Investigation of thermal protection systems for hybrid rocket motors

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Outline

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  - Oxy-acetylene torch
  - Subscale hybrid motor test
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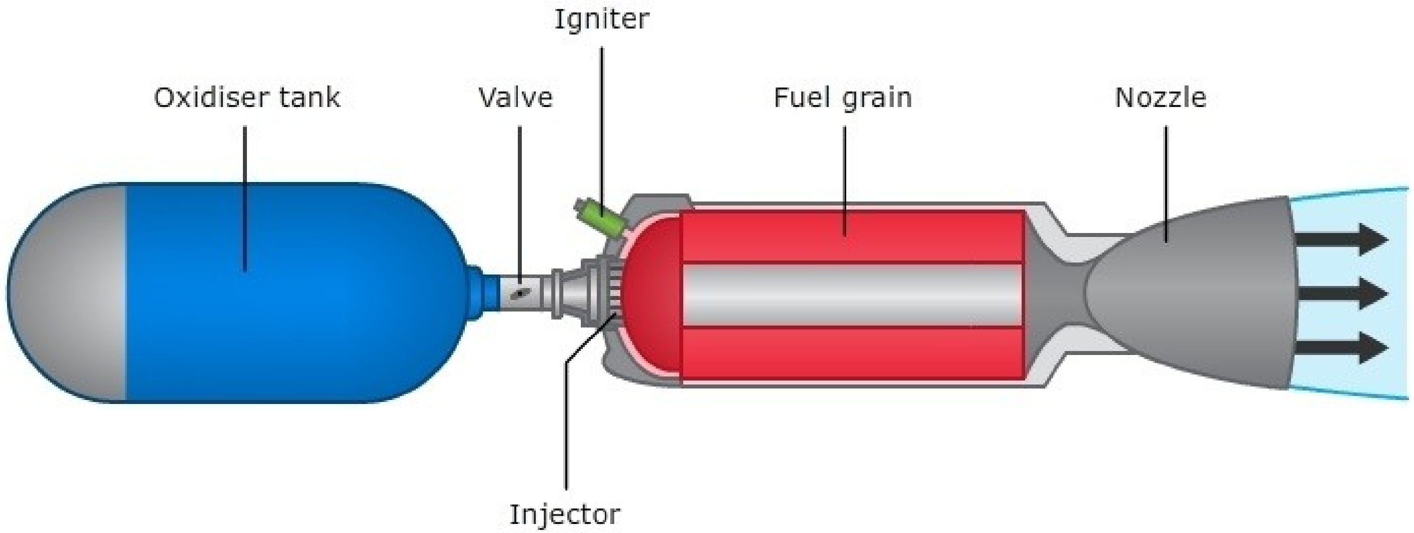
Introduction - Hybrid Rocket Motors



Advantages

- Safety
- Low costs
- Simplicity
- Green propellants
- Oxidizer flow control
  → Mission abort and throttlability

Main characteristics

- Oxidizer stored liquid in the tank
- Fuel stored solid in the combustion chamber
- One controllable feeding line
- Different technological solutions and propellant formulations

Disadvantages

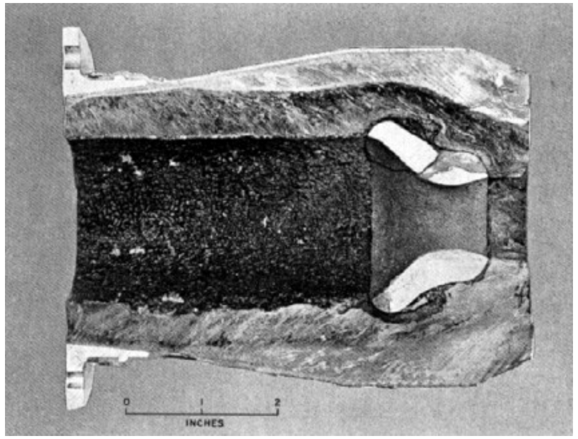
- Low regression rates
  → Low volumetric efficiency
- Combustion efficiency
- High oxigen content in the exhaust gases

Introduction – Thermal protection systems

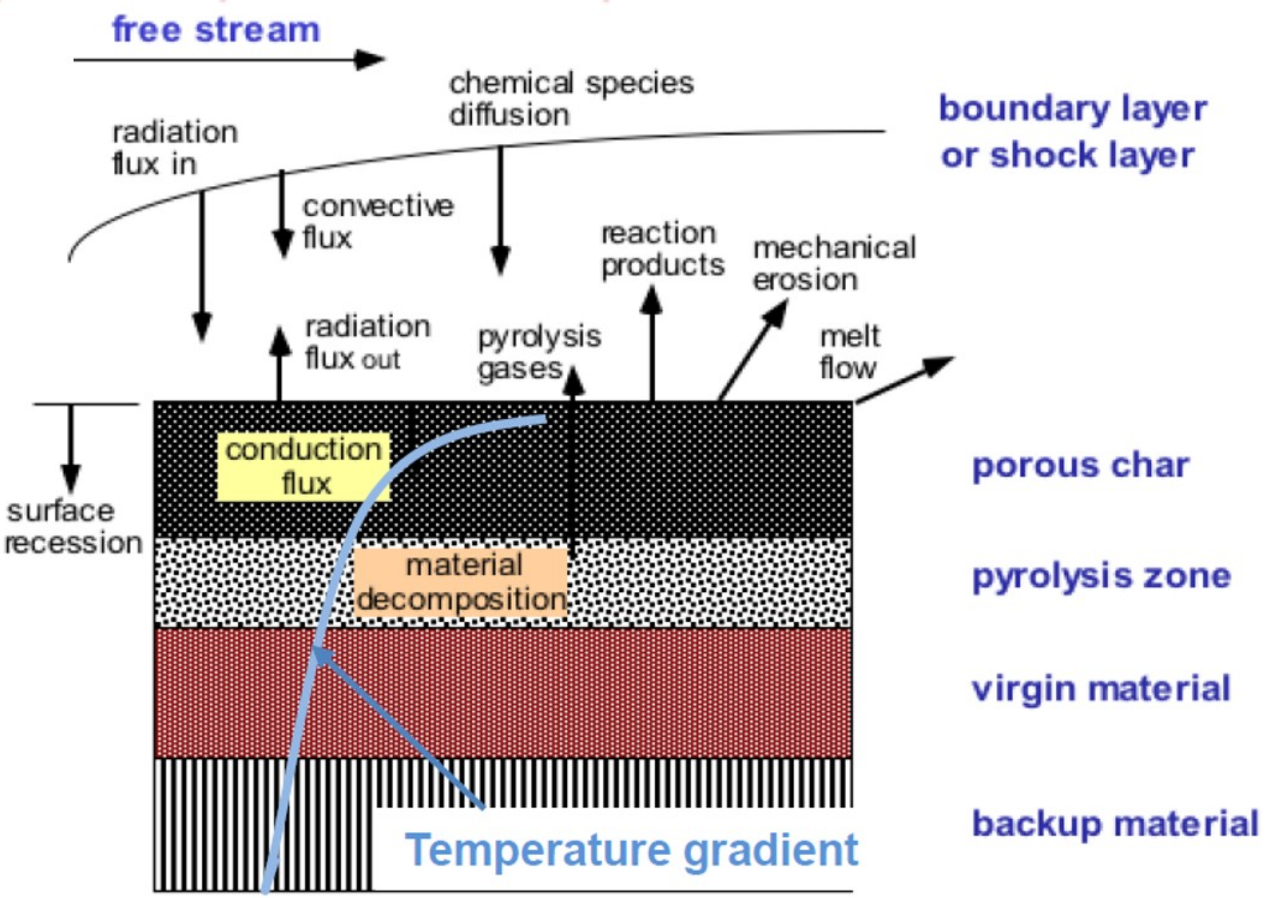
Active cooling systems

- ~~Low costs~~
- ~~Simplicity~~

Passive cooling systems



General concepts



- ❑ Hot gases convective heat
- ❑ Conduction flux
- ❑ Oxidation reactions (exothermic)

- ➢ Poor conductivity
- ➢ Melting
- ➢ Vaporization
- ➢ Sublimation
- ➢ Decomposition (pyrolysis)
- ➢ Blowing of the pyrolysis gases

→ Material consumption (ablation)

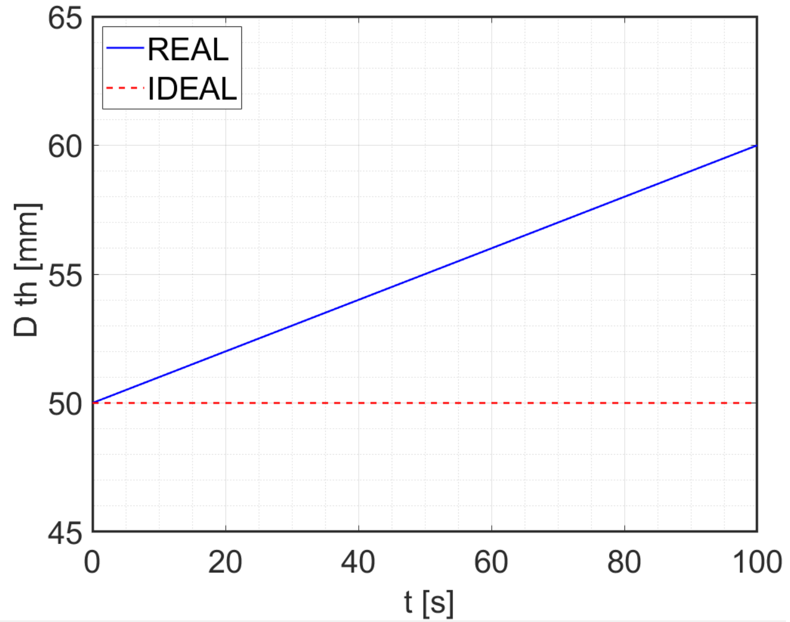
Effects on motor performance

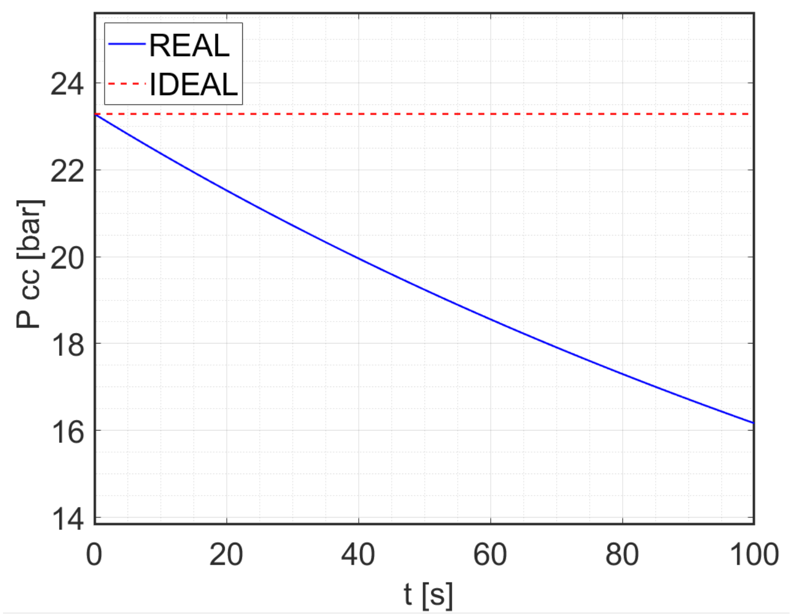
INPUT

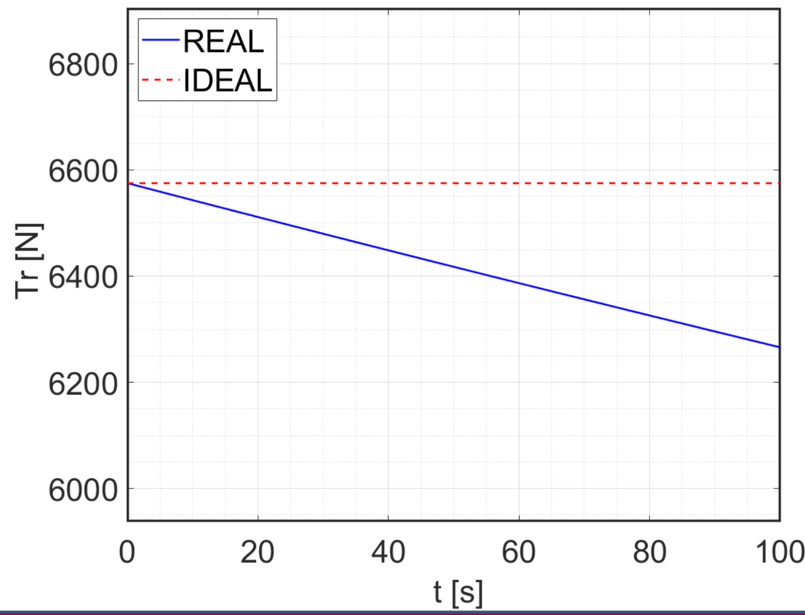
- Throat regression rate = 0.05 mm/s
- Burning time = 100 s
- Initial throat diameter = 50 mm
- Initial chamber pressure = 23.3 bar
- Initial motor thrust = 6575 N

OUTPUT

- Pressure loss = 30 %
- Trust loss = 4.7 %

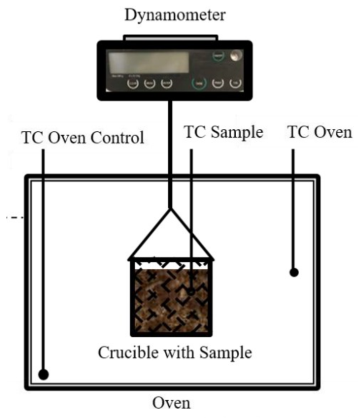


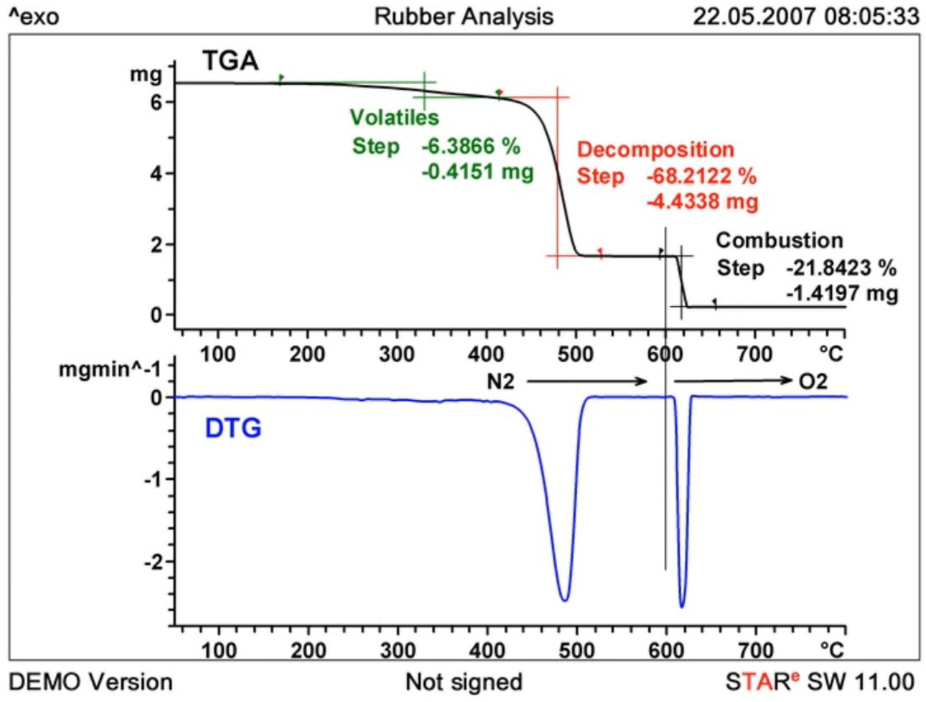




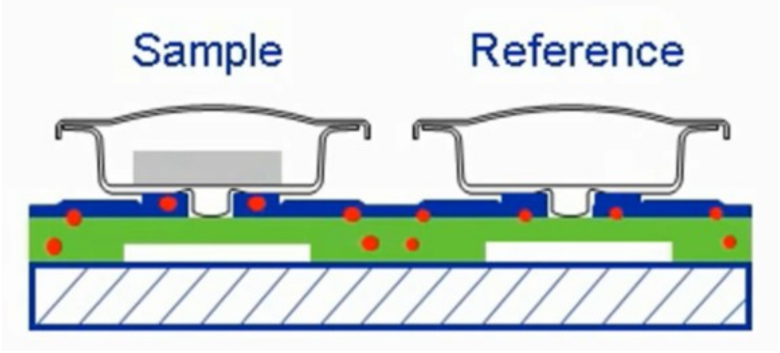
Testing techniques

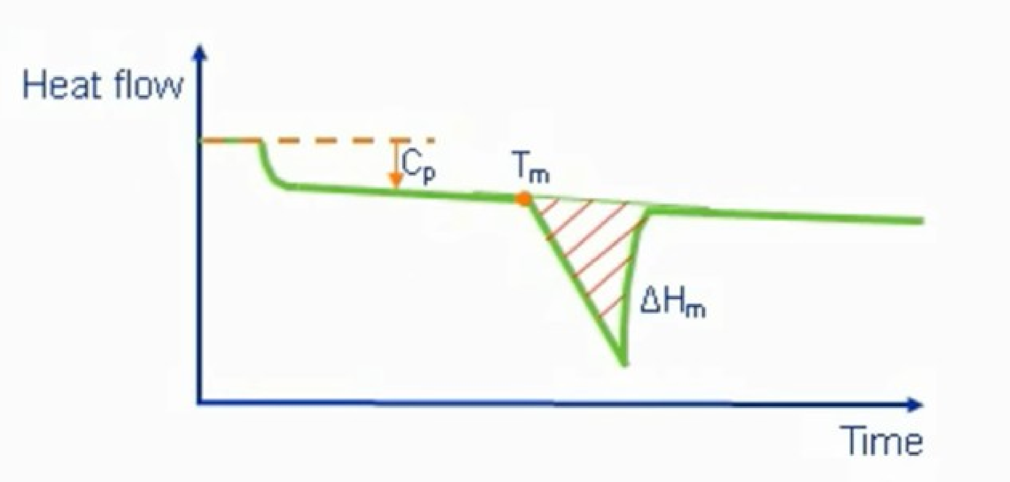
TGA





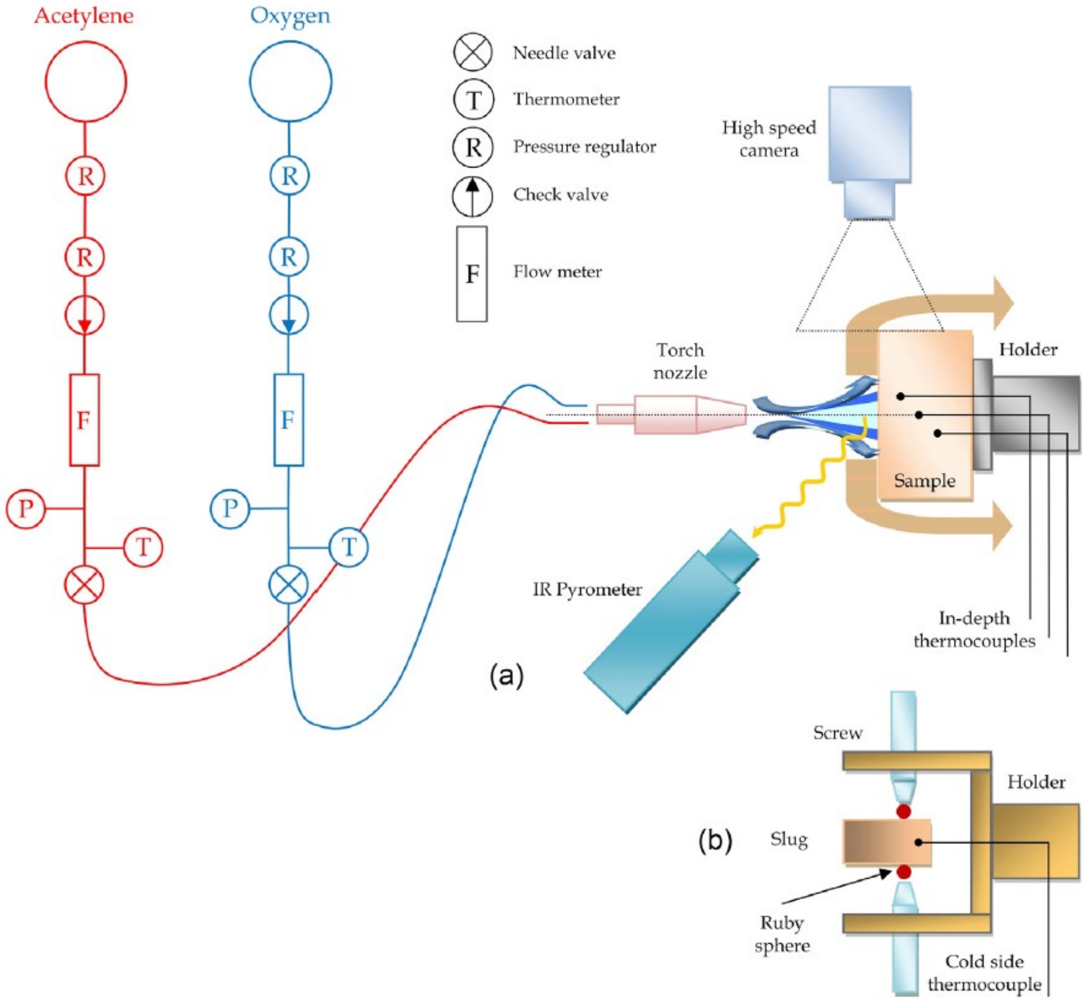
DSC

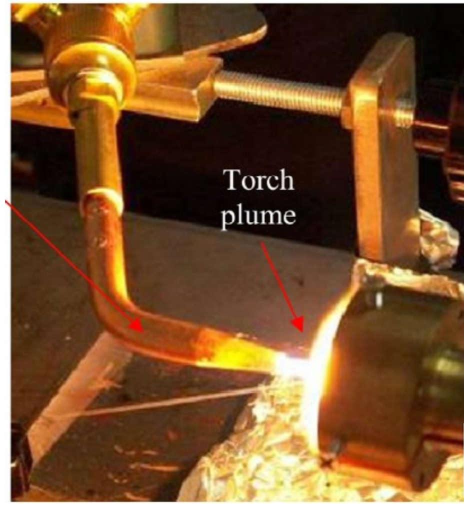


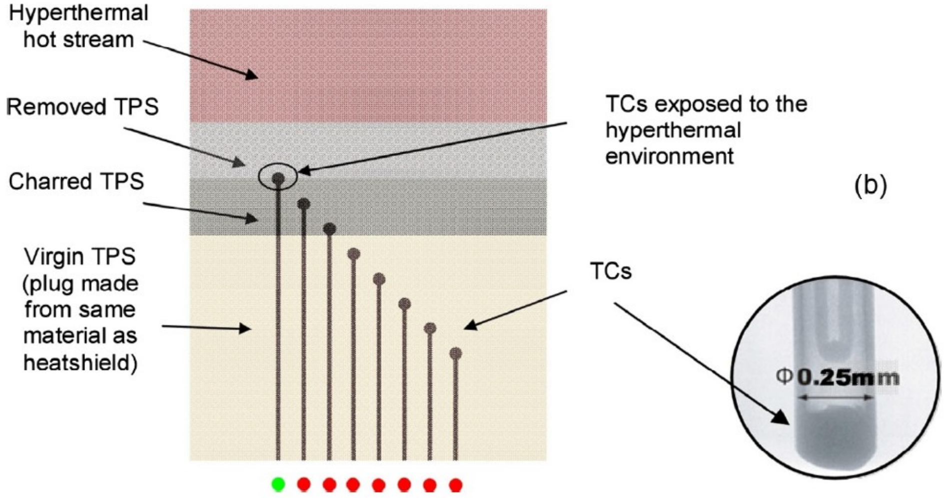


Testing techniques

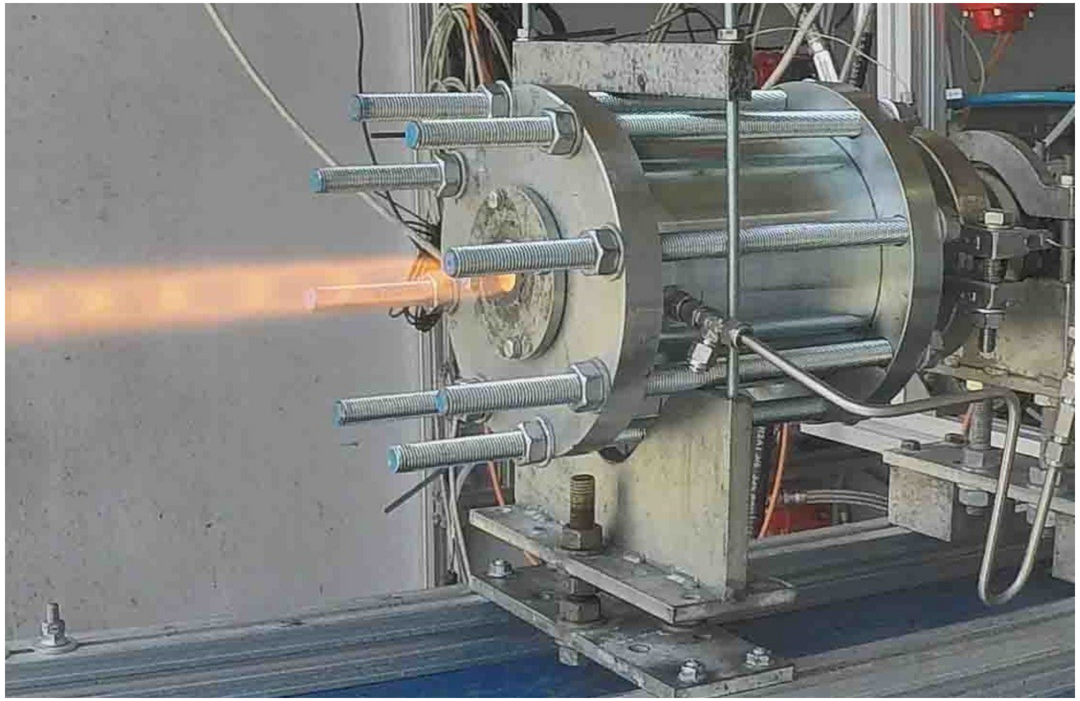
Oxy-acetylene torch



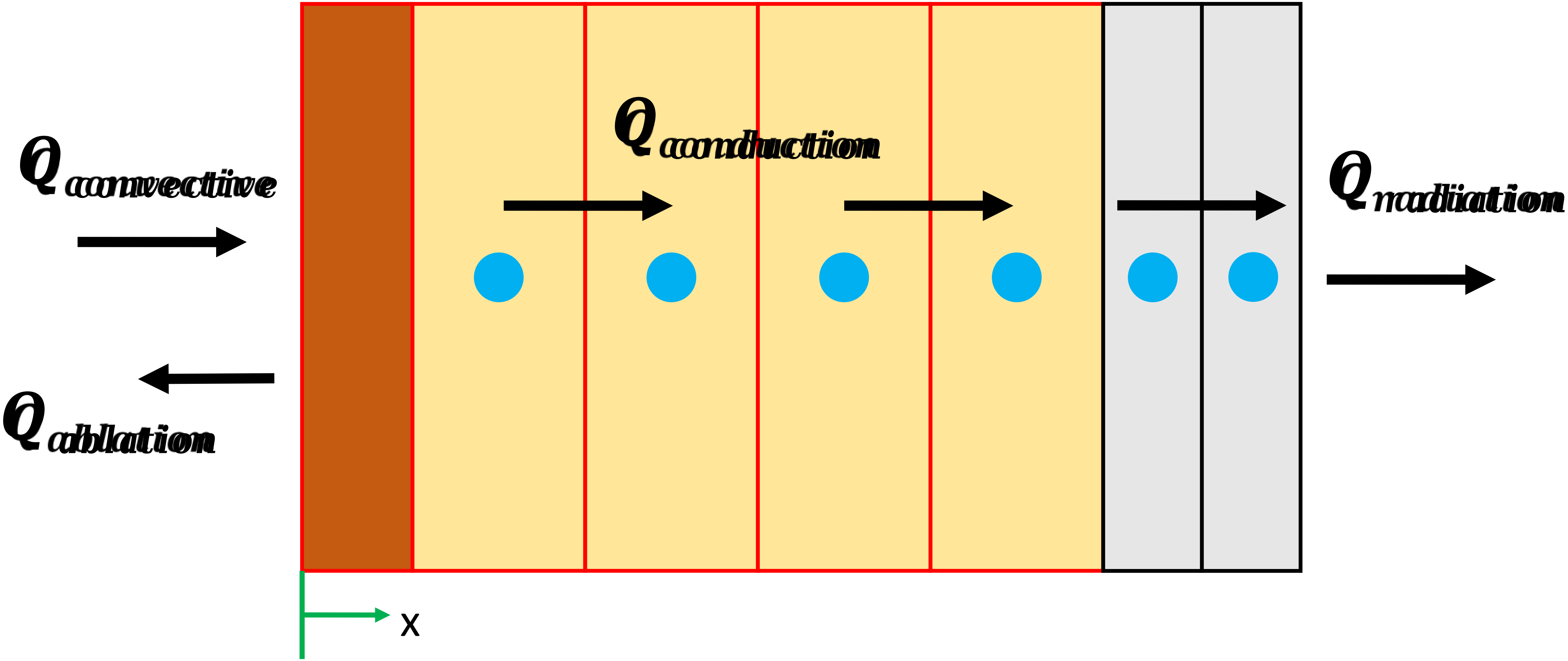




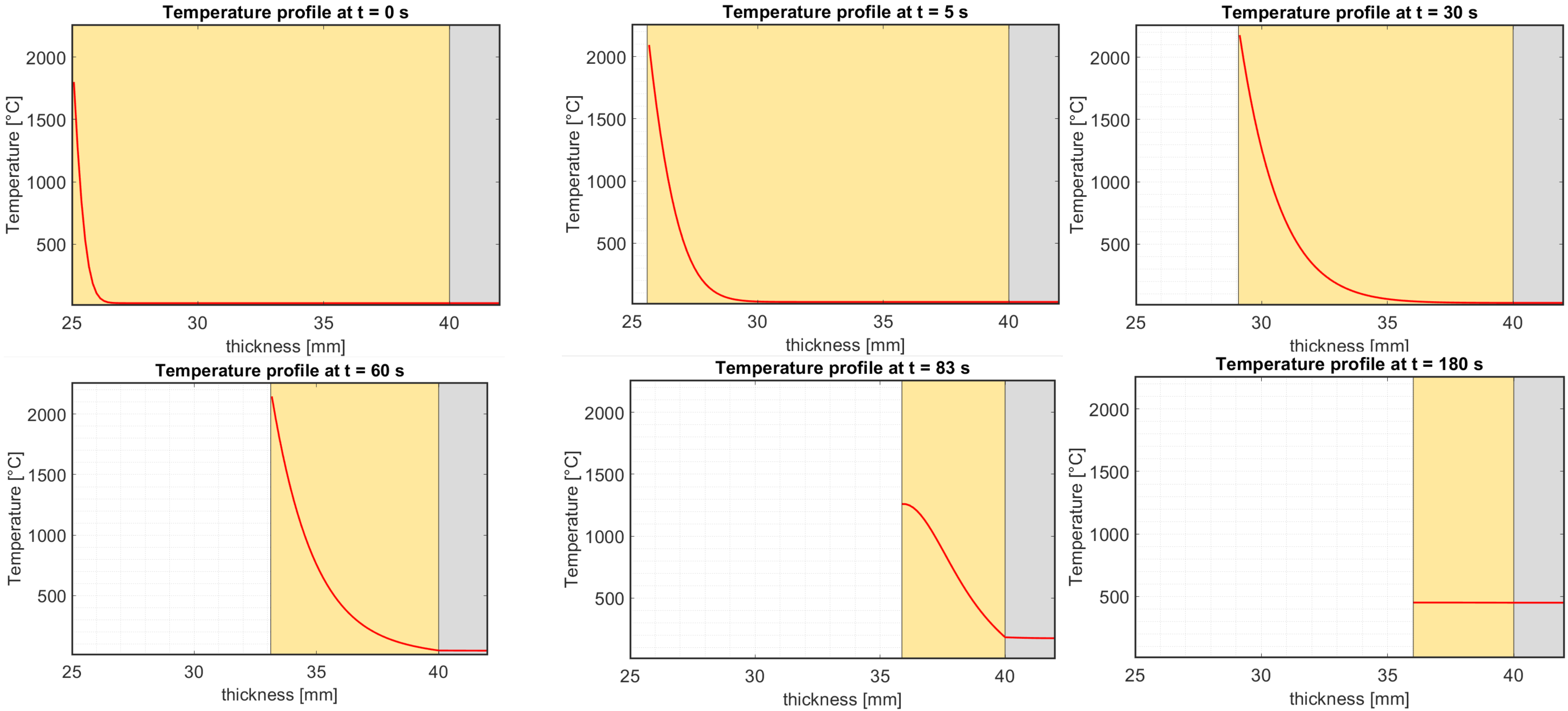
Subscale hybrid motor test



1D ablation model



1D ablation model



Future work

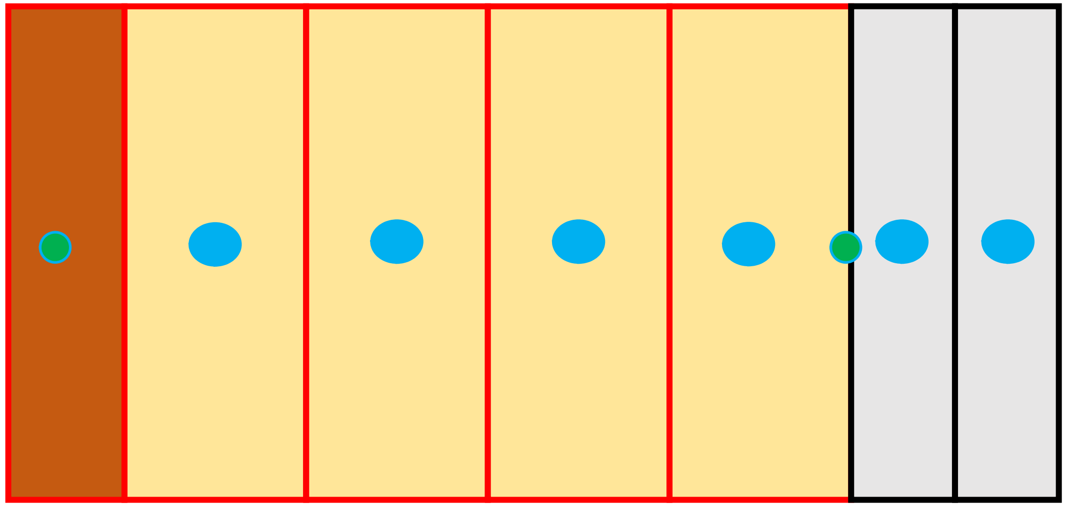
Thank you for your time! Any questions?

EXTRA

1D ablation model

Convective heating:

- *Bartz equation* $\begin{cases} Flat\ plate\ aproximation \\ Pr = 1 \\ Reynolds\ analogy \\ Fully\ developed\ turbulent\ flow \end{cases}$
- Gas total temperature = 2800 K (thermochemical code)
- Total mass flow rate = 2 kg/s
- Initial internal diameter = 50 mm



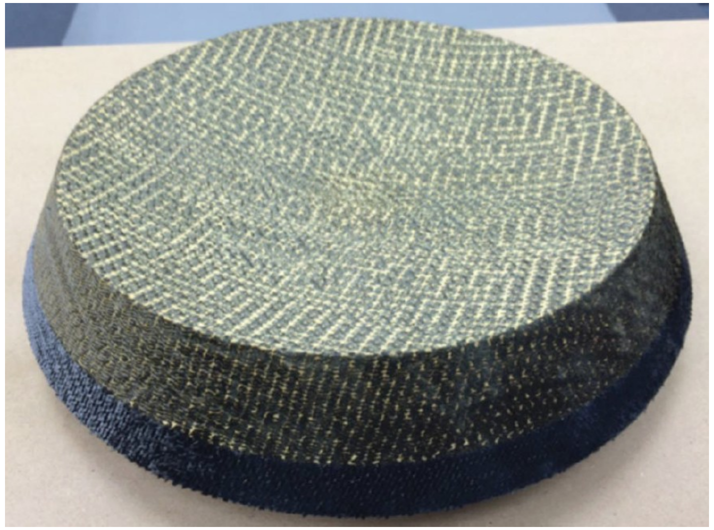
Conduction and radiation:

- ❑ TPS material (Silica phenolic)
  - $\rho = 1650$ kg/m^3
  - $\lambda = 0.49$ W/mK
  - $c_p = 1200$ J/kg K
- ❑ Metal case (Inconel 718)
  - $\rho = 8200$ kg/m^3
  - $\lambda = 11.4$ W/mK
  - $c_p = 435$ J/kg K
  - $\epsilon = 0.8$

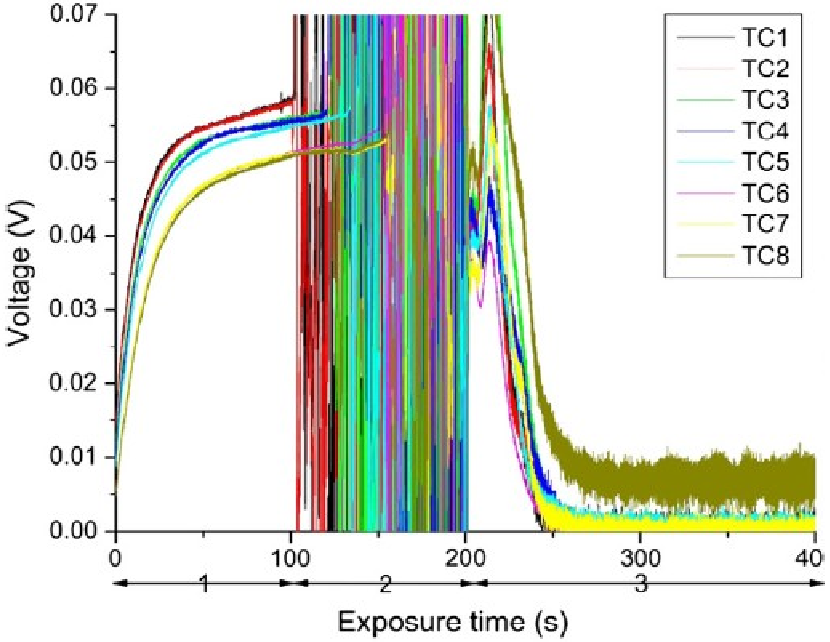
- $c_p\rho\frac{A_{sur}}{dt}\left(T_{sur,j} - T_{sur,j-1}\right) = Q_{net}P_{sur} - \frac{\lambda P_{ur}}{dxs}\left(T_{sur,j} - T_{1,j}\right)$
- $c_p\rho\frac{A_i}{dt}\left(T_{i,j} - T_{i,j-1}\right) = \frac{\lambda P_{i-1}}{dx}\left(T_{i-1,j} - T_{i,j}\right) - \frac{\lambda P_i}{dx}\left(T_{i,j} - T_{i+1,j}\right)$
- $\frac{\lambda_1 P_{1-int}}{\frac{dx_1}{2}}\left(T_{n_1,j} - T_{int,j}\right) - \frac{\lambda_2 P_{int-2}}{\frac{dx_2}{2}}\left(T_{int,j} - T_{n1+1,j}\right) = 0$
- $c_p\rho\frac{A_i}{dt}\left(T_{i,j} - T_{i,j-1}\right) = \frac{\lambda P_{i-i}}{dx}\left(T_{i-1,j} - T_{i,j}\right) - \sigma P_i \epsilon T_{i,j-i}^4$

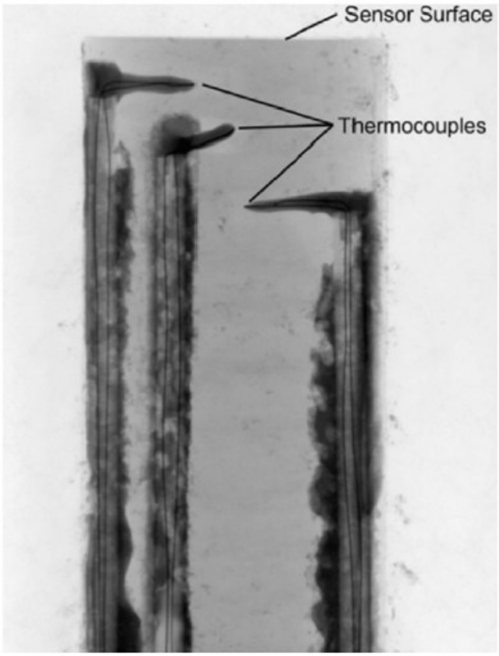
Materials

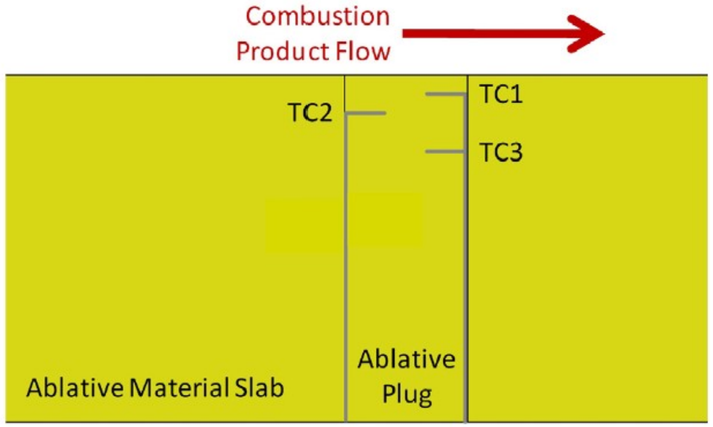
- ❑ Carbon-carbon
- ❑ Fiber reinforced polymeric ablator→ fibers: 60/75 % wt
  - Carbon phenolic
  - Glass phenolic
  - Silica phenolic



TC measurements







TC diffusivity << TPS diffusivity

To reduce the intrusiveness of the TC:

- Small size of the TC (e.g. 250 μm)
- TC perpendicular to the heat flow
- Maximize the thermal contact filling the holes with saving of the TPS recovered from the drilling process
- Coating of zirconia to reduce the electrical contact