Inter-Code Calibration exercise series#2, Amaryllis results

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1D/Axis-symmetric/3D finite element code:
- Non-linear structural analysis + thermal + charring-ablation code
- Temperature (T), Pressure (P), density ($\rho$) and species density ($\alpha_i$)
- Mesh deformation due to ablation (multiple ablation zones)
- Thermal contact algorithms for contact between:
  - Different ablation zones
  - Support structure and ablation zone
- Multiple boundary condition types:
  - Convection (classical, enthalpy form)
  - flux
  - radiation
- Ablation (imposed boundary condition):
  - Phase change
  - Chemical (explicit ablation speed or $Bc'$ table; $Bc'=Bc'(T,P,Bg')$)
  - Mechanical (erosion; temperature and/or density dependent)
- Fully coupled thermo-mechanical solution (char swell)
Amaryllis Test 2.1

- Comparison Amaryllis:
  - PATO-PAM2 results are “identical”
  - No CMA/FIAT baseline available
- Fine mesh distribution is needed for the gas mass flow, not for temperatures
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- Arrhenius type charring equations
  \[ \dot{\rho} = -\sum \Delta \rho^i A_i \rho_v^{1-N_i} (\rho_v - \rho_c)^{N_i-1} (1-\alpha_i)^{N_i} e^{-E_i/RT} \]

  - Generalized densities
    \[ \rho = \rho_v - \sum \Delta \rho^i \alpha_i \]

  - Mass balance equations
    \[ \nabla (K_p \nabla P) = \dot{\rho} \]
    \[ \dot{m}^g = -K_p \nabla P \]

  - Heat balance equation
    \[ -\frac{\partial \rho}{\partial t} H_p + \rho c \frac{\partial T}{\partial t} = \nabla (\lambda \nabla T) - \dot{m}^g \cdot \nabla h^g \]
    \[ \bar{q} = -\lambda \nabla T \]
- Equivalence with the FIAT formulation.
  - Interpolation
    \[ \alpha = \frac{\rho_v - \rho}{\rho_v - \rho_c} \]
  - Capacity
    \[ \rho_c = \rho c_v(T) - \alpha(\rho c_v(T) - \rho c_c(T)) \]
  - Pyrolysis heat
    \[ H_p = h^g - \frac{\rho_v h_v - \rho_c h_c}{\rho_v - \rho_c} \]
  - Charring
    \[ \Delta \rho^i = \frac{\rho_{0_i} - \rho_{r_i}}{\rho_{0_i} - \rho_{r_i}}(\rho_v - \rho_c) \quad A_i = \frac{\Gamma_i (1 - \varphi) B_i \rho_0^{1-N_i} (\rho_{0_i} - \rho_{r_i})^{N_i}}{\Delta \rho^i \rho_v^{1-N_i} (\rho_v - \rho_c)^{N_i-1}} \]

- Difference with the FIAT formulation
  - Interpolation
    - conductivity
  - Mass balance
    - Perfect gas:
      \[ K_p = \frac{M^g \beta P}{\mu RT} \quad \beta = \beta_v \frac{\Omega}{\Omega_v} \quad \Omega = \Omega_v + (1 - \Omega_v) \frac{\rho_v - \rho}{\rho_v} \]
    - \( K_p \) interpolation:
      \[ K_p(T, \rho) = K_{p_v}(T) - \alpha(K_{p_v}(T) - K_{p_c}(T)) \]