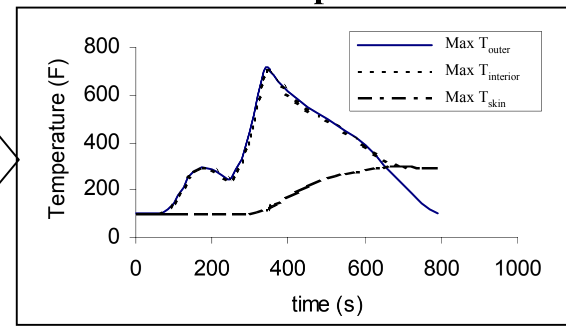
Elementary TPS Sizing of AFRSI

- TPS element selected on windward centerline of X-34 (point A @ L = 50'')
- Heat Rate Input provided by ZONAIR+SHABP from trajectory/aeroheating
- Minimum TPS weight obtained by MINVER/EXITS

Input

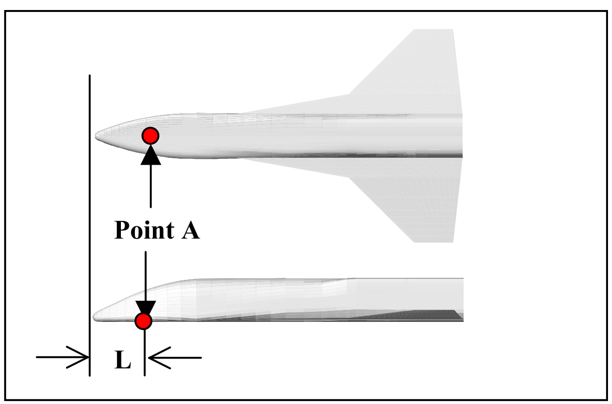


Output

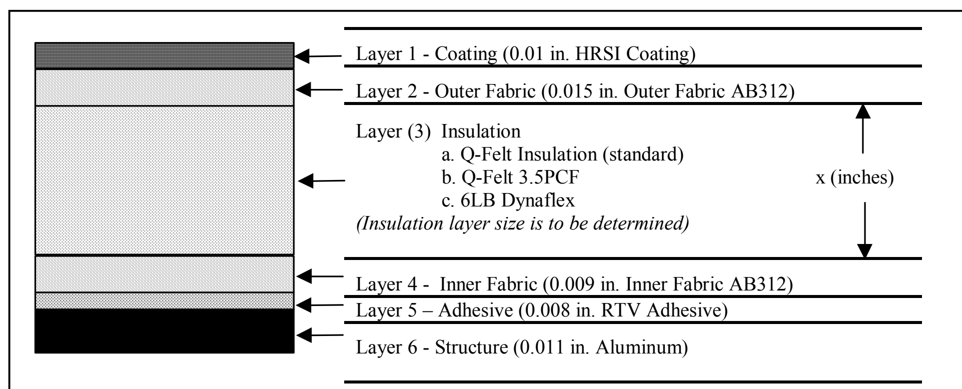


Thickness and Weight Solution of Layer (3)/AFRSI

Layer 3 material	Thickness	Normalized weight, TPS	Normalized weight, layer 3	Max T_{outer}	Max $T_{interior}$	Max T_{skin}
Q-Felt insulation	0.456 in	1.000	1.000	708.7° F	696.4° F	300.3° F
Q-Felt 3.5PCF	0.638 in	0.694	0.408	713.6° F	702.0° F	300.2° F
6LB Dynaflex	0.560 in	1.118	1.228	696.9° F	681.6° F	300.2° F



AFRSI Definition



- *T_{outer} and $T_{interior}$ are the temperatures at the outer edge and (1) to (5) interior layers of the TPS. T_{skin} is the temperature at the nodes within the skin* layer 6.

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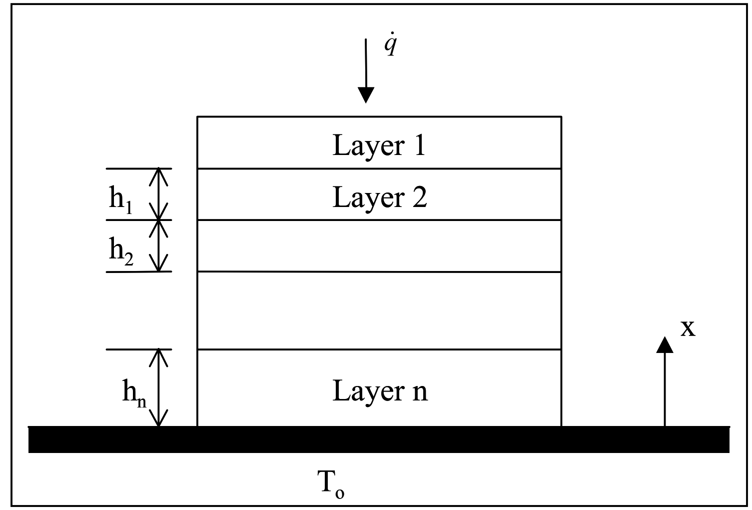
TPS Sizing Optimization Using Complex-Variable Differentiation Sensitivity

- TPS sizing will be automated by developing an optimization driver of the MINIVER/EXITS code.
- For a given heat flux $\dot{q}$ applied on the outer boundary, the objective is to minimize the total weight of the TPS system while keeping the temperature at each layer *(T_i)* below their respective maximum operational temperature, T_{oi}.
- Minimize: $W = \sum_{i=1}^{n} \rho_i h_i$ where ρ_i is the density of the i^{th} layer.

  Subjected to: $T_i < T_{oi}$ $\quad i = 1,2\ldots n$

  Design variables: $h_i > 0$ $\quad i = 1,2\ldots n$



Typical TPS Sizing Problem

- The complex-variable differentiation can provide “numerically exact” derivatives of a complicated function.
  - -The variable h of a real function $T(h)$ is replaced by $h + i\Delta h$.
  - -For small Δh: $T(h + i\Delta h) = T(h) + i\Delta h \frac{\partial T}{\partial h} + \ldots$ Yields: $\frac{\partial T}{\partial h} = \frac{Im\left(T(h + i\Delta h)\right)}{\Delta h} + 0\left(\Delta h^2\right)$
- To incorporate the complex variable technique into the MINIVER/EXITS module for sensitivity analysis is straightforward simply by declaring all variables in the MINIVER/EXITS module as complex variables.
  - -The imaginary part of the thickness input of MINIVER/EXITS represents a small incremental thickness.
  - -The sensitivity is the imaginary part of the temperature output divided by the incremental thickness.

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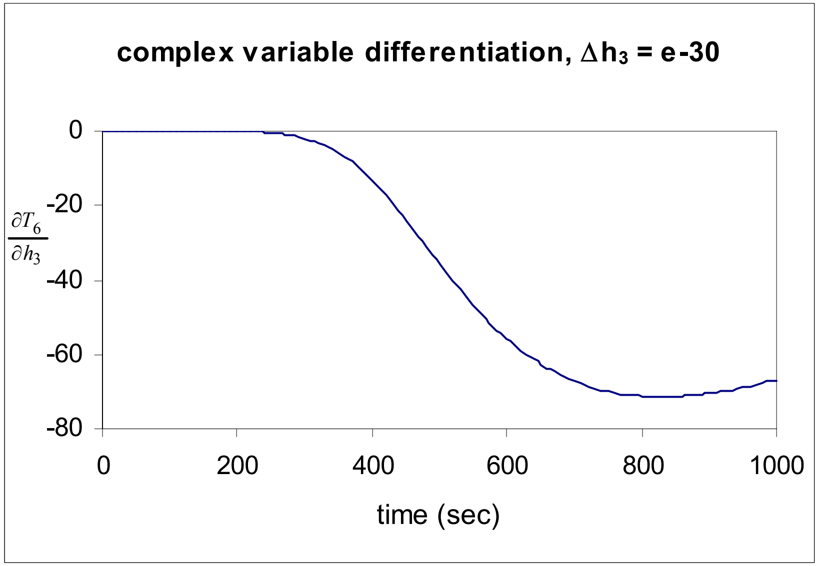
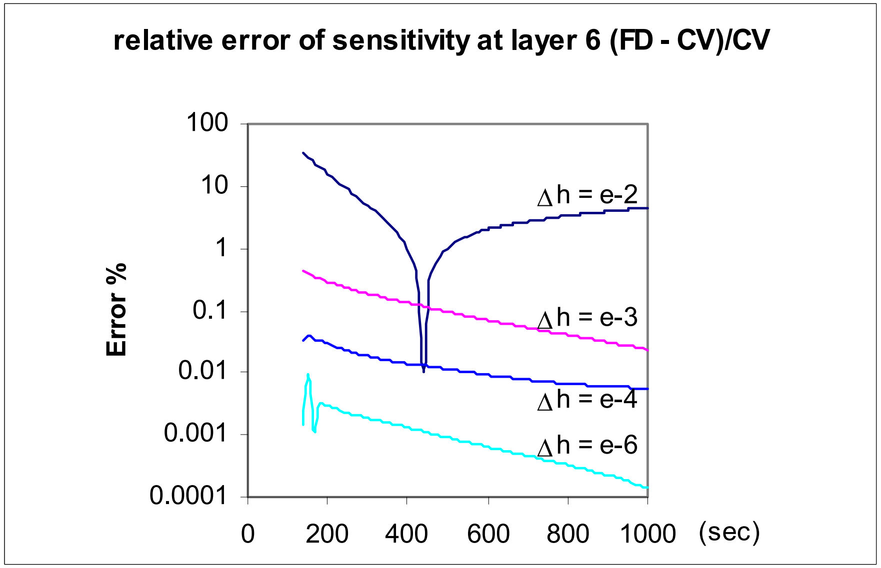
Development of an Optimization Procedure for TPS Sizing (II)

Validation of complex variable differentiation for sensitivity

- Temperature change at Layer 6 due to the change of thickness of layer 3 ($\partial T_6/\partial h_3$) is computed using both the Complex Variable Differentiation (CV) and the Finite Difference (FD) techniques.
- In order to demonstrate the robustness of the CV, $\Delta h_3=10^{-30}$ (near machine zero) is assigned for the CV technique whereas Δh_3 for the FD technique varies from 10^{-2} to 10^{-6}.
- Results show that the accuracy of the FD technique depends on Δh_3 but the CV technique does not.



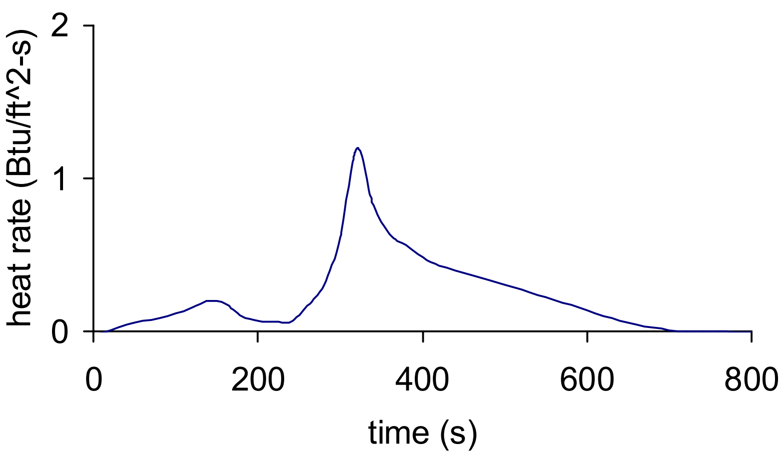


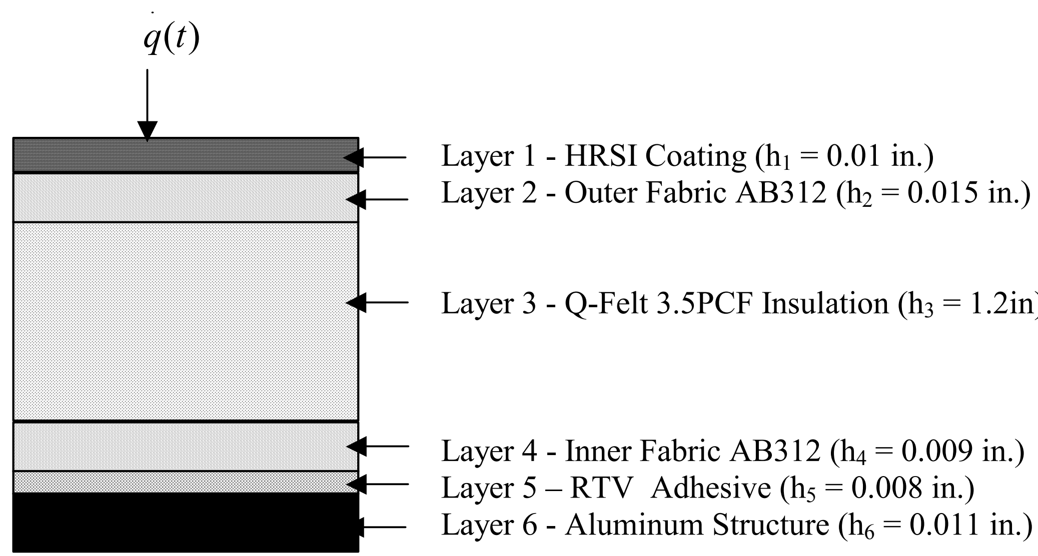
Development of an Optimization Procedure for TPS Sizing (I)

Description of the selected test case

- A six layer TPS system is selected as the test case

- Heat flux time history is obtained from windward side of X-34 centerline.





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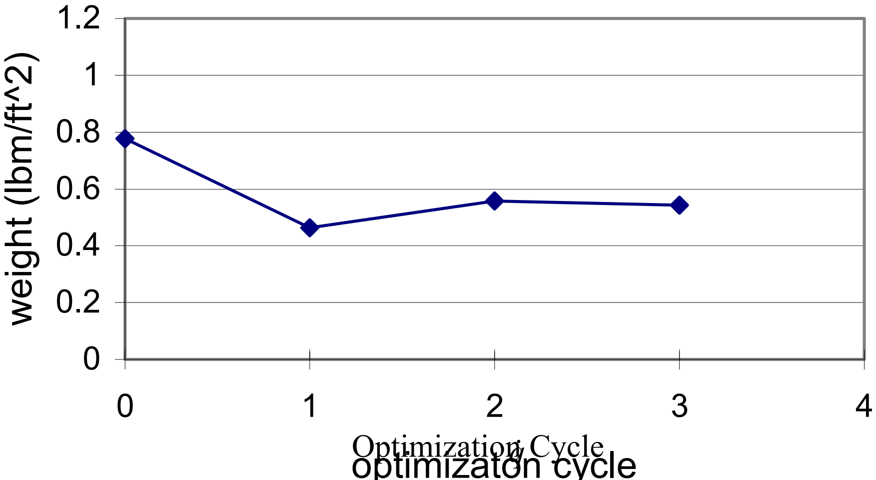
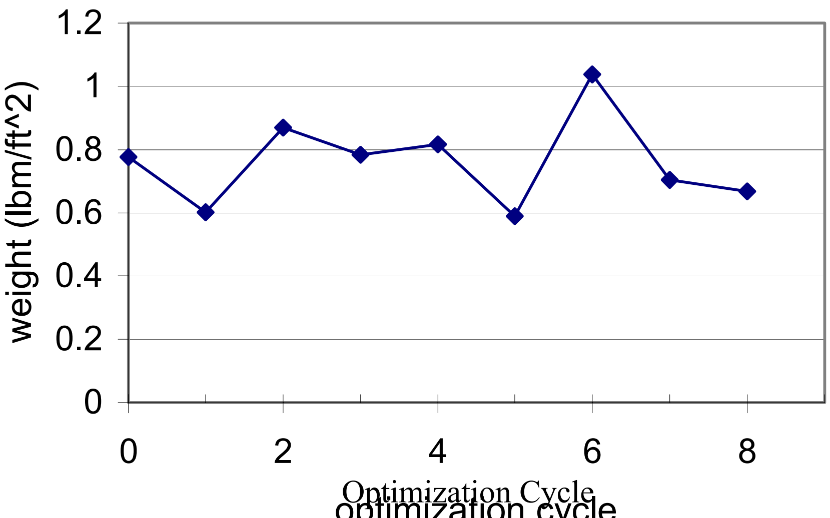
TPS Optimization using MINIVER/OPT

Weight Variation During Optimization

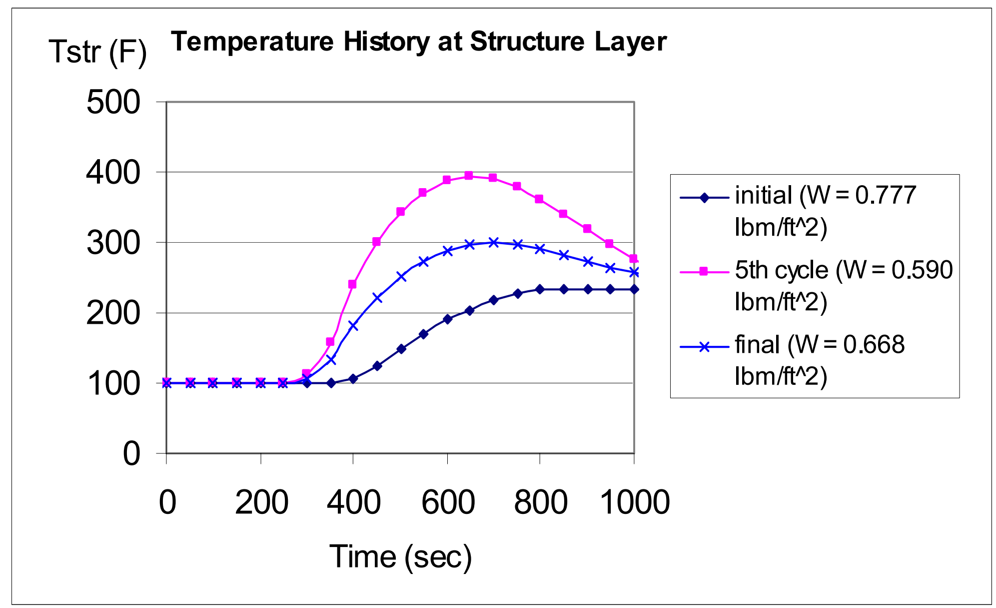


(a) Case A with a given $\dot{q}$ (in 263 Sec)



(b) Case B with 1.5x $\dot{q}$ (in 396 Sec)

Temperature History at the Structure Layer During Optimization (Case B)



Development of an Optimization Procedure for the TPS Sizing (III) Optimization Results with upper bound = 1.0”

- All design variables reduce to the minimum thickness (0.0072”) except layer 3 (h_3 = 0.68496”).
- The total weight is reduced from the initial weight =0.777 lbs/ ft^2 to the final weight = 0.54256 lbs/ft^2

Layer	Material	Temp Limit (°F)	Density (lbm/ft^3)	Specific Heat (But/lbm °F)	Initial Thickness (in)	Max Temp in the Layer (°F)	Optimized Design (in)
1	HRSI Coating	2300	104	0.20	0.01	705.2	0.0072
2	AB312 Fabric	2040	61.5	0.166	0.015	704.9	0.0072
3	Q-Felt	1800	3.5	0.1875	1.2	701.6	0.68496
4	AB312 Fabric	2024	61.5	0.166	0.009	300.0	0.0075
5	RTV-560	550	88	0.285	0.008	300.0	0.0072
6	Aluminum	300	173	0.22	0.011	300.0	0.011

Note: For structure layer (6), thickness is not a design variable.
upper bound thickness = 1.0 in, lower bound = 0.0072 in with original heat flux of X1004601 trajectory