Definition of Ablation test-case series #3

5th Ablation Workshop
Lexington, KY

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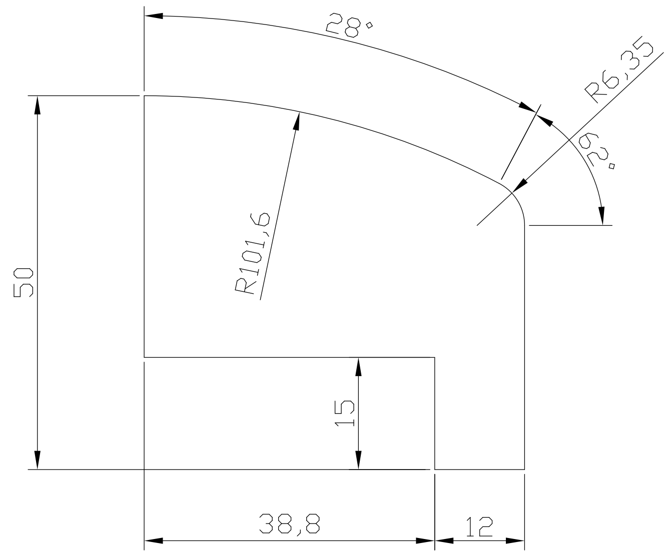
Outline

- Definition of the mandatory Test-case
  - Basic case (Test 3.1)
    - Geometry definition
    - Material choice
    - Heat –load and boundary conditions
  - Initial results for the basic case
  - Modification of the basic case:
    - Orthotropic TACOT material (Test 3.2)
    - Full 3D test-case (Test 3.3)
  - Discussion of the test-cases

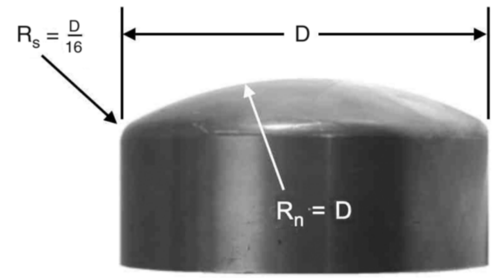
- Discussion of a possible re-entry probe test-case

Mandatory test-case

- Goal: to extend series #2 to 3D
- Test 3.1
  - Iso-q specimen
  - Geometry well defined

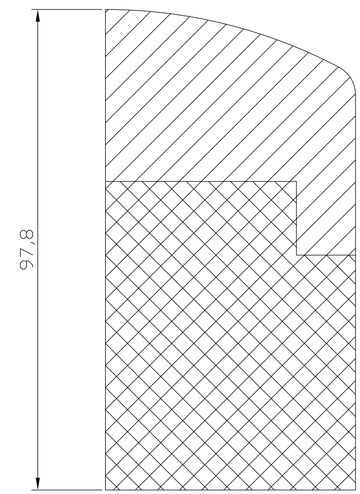


  - Heat load distribution available
- Material (iso-q + support): TACOT v2.2



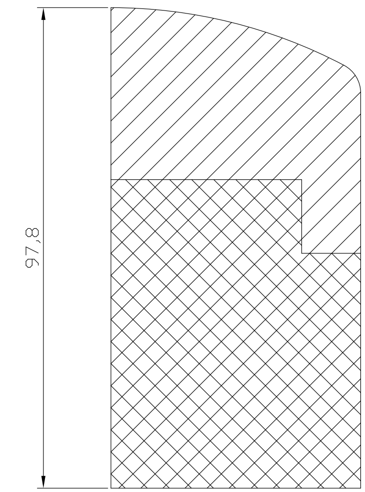
"Iso-q" Calorimeter

Milos F. and Chen Y.-K., *Two-Dimensional Ablation, Thermal Response, and Sizing Program for Pyrolyzing Ablators*.



Mandatory test-case

- Load & boundary conditions (Similar to Test 2.3)
  - Initial uniform temperature
  - Initial uniform pressure
  - Adiabatic/impermeable bottom surface



- Radiation with the environment

$$q = \sigma\varepsilon\left(T_\infty^4 - T_w^4\right)$$

- Enthalpy flux (stagnation point)

$$q = \rho_e u_e C_H\left(h_e - h_w\right) + \rho_e u_e C_H\left[B_c^{'}\left(h_c - h_w\right) + B_g^{'}\left(h_g - h_w\right)\right]$$

$$\frac{C_H}{C_{H_0}} = \frac{2\lambda B_0^{'}}{e^{2\lambda B_0^{'}} - 1}$$

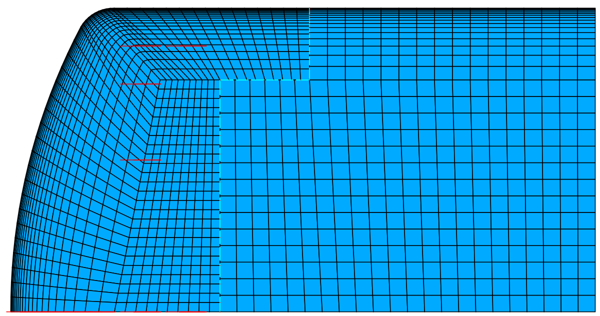
$$\lambda = 0.5$$

time (s)	$\rho_e u_e C_H(0)$ (kg· m^{-2}· s^{-1})	h_e (J· kg^{-1})	p_w (Pa)
0	0	0	101325
0.1	0.3	$2.5 \cdot 10^7$	101325
40	0.3	$2.5 \cdot 10^7$	101325
40.1	0	0	101325
120	0	0	101325

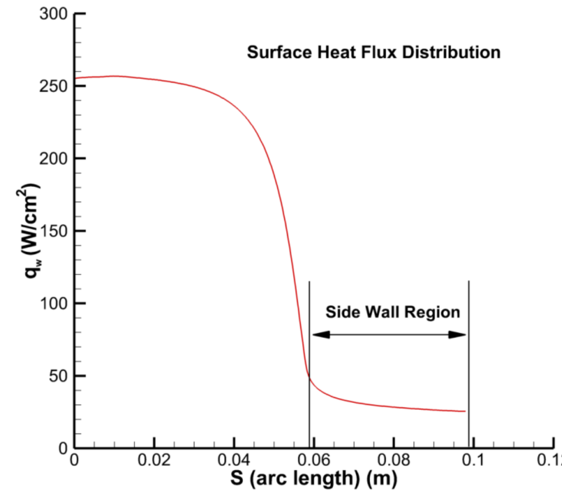
- Isotropic conductivity (axis-symmetric/3D)

Mandatory test-case

- $C_H(s)$ distribution



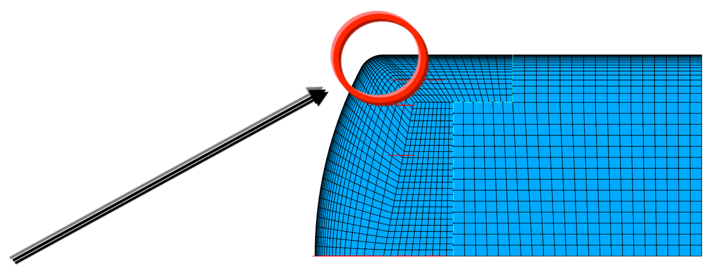
s (cm)	Y-coord. (cm)	Z-coord. (cm)	$q_w/q_w(0)$	s (cm)	Y-coord. (cm)	Z-coord. (cm)	$q_w/q_w(0)$
0.00	0.000	0.000	1.000	5.50	5.068	1.617	0.476
2.00	1.987	0.196	1.000	5.75	5.080	1.864	0.261
3.00	2.957	0.439	0.971	6.00	5.080	2.114	0.169
3.50	3.431	0.597	0.955	6.50	5.080	2.614	0.137
4.00	3.898	0.777	0.925	8.00	5.080	4.114	0.111
4.50	4.354	0.980	0.863	10.00	5.080	6.114	0.101
5.00	4.800	1.209	0.743	13.70	5.080	9.780	0.101



Dec J.A., Laub B. and Braun R.D., *Two-Dimensional Finite Element Ablative Thermal Response Analysis of an Arcjet Stagnation Test*

$$\rho_e u_e C_H(s) = \rho_e u_e C_H(0) \frac{q_w}{q_w(0)}$$

- Constant and uniform pressure because of:
  - Possible pressure egalization
  - Cooldown due to (non-charring) gas flow

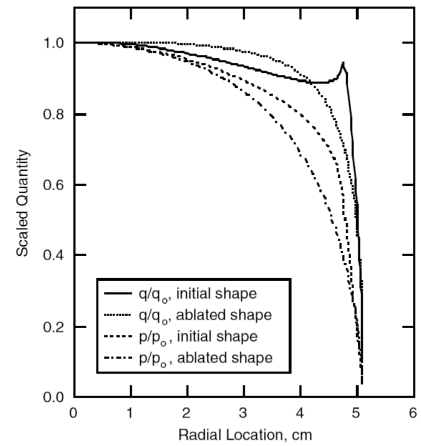


Mandatory test-case

- Pressure distribution
  - Heat flux at start of the calculation

$$q = \ldots + \rho_e u_e C_H B_g^{'} \left(h_g - h_w \right)$$

  - Example: Test 2.3
    - Fixed back-surface pressure P_0
    - Front surface pressure $0.2{*}P_0$
  - Temperature evolution at outer wall



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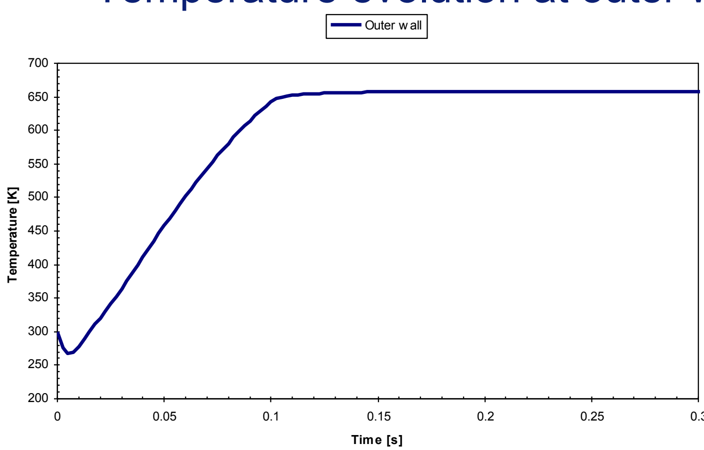
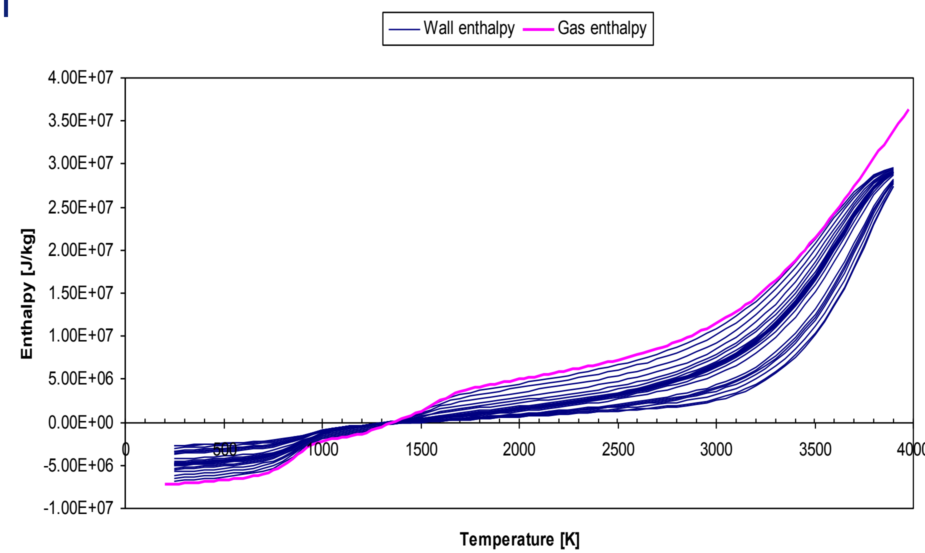




- Cooldown due to equilibrium hypothesis for the enthalpy

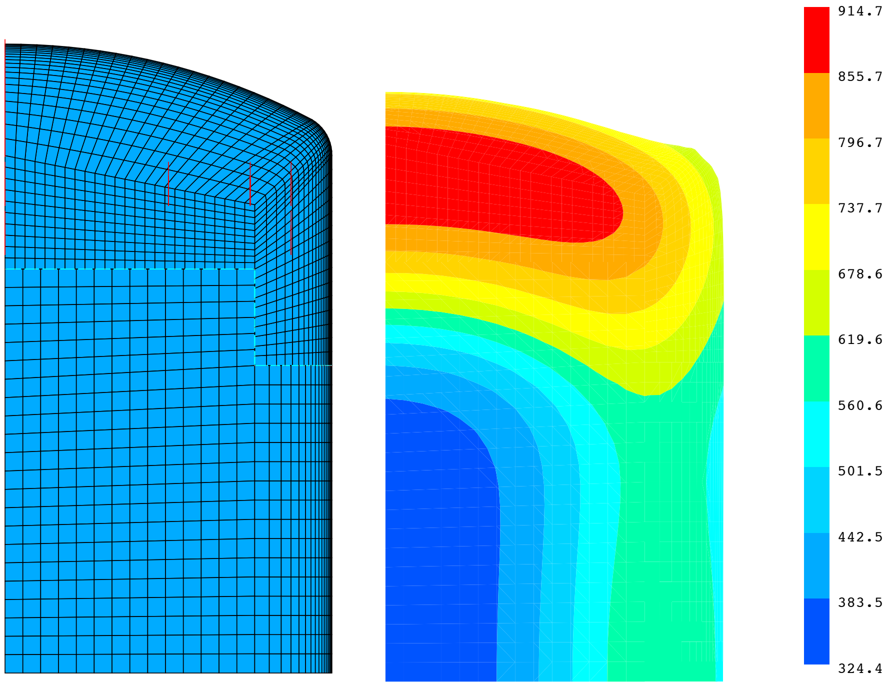
Leading Partner in
Test & Mechatronic Simulation

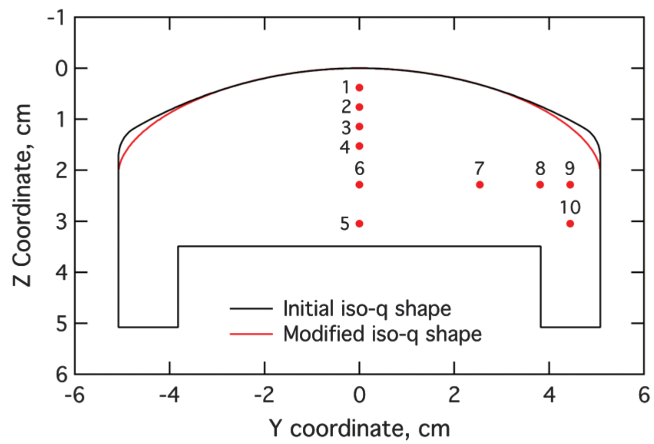
Mandatory test-case

- Results Test 3.1
  - Thermo-couples:
    - Temperature
    - Density
  - Charring at stagnation point
  - Global mass-loss

Table 1. Coordinates of the thermo-couples.

TC	Y-coordinate [cm]	Z-coordinate [cm]	TC	Y-coordinate [cm]	Z-coordinate [cm]
1	0.00	0.381	6	0.00	2.286
2	0.00	0.762	7	2.540	2.286
3	0.00	1.143	8	3.810	2.286
4	0.00	1.524	9	4.445	2.286
5	0.00	3.048	10	4.445	3.048





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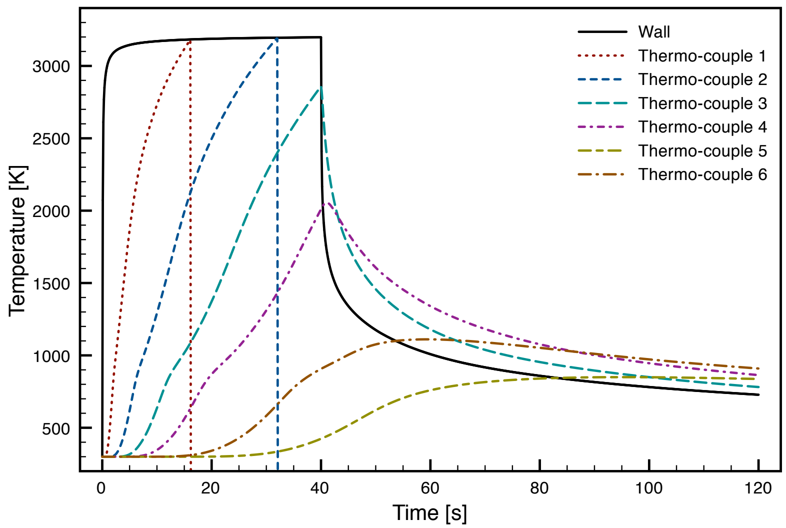
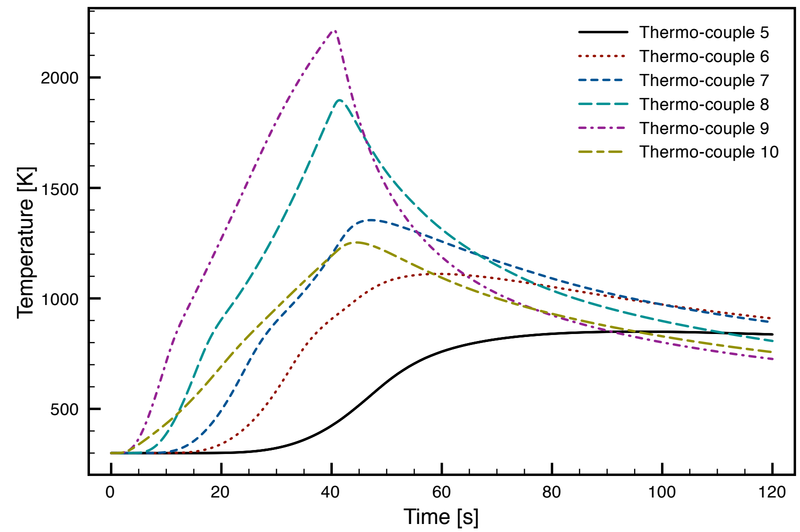
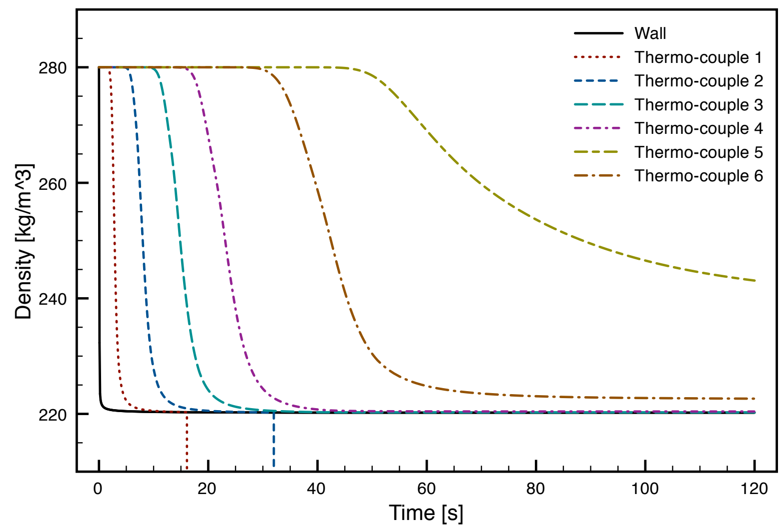
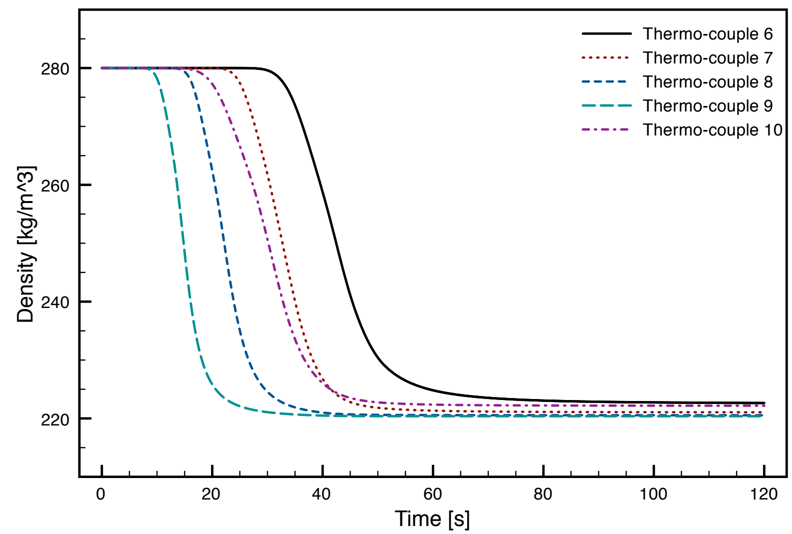
Mandatory test-case



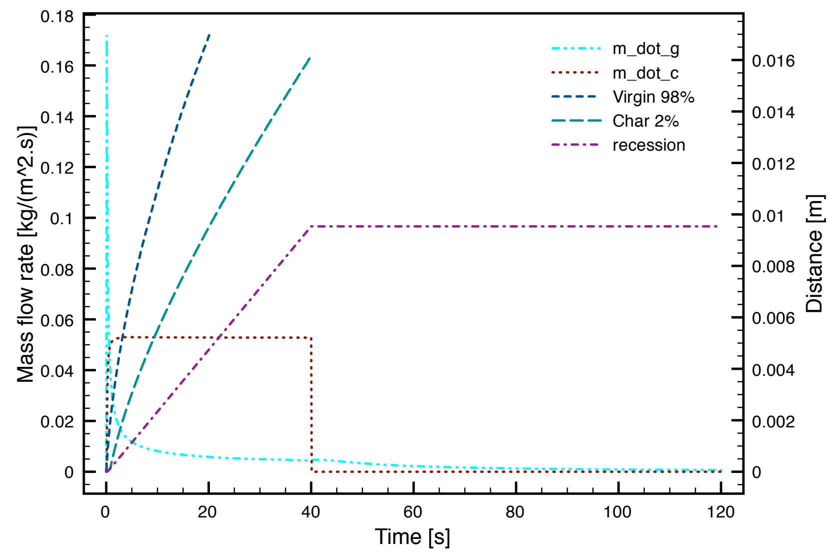


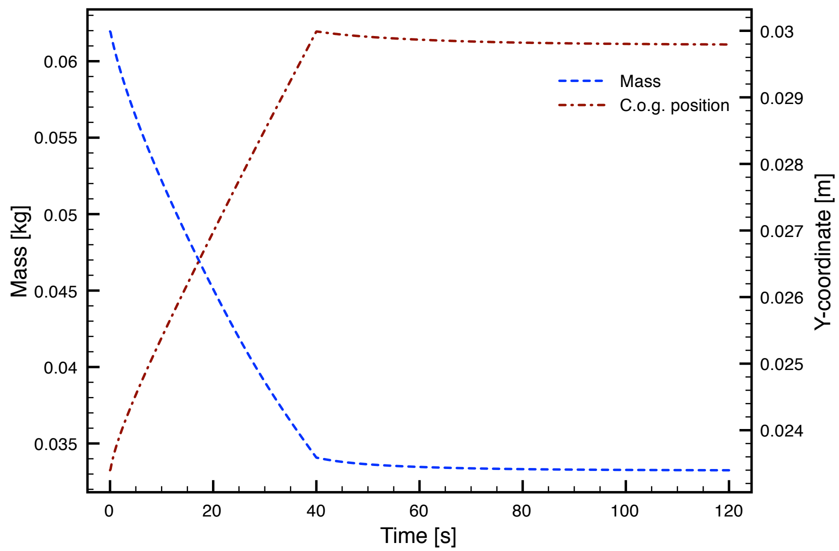


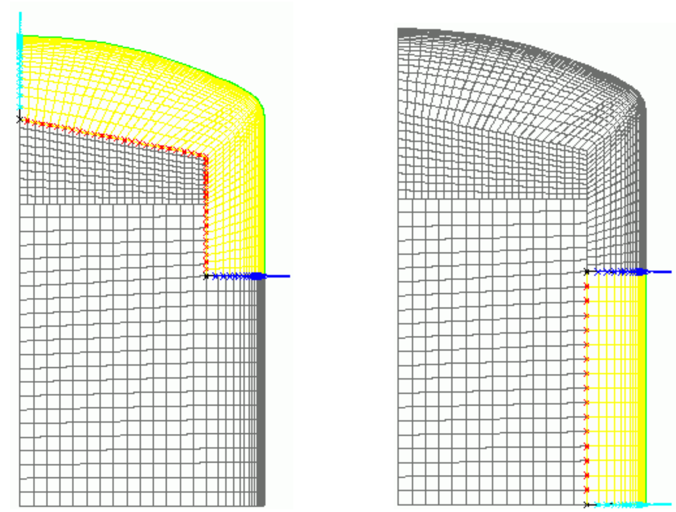


Mandatory test-case

- Charring results at stagnation point
  - Gas mass flow
  - Char mass flow
  - Virgin 98% distance
  - Char 2% distance
  - Recession
- Mass loss
- C.o.g. position







Mandatory test-case

- Modification of the basic case
  - 3.2: Orthotropic conductivity (axis-symmetric/3D)
    - Define the values α_1 and α_2

$$\begin{vmatrix} \lambda_{TTT} & 0 \\ 0 & \lambda_{IP} \end{vmatrix} = \begin{vmatrix} \alpha_1 & 0 \\ 0 & \alpha_2 \end{vmatrix} \lambda_{isotropic}$$

    - TTT-direction along the axis of axis-symmetry
  - 3.3 Orthotropic conductivity with 3D heat flux (3D)
    - 3D heat flux to test 3D behavior

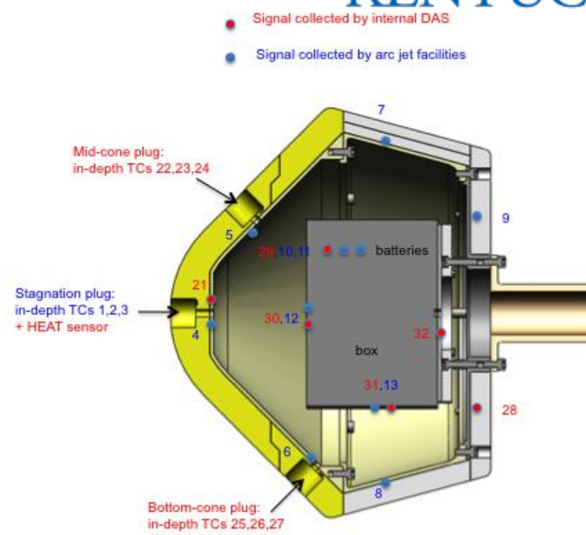
$$f(x,y) = 1 + \beta e^{-\frac{1}{2\sigma^2}\left[(\mu_x - x)^2 + (\mu_y - y)^2\right]}$$

    - Replaced by →
  - Orthotropic material with TTT non-aligned with axis of axis-symmetry

- Other ideas are welcome …

Re-entry probe case

- Small entry probe (SPRITE) test-case proposal
- Questions that need to be answered:
  - Will we apply a realistic re-entry load, and if so who will be capable and willing to supply this?
  - How will the geometry of the test-case be defined:
    - will a 2D (cross section) description be given?
    - will a full 3D CAD model be supplied?
    - will a finite element mesh be supplied?
  - What are the results we would like to obtain?
  - Do we need to model radiation heat exchange (between structure and instruments) inside the capsule?
  - Which of the participants is able and willing to do this test?



Empey D.M., Skokova, K.A., Agrawal P., Swanson, G.T., Prabhu D.K., Peterson, K.H. and Venkatapathy E., *Small Probe Reentry Investigation for TPS Engineering (SPRITE)*