Definition of Ablation test-case series #3

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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
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

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)
  \[ q = \rho_e u_e C_H \left( h_e - h_w \right) + \rho_e u_e C_H \left[ B^c_e \left( h_c - h_w \right) + B^g \left( h_g - h_w \right) \right] \]
  \[ C_H = \frac{2\lambda B_0^c}{e^{2\lambda \delta_0} - 1} \]
  \[ \lambda = 0.5 \]

- Isotropic conductivity (axis-symmetric/3D)

<table>
<thead>
<tr>
<th>time (s)</th>
<th>( \rho_e u_e C_H (0) ) (kg m(^{-2}) s(^{-1}))</th>
<th>( h_e ) (J kg(^{-1}))</th>
<th>( p_w ) (Pa)</th>
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<td>( 2.5 \cdot 10^7 )</td>
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<td>( 2.5 \cdot 10^7 )</td>
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\[ C_H(s) \text{ distribution} \]

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

<table>
<thead>
<tr>
<th>s (cm)</th>
<th>Y-coord. (cm)</th>
<th>Z-coord. (cm)</th>
<th>( q_w/q_w(0) )</th>
<th>s (cm)</th>
<th>Y-coord. (cm)</th>
<th>Z-coord. (cm)</th>
<th>( q_w/q_w(0) )</th>
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<td>0.00</td>
<td>0.000</td>
<td>0.000</td>
<td>1.000</td>
<td>5.50</td>
<td>5.068</td>
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<td>0.196</td>
<td>1.000</td>
<td>5.75</td>
<td>5.080</td>
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<td>0.971</td>
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<td>0.597</td>
<td>0.955</td>
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Dec J.A., Laub B. and Braun R.D., Two-Dimensional Finite Element Ablative Thermal Response Analysis of an Arcjet Stagnation Test
Mandatory test-case

- Pressure distribution
  - Heat flux at start of the calculation
    \[ q = \ldots + \rho u C_H B^i (h_g - h_w) \]
  - Example: Test 2.3
    - Fixed back-surface pressure \( P_0 \)
    - Front surface pressure \( 0.2 \times P_0 \)
  - Temperature evolution at outer wall

- Cooldown due to equilibrium hypothesis for the enthalpy

Mandatory test-case

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

<table>
<thead>
<tr>
<th>TC</th>
<th>Y-coordinate [cm]</th>
<th>Z-coordinate [cm]</th>
<th>TC</th>
<th>Y-coordinate [cm]</th>
<th>Z-coordinate [cm]</th>
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<td>3.048</td>
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</table>

D includes the off-axis thermocouples that were used in two tests that will be thoroughly discussed in Sec. VI, Model Validation. X-ray images of all pretest models confirmed that thermocouples were installed within \(0.0006\) cm of the nominal locations.

Arcjet tests were conducted in the Aerodynamic Heating Facility (AHF) and Interaction Heating Facility (IHF) at NASA ARC and in the TP2 facility at NASA Johnson Space Center (JSC). For all test conditions multiple runs and multiple swing arms were used to obtain calibration measurements of stagnation pressure and cold-wall heat flux, and if possible, temperature response from multiple arcjet models with the same or different exposure durations.

At the end of the exposure, the model was removed from the arcjet flow field and held in a low-pressure environment during a cooldown period of several hundred seconds. For safety reasons, models are not exposed to atmospheric pressure until after they have cooled down.

The stagnation pressure and heat flux were measured using a combination slug-calorimeter/pitot-pressure device (Fig. 1) that had the same external shape as the TPS samples to be tested. The calorimeter is inserted into the arcjet flow for approximately 3 s. Because the arcjet flow is both unsteady and swirling, there is natural variation in the stagnation measurements obtained from a short arcjet flow.

*Fig. 4 Cross section of iso-q arcjet models. Model types II and III may contain a thermocouple plug (as shown). The initial thickness at the centerline varied from 3.49 to 4.13 cm.*

*Fig. 5 Axial plug containing thermocouples 1 to 5 for model types II and III.*

*Fig. 6 Cross-sectional drawing of iso-q-shaped arcjet model with thermocouple locations for TC-placement options B and D (see Table 1). Thermocouples are not coplanar.*

*Fig. 7 Side-view and top-view x-ray images of arcjet model with thermocouple placement D.*

Mandatory test-case

Temperature [K]

Density [kg/m^3]

Time [s]
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
- Modification of the basic case
  - 3.2: Orthotropic conductivity (axis-symmetric/3D)
    - Define the values $\alpha_1$ and $\alpha_2$
    
    \[
    \begin{bmatrix}
    \lambda_{TTT} & 0 \\
    0 & \lambda_{IP}
    \end{bmatrix} = \begin{bmatrix}
    \alpha_1 & 0 \\
    0 & \alpha_2
    \end{bmatrix} \lambda_{isotropic}
    \]
    
    - TTT-direction along the axis of axis-symmetry
  
  - 3.3 Orthotropic conductivity with 3D heat flux (3D)
    - 3D heat flux to test 3D behavior
    
    $$f(x, y) = 1 + \beta e^{-\frac{1}{2\sigma^2}[(\mu_x - x)^2 + (\mu_y - y)^2]}$$
    
    - Replaced by $\Rightarrow$
    - Orthotropic material with TTT non-aligned with axis of axis-symmetry

- Other ideas are welcome …
- 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?