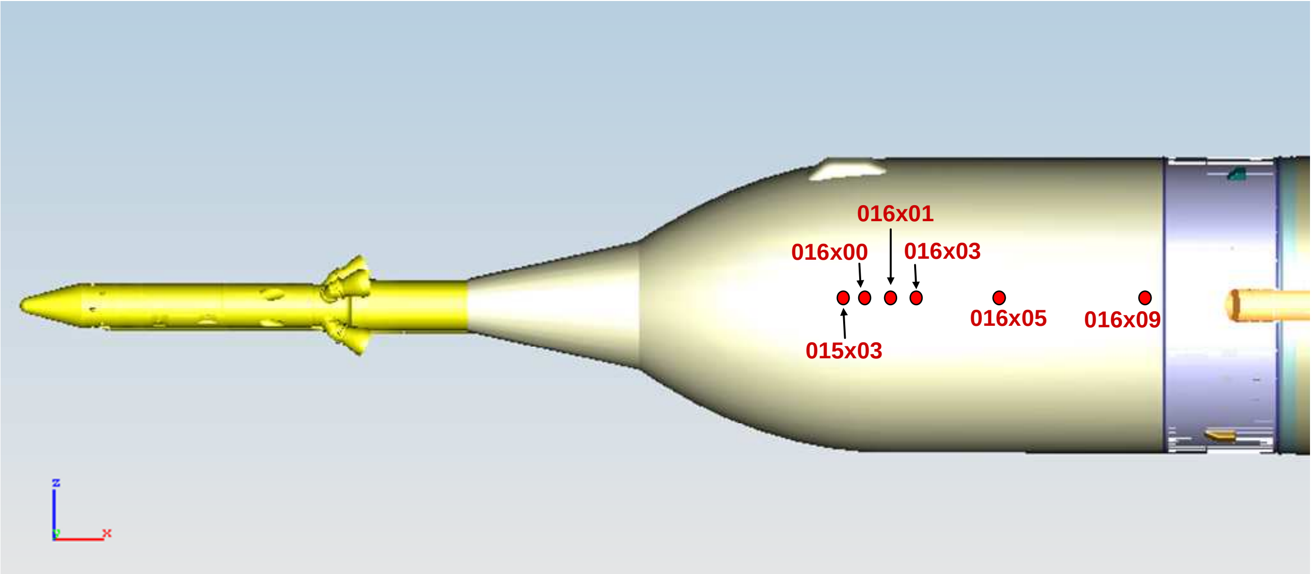
Ascent Heating Thermal Analysis on Spacecraft Adaptor (SA) Fairings and the Interface with CLV

XiaoYen Wang, James Yuko, Brian Motil
NASA Glenn Research Center

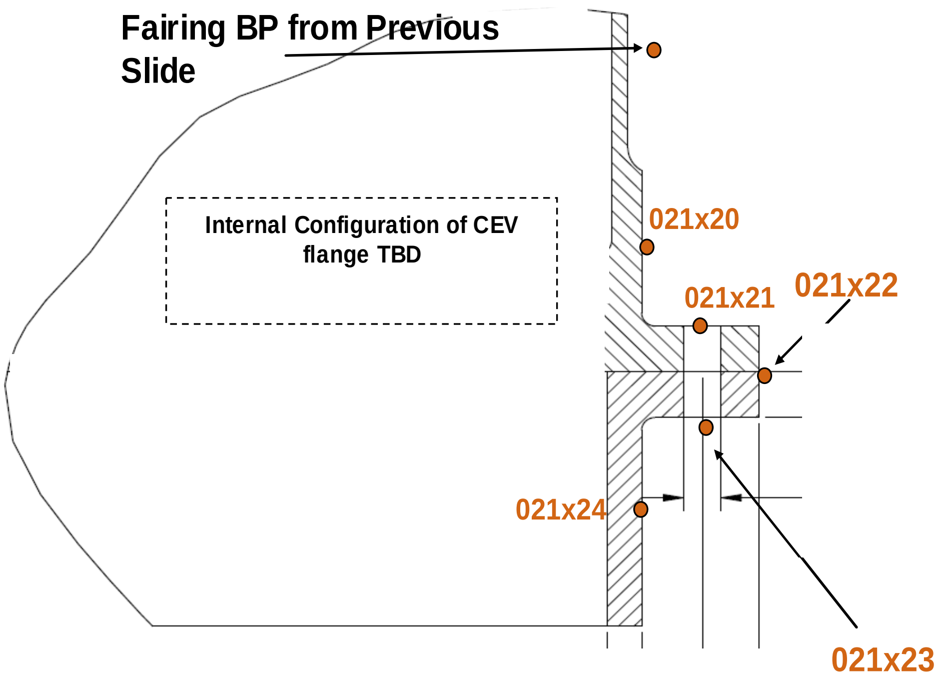
Thermal & Fluids Analysis Workshop
(TFAWS 2008)
San Jose State University, San Jose, CA
August 18-22, 2008

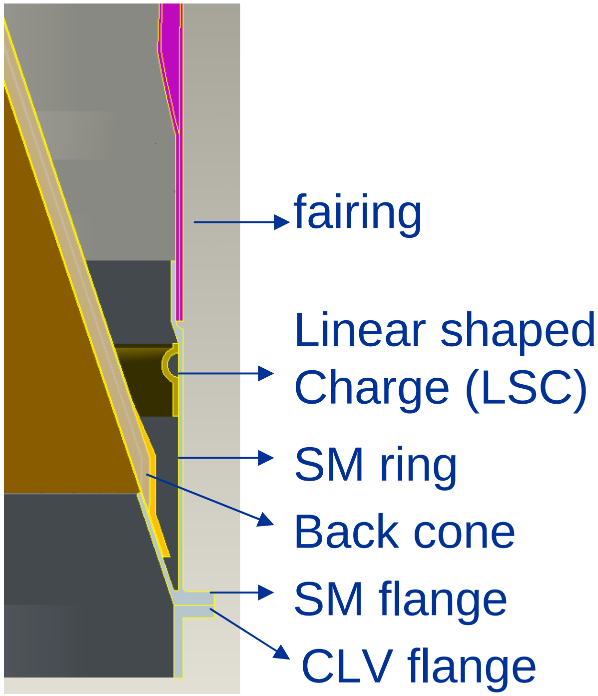
Contents

SA fairing ascent heating data (606 ALAS-11 Rev. 3, MFSC) (09/24/2007)

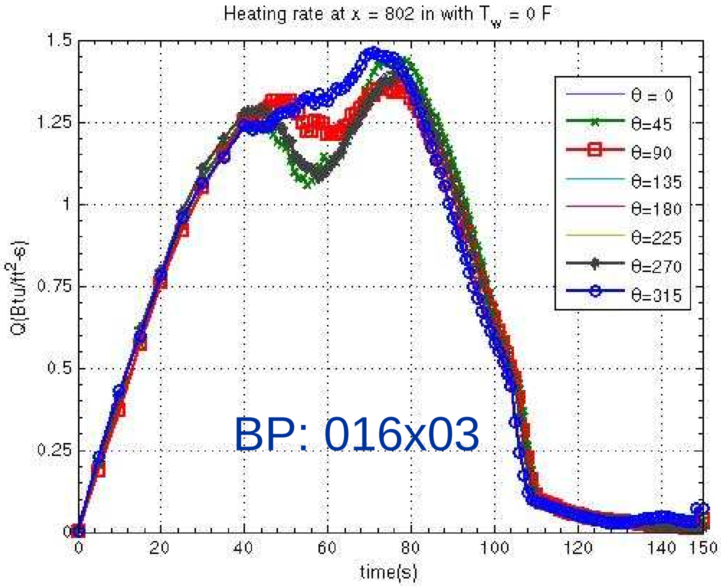


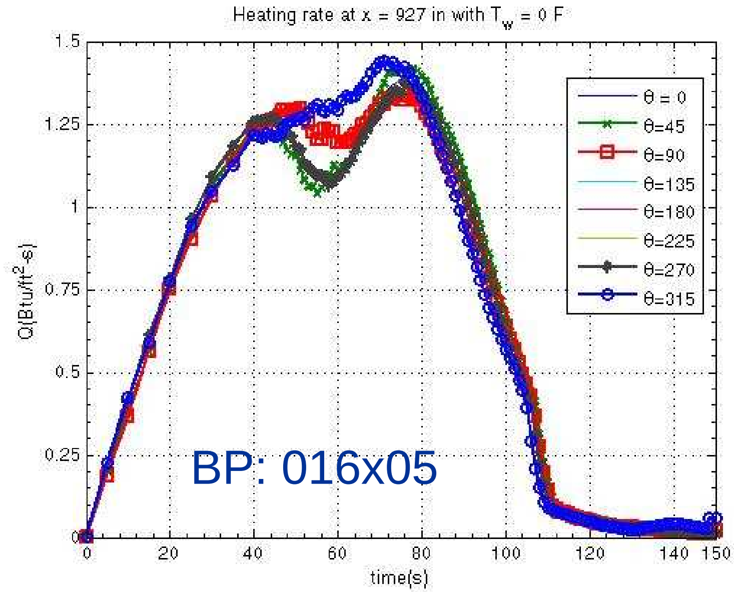
Along axial directions: 3 points (BP: 016x03, 016x05, 016x09)
Along circumferential direction: 8 points
Along time direction: 119 points

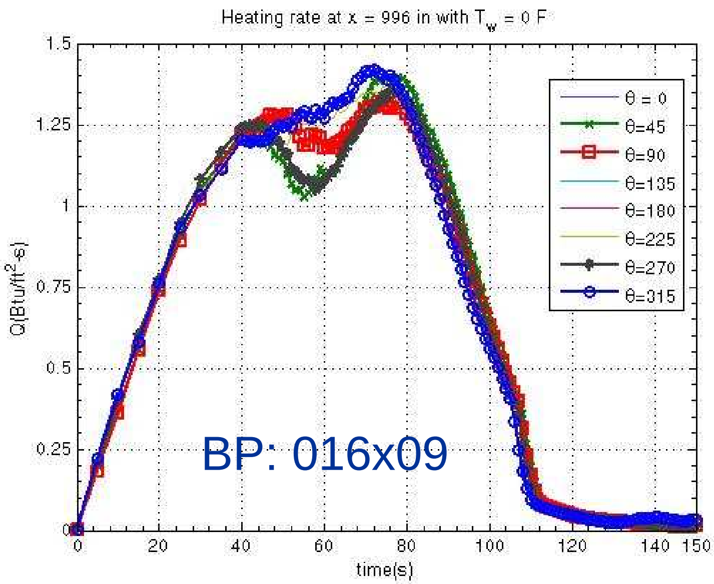




BPs on the SM/CLV interface flanges







TE3 data provided by MFSC.

To simplify the analysis, use the data at BP 016703 (x=802", θ = 315^o), that has highest heating rate for most of the time, over the entire surface of OFS.

Geometry issues in Thermal Desktop (TD)

- TD can only use very simple geometries, such as cone, cylinder, disk, ellipsoid, rectangle, sphere, etc, for surfaces, and solid brick, solid cone, solid cylinder, and solid sphere. For any more complicated geometry involving curvatures can not be modeled in a straightforward and accurate way.
- Most of CAD geometry will NOT be recognized in TD. Only lines or points from geometry imported from CAD file can be used to build TD surfaces or solids.
- TDmesh is available and also under improvement in TD. It can create FEM for any solids/surfaces defined in AutoCAD and ACIS file. The geometry is then represented by FE mesh and can be used in TD. But the problem is that the boundary information is not available, which make it difficult to define the boundary conditions (BCs).
- TD can read in FE mesh from NASTRAN, FEMAP, and others. But no boundary information is available. The user has to deal with thousands or more FE elements with no geometry information, which is the fundamental data that the users need for defining BCs.
- Due to TD's limitations on modeling the geometry, the conduction becomes very difficult to model.

BCs specification issues in Thermal Desktop

When the mesh is changed, BCs have to be changed too!

- Ways to define boundary conditions:
  - Conductor:
    - node-to-node: one node to one node
    - node-to-nodes: one node to a group of nodes
    - node-to-surface: need surface representation
    - line-to-surface: not available
  - Contactor: surface to surface, edge to surface
  - heat loads: on nodes or surfaces or solids
- Conductance, contact resistance, and heat load is only time or ΔT dependent. Not allowed to define boundary conditions that are dependent on time, temperature, and spatial locations simultaneously.

Simplification of the ascent heating data

- ALAS-11 TE3 ascent heating rate on SM provided by MFSC is functions of time, wall temperature, and spatial location (x,y,z). TD does not have this capability, extra programs needs to be done in Sinda to interact with TD model, which is not straightforward and easy to create errors.
- Simplification:

  1. Eliminate spatial dependence:

     use the data at BP 016703 (x=802", $\theta = 315^o$), that has the highest heating rate for most of the time, over the entire surface of OFS.

     use the heating rate at BPs with $\theta = 0^o$ for CLV/SM ring and flanges.

  2. Eliminate wall temperature dependence:

     convert heat flux into temperature-based heat transfer coefficient and air recovery temperature.

With the simplification, BC is only time dependent;
Thermal analysis gives the worst case for the temperature on the fairings
But not the temperature gradient across the fairings.

ALAS-11 TE3 ascent heating data representation

$$\dot{q}_{total} = \underbrace{h_c(H_{rec} - H_{wall})}_{\text{Gas convection}} + \overbrace{\dot{q}_{rad} + \underbrace{h_{c_p}(H_{rec_p} - H_{wall_p})}_{\text{particle convection}} + \dot{q}_{p_{ke}}}^{\text{Are zero for SA fairings}}$$

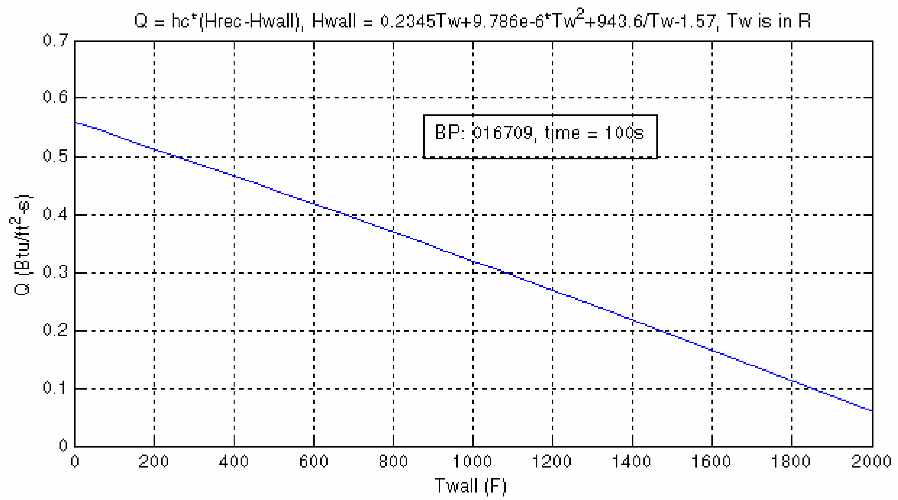
Plume radiation

Particle kinetic energy

$$H_{wall} = 0.2345T_{wall} + 9.786x10^{-6}T_{wall}^2 + 943.6/T_{wall} - 1.57$$

$$T_{wall} = \text{wall temperature (R)}$$

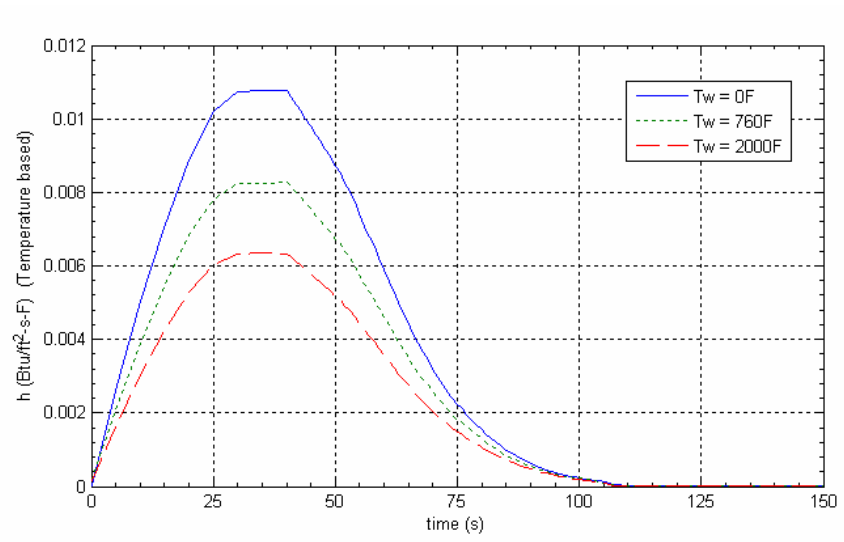
TE3 heating data is computed based on enthalpy and has only gas convection for the fairings. It is almost a linear function of T_{wall} for T_{wall} < 760 F. Enthalpy-based heat transfer coefficient (h_c) will be converted to temperature-based heat transfer coefficient (h_t).

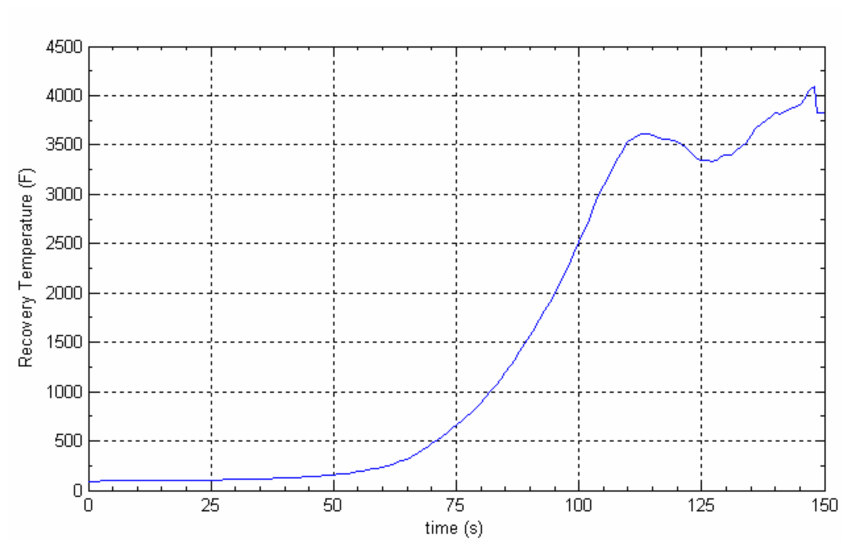


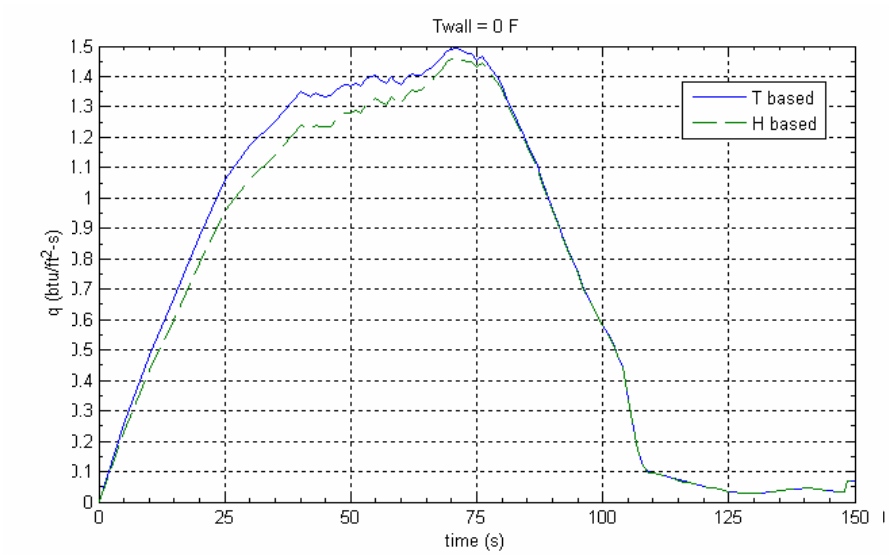
$$h_t = c_p h_c, \text{ where } c_p = 0.2345 \text{ Btu/lbm} - \text{F for air}$$

$$\dot{q}_{total} = h_c(H_{rec} - H_{wall}) = h_t(T_{rec} - T_{wall})$$

Temperature-based versus enthalpy-based h





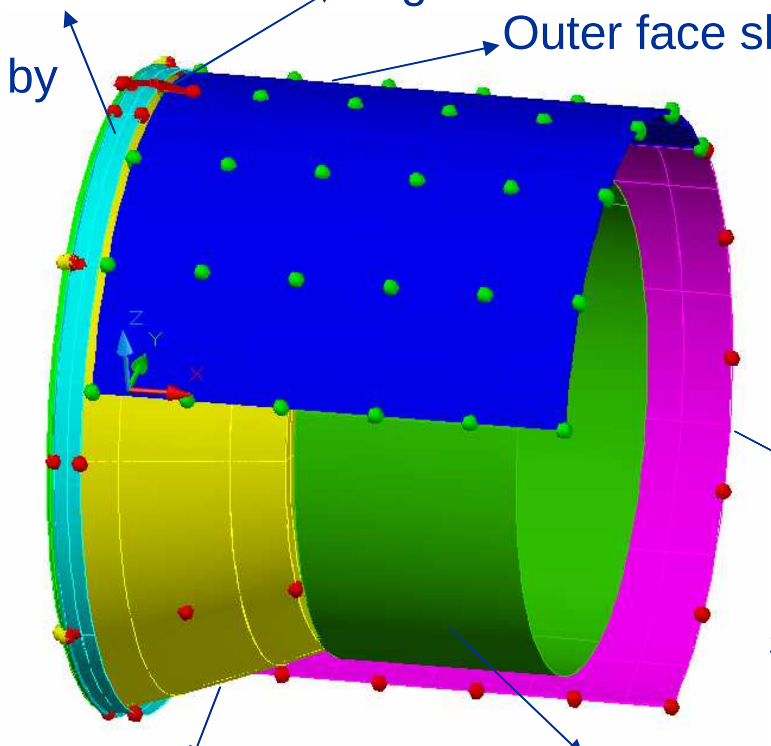


Computed h_t and T_{rec} that are used in the thermal analysis.

Temperature based h gives higher heat flux than the enthalpy based. It is more conservative.

Thermal Model in Thermal Desktop

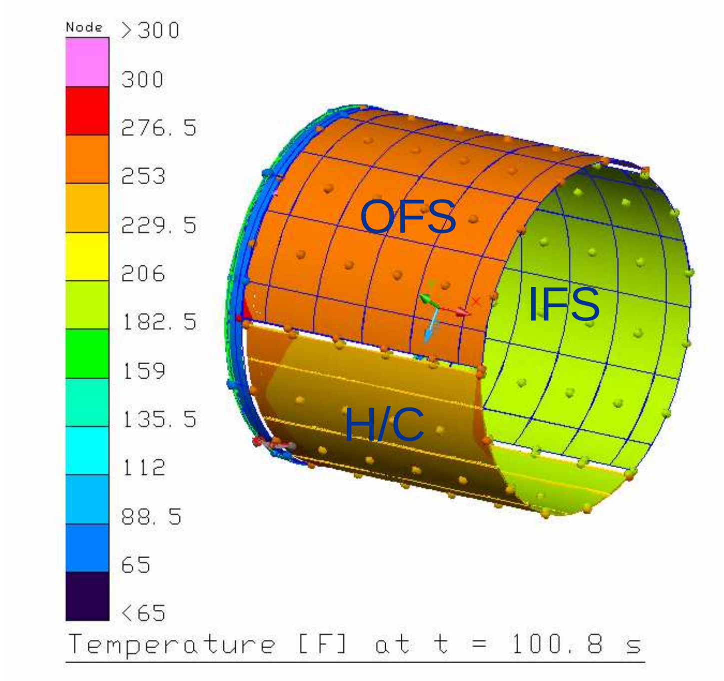
- Import ACIS file provided by LM to build TD surfaces and solids.
- Circumferential direction:
  OFS: three pieces
  Honeycomb (H/C) core: three pieces
  IFS: three pieces
- Radial direction:
  OFS (0.0424” thick)
  H/C core (1.5” thick)
  IFS (0.0424” thick)

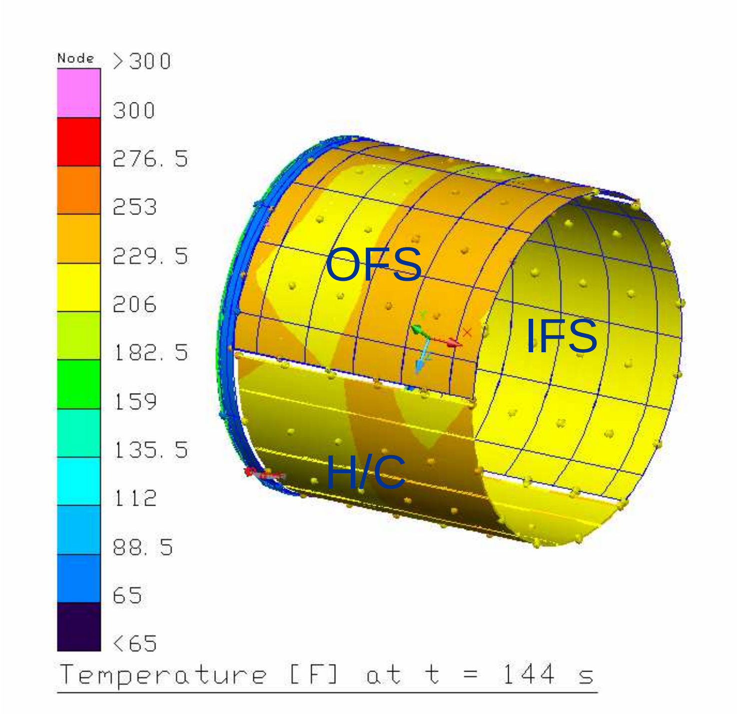


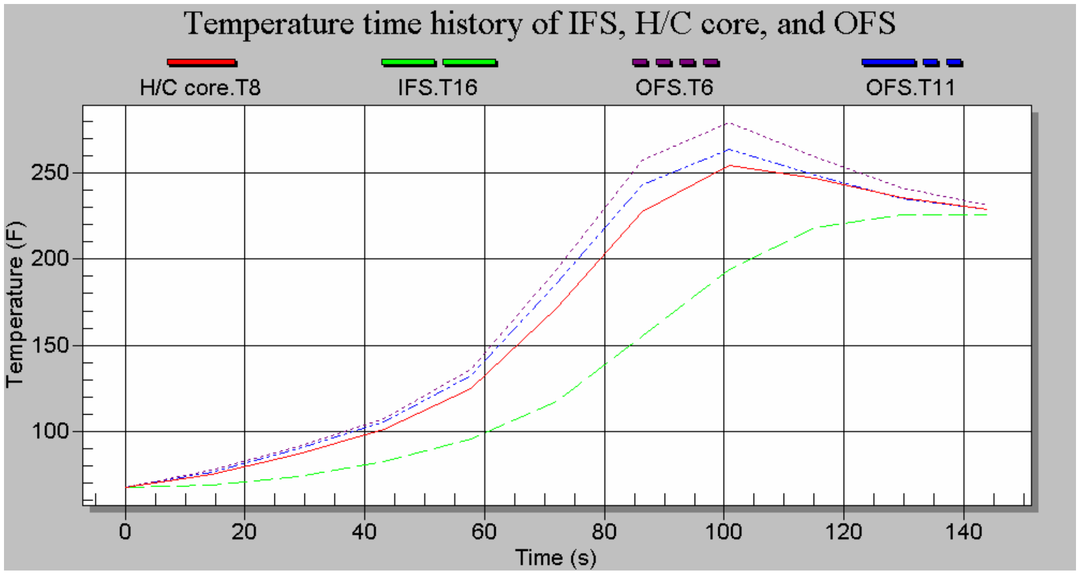
- Material properties are obtained from LM (refer to Randy Barsoum’s report in TIM#8).

Boundary Conditions (BCs):

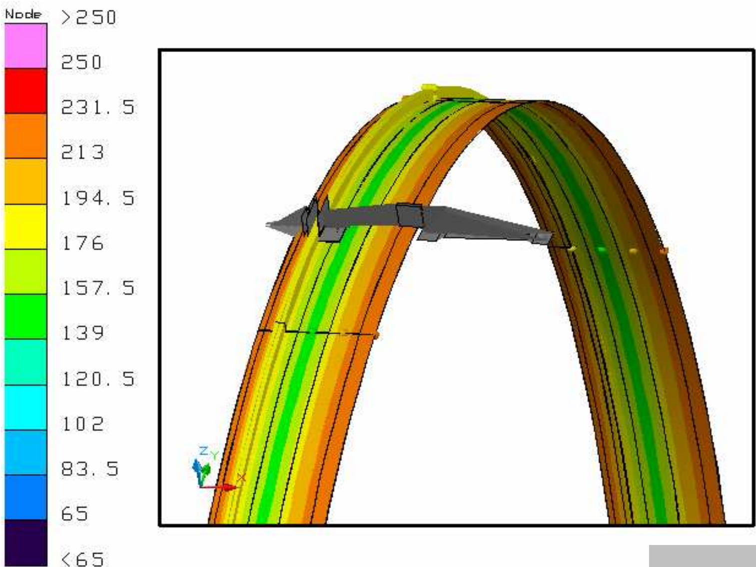
- Node-to-surface conductor: convection BCs
  ambient node: defined using air recovery temperature;
  outer surfaces of SM fairing and CLV/SM interface: defined using the h_t.
  hinges: heat load is NOT defined here.
- Contactor:
  1. inner surface of OFS to H/C core
     outer surface of IFS to H/C core: (surface to surface)
     h = 0.694 Btu/hr-in^2-F for low resistance;
  2. IFS to SM ring: (edge to surface)
     h = 0.0014 Btu/hr-in-F, assume that a minimum heat transfers to the ring from IFS, and the overlap between IFS and ring is 2.0".
  3. SM ring to back cone: (edge to surface)
     h = 14 Btu/hr-in-F for low resistance
  4. Flange to ring on CLV, Flange to ring on SM, CLV flange to SM flange: (surface to surface)
     h = 6.94 Btu/hr-in^2-F for low resistance.
- Outer surface of fairing radiates to the ambient air at T = 50 F
- Inner surface of fairing radiates to the radiator at T = 70 F





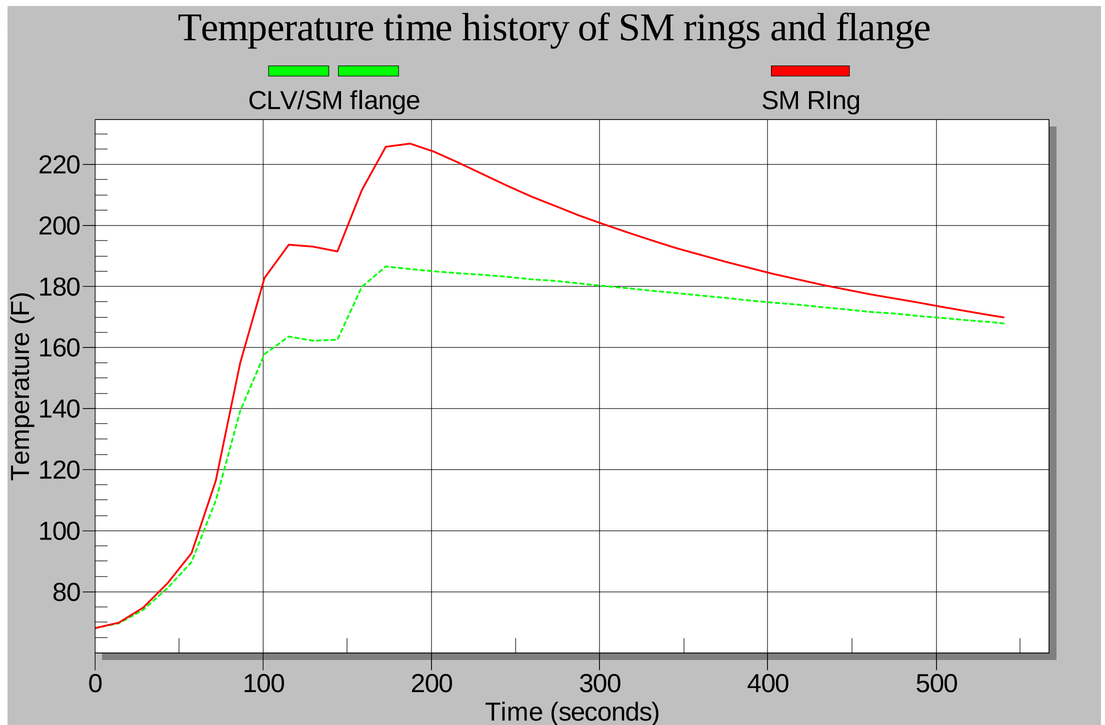


TD results of OFS, H/C core, and IFS.



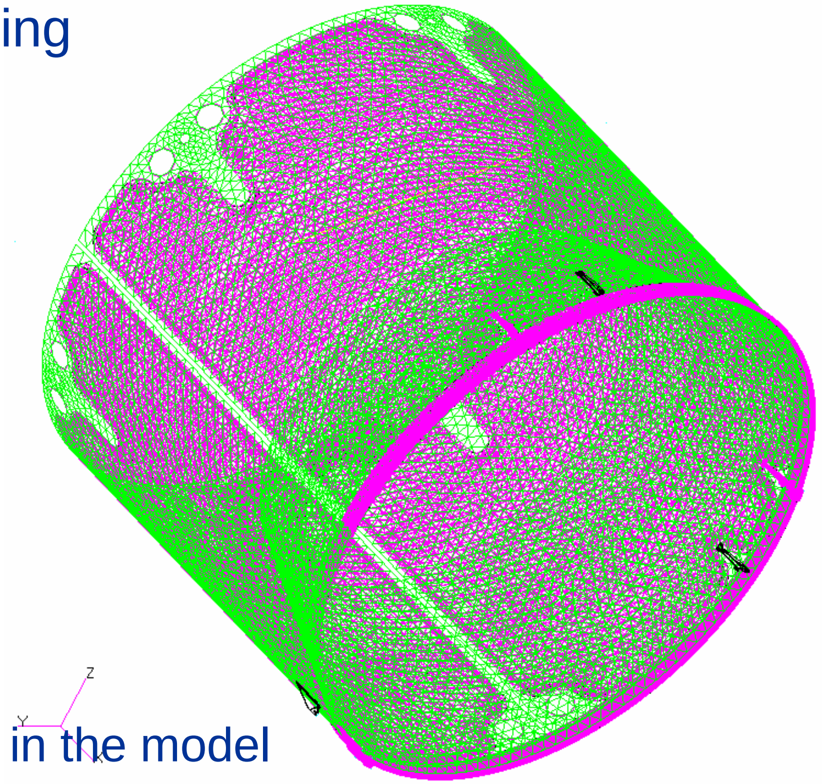
Temperature [F] at t = 172.8 s

TD result of SM ring and CLV/SM flange interface at t = 172.8 s.

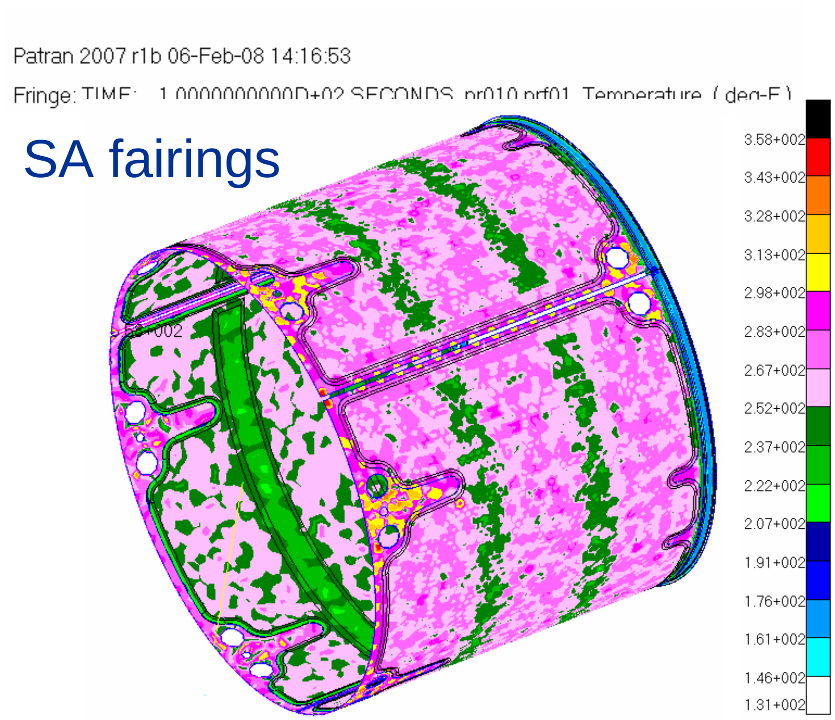


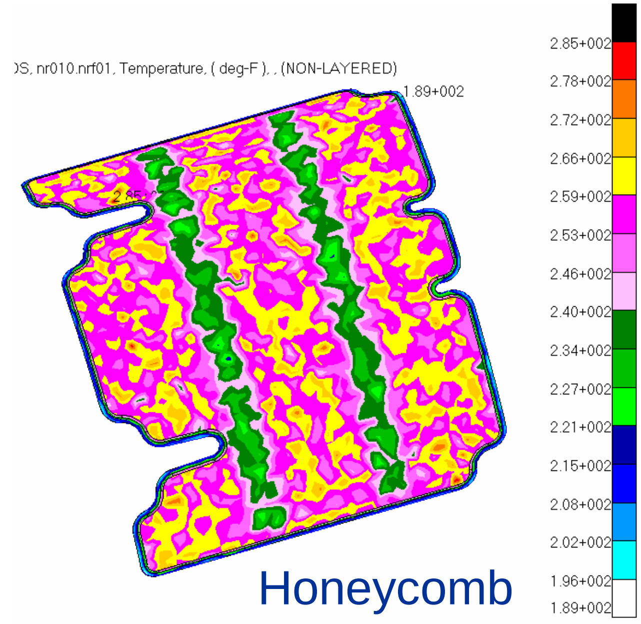
Thermal Model in MSC Patran/Pthermal

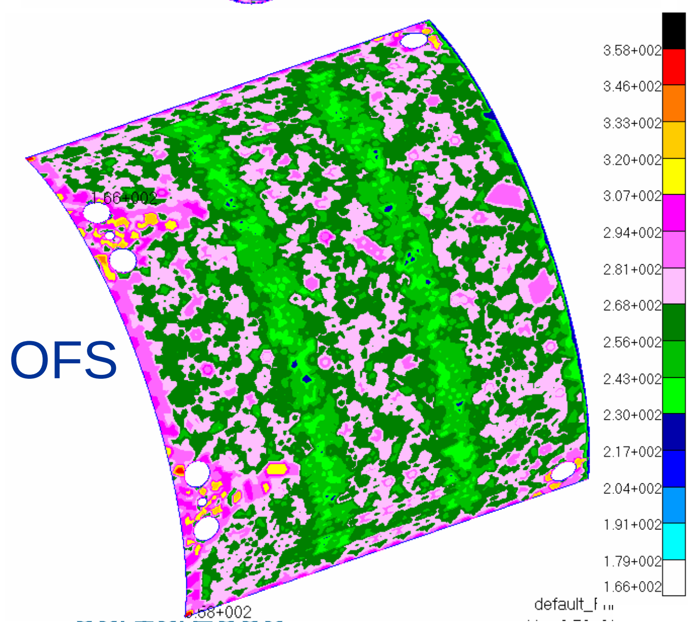
- Import geometry from ProE parts or assembly file. No need to convert ProE geometry into Patran geometry. Most solids or surfaces can be used/meshed right away. Some might need modification or simplification for thermal analysis.
- Mesh the solids or surfaces using FEM (Nodes: 116,552,
  Elements: 290,249)
- BCs are the same as those used in TD model.
- Heat flux or heat transfer coefficient that is function of time and space (x,y,z) can be implemented straightforward.

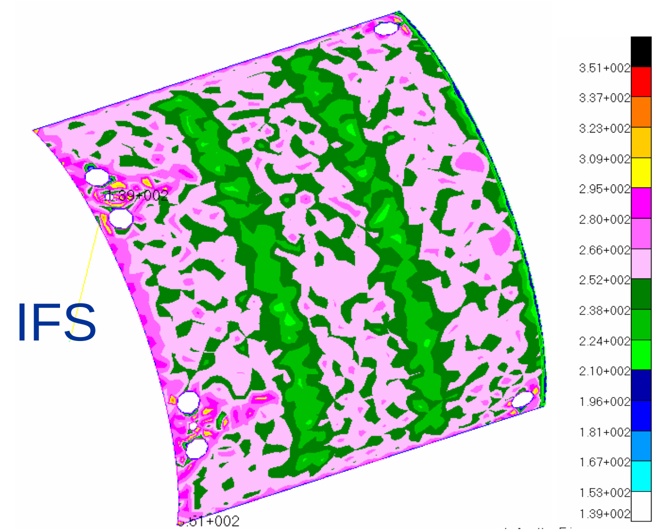


FEM in the model

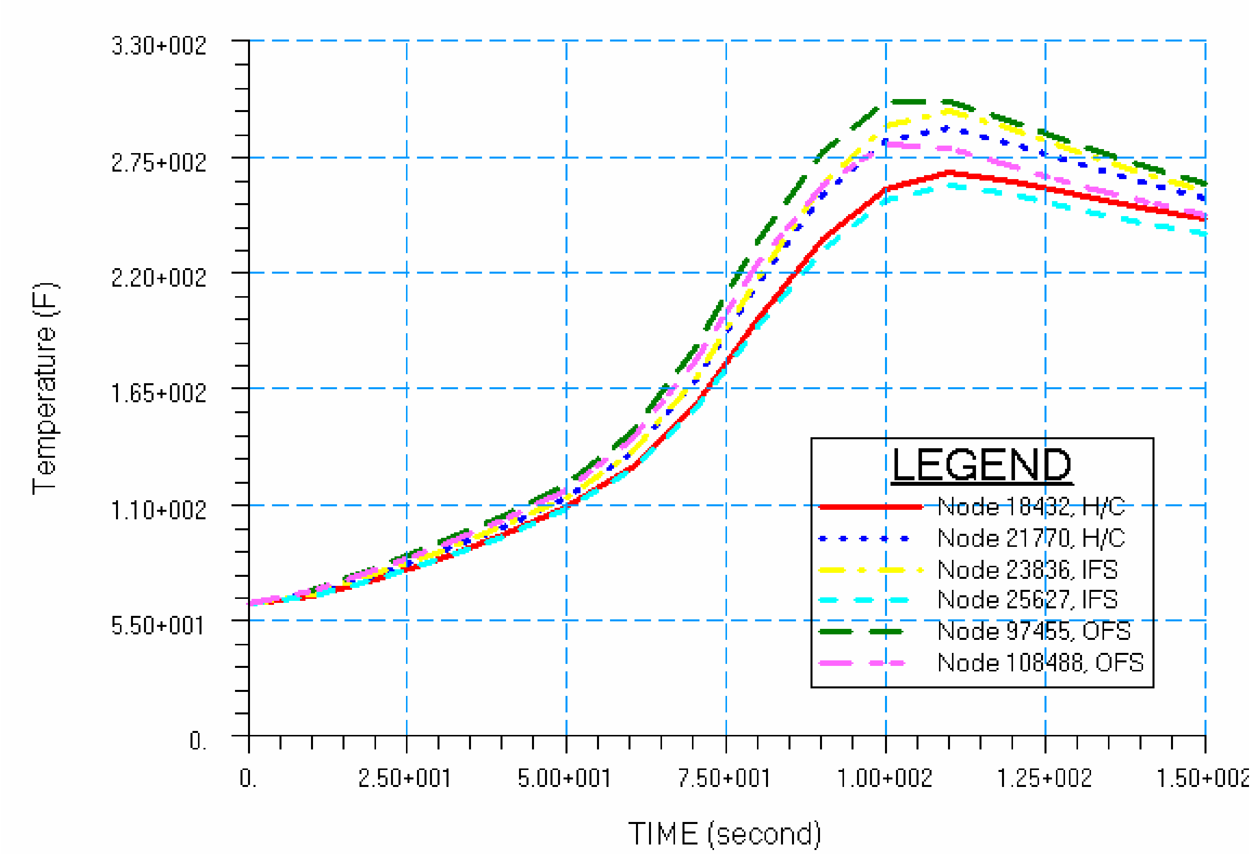




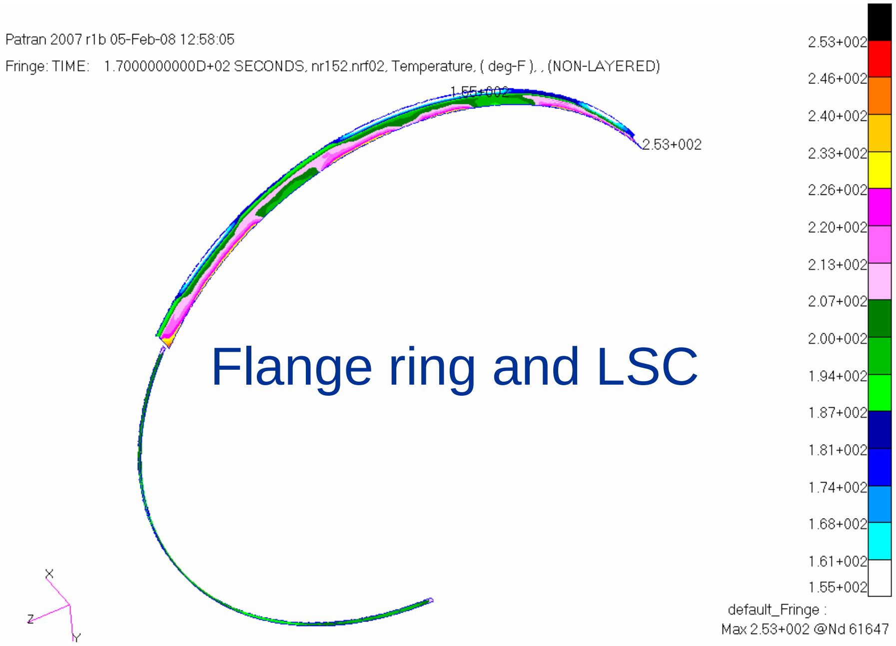


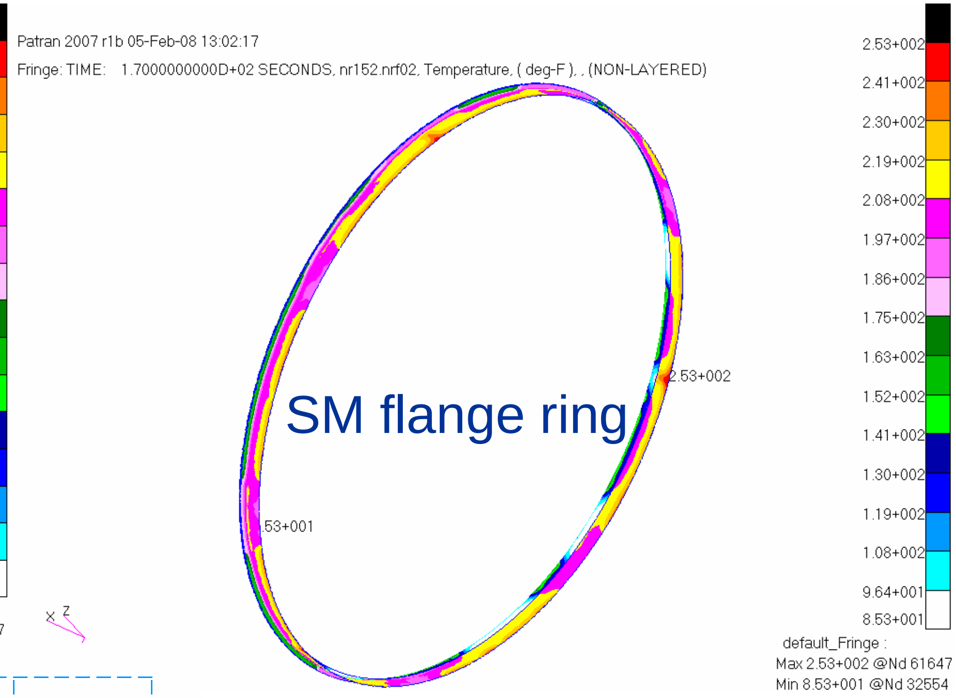


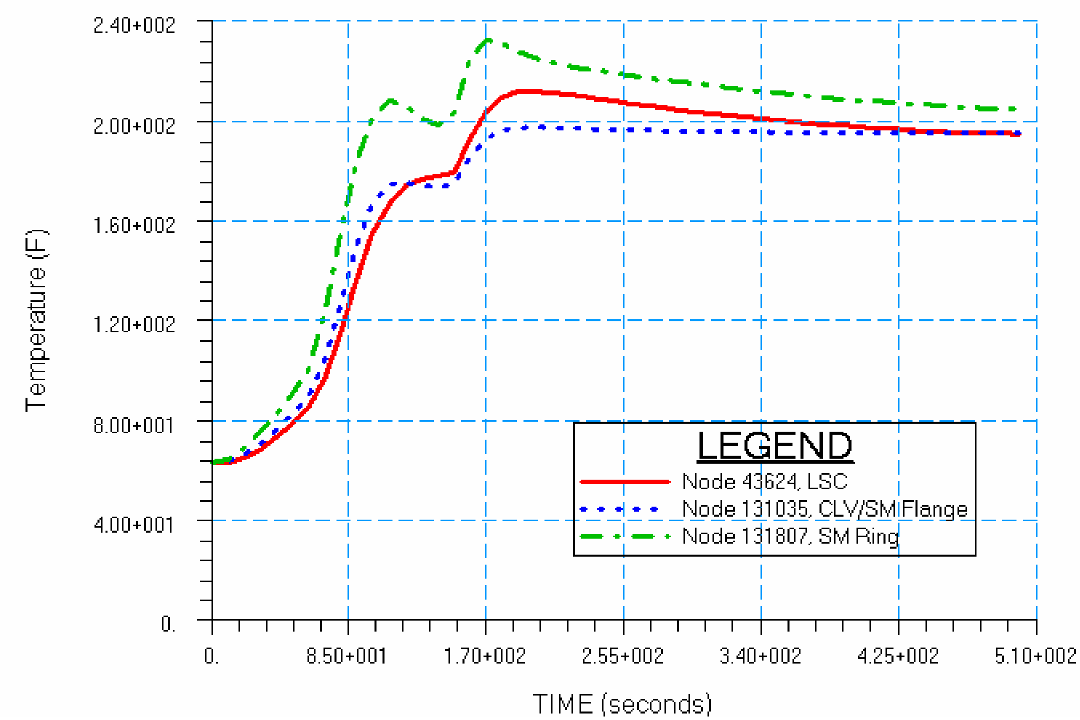
MSC Patran result of OFS, H/C and IFS.



Time history of the temperature on OFS, IFS and Honeycomb (MSC Patran results).







MSC Patran/pthermal result of SM ring and CLV/SM flange interface.

Comparison with LM reported results

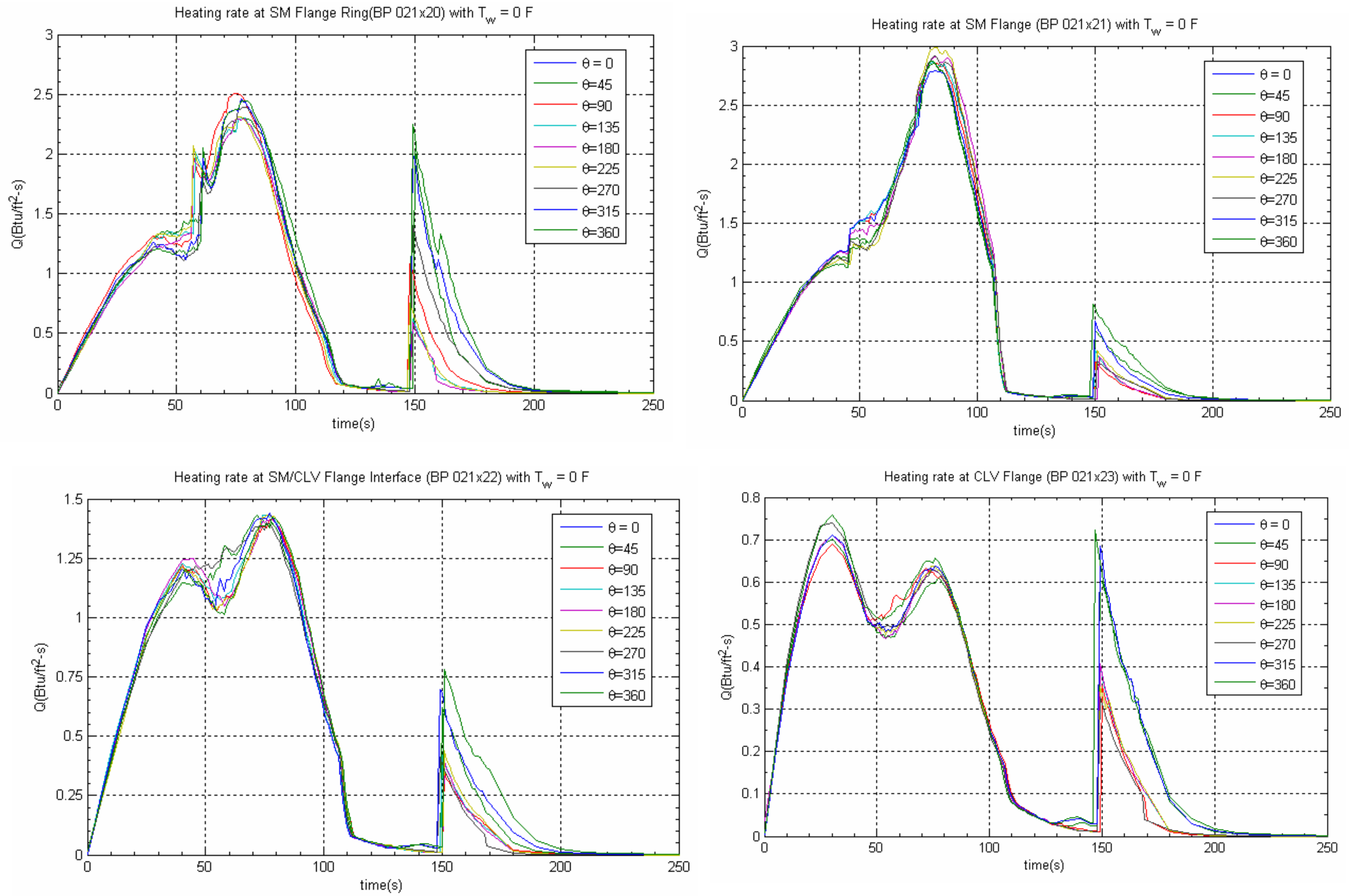
	Max Temp (F) No hinge localized heating (with margin of 1.35 included in TE3 data)			Max allowed temp (F)
	LM result	Current TD result	Current MSC Patran result	
Fairing (OFS)	272	280	280	325--400
CLV/SM flange	184	186	196	150-180
SM ring	200	225	232	
LSC	200	NA	210	220

11^{o}F margin are not included.

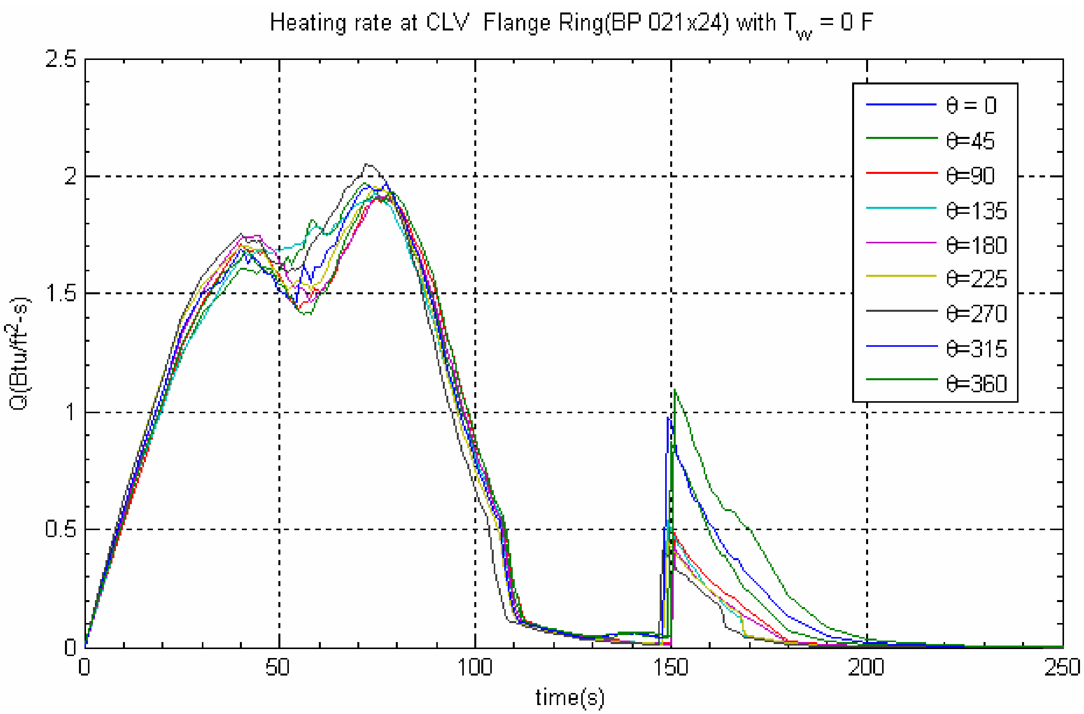
Summary

- Both TD and MSC Patran results agree reasonably well with those reported by LM on fairings and CLV/SM flange interface. Both results predict higher temperature than LM reported due to the use of temperature-based h in the analysis, which gives higher heat flux.
- SA fairing jettisons at t = 150s, fairing reaches maximum temperature (280 F) at t = 100s; The hottest spots are next to hinges, and the areas that are not covered by honeycomb (as shown in MSC Patran model, 320 F).
- SM flange ring and LSC reach maximum temperature at t = 170s. The temperature at the corner of the ring could reach 253 F.
- With hinge effects, the fairing temperature under the hinges could get higher than predicted here.

Back up



Heating rate at SM Flange Ring(BP 021x20) with T_w = 0 F
Q(Btu/ft2-s)
time(s)
θ = 0
θ=45
θ=90
θ=135
θ=180
θ=225
θ=270
θ=315
θ=360
Heating rate at SM Flange (BP 021x21) with T_w = 0 F
Heating rate at SM/CLV Flange Interface (BP 021x22) with T_w = 0 F
Heating rate at CLV Flange (BP 021x23) with T_w = 0 F


Heating rate at CLV Flange Ring(BP 021x24) with T_w = 0 F
Q(Btu/ft²-s)
time(s)
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
θ = 0
θ=45
θ=90
θ=135
θ=180
θ=225
θ=270
θ=315
θ=360