High-Enthalpy Testing to Validate Simulation of an Aerosol Capture Probe

C. Naughton[1], C. Espinoza[1], J. Meurisse[2], A. Borner[2], D. Gentry[1].
[1]NASA Ames Research Center, [2]AMA Inc. at NASA Ames Research Center

Introduction

Background: AERACEPT (AErosol Rapid Analysis Combined Entry Probe/sonde Technology) is a developing technology designed to enable in-situ aerosol particle sampling and analysis in a small spacecraft mission envelope. By integrating a passive aerosol sample collection system into a probe's thermal protection system (TPS), this technology removes the need for heat shield separation and active descent control (parachutes, gliders, etc.) [1]. See Abstract #115 (Gentry et al.) in the Venus poster session for more information on AERACEPT.

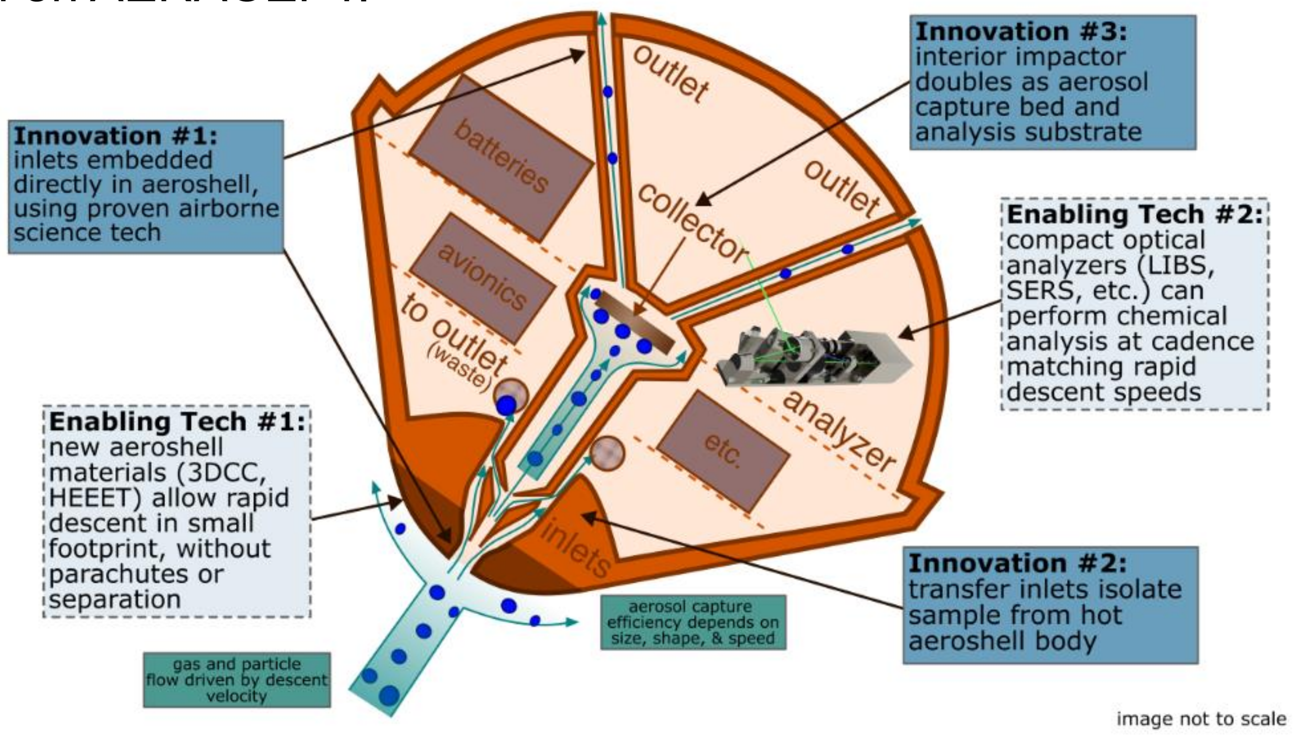

Fig. 1: AERACEPT Technology Concept Diagram

Motivation: The proposed technology employs the TPS material 3D Carbon-Carbon (3D/CC) at the heatshield nose to withstand entry environments without pyrolysis gas contamination. This comes with two major considerations:

- Any shape change of the sample inlet during the entry heat pulse will affect aerosol sample collection bias and efficiency.
- Any residual heating from the TPS may affect sample integrity.

Test Objectives: Demonstrate the capability to predict the material response of 3D/CC samples with and without a through-hole under conditions that lead to material shape change that is representative of a Venus entry. This will be achieved through the following:

Goals	Metrics
1) Test 3D/CC at conditions that produce representative shape change for a small spacecraft Venus entry.	a) Expose test articles to conditions that result in at least 1 mm and no more than 5 mm of material recession at the stagnation-point.
2) Validate material recession predictions of 3D/CC samples with and without through-holes.	a) Predict measured through-hole diameter change to within 50%. b) Predict measured stagnation-point recession to within 0.5 mm.
3) Validate both heating and cooling predictions of 3D/CC samples.	a) Predict maximum temperatures of the 3D/CC backface to within 10%. b) Predict time for the 3D/CC backface to drop below 1000 K to within 20 s.

Mission Concept

AERACEPT is being evaluated against the Nephele mission concept targeting the middle and lower Venus cloud layers.

- V_{EI}: 11 km/s, γ_{EI}: -10 deg, M: 95 kg.
- Science performed between 40-60 km and so is independent of heat pulse.
- Entry vehicle has a 45 deg cone angle and a 0.8 m max diameter.
- Thermal estimates calculated using the NASA Ames CFD code DPLR.

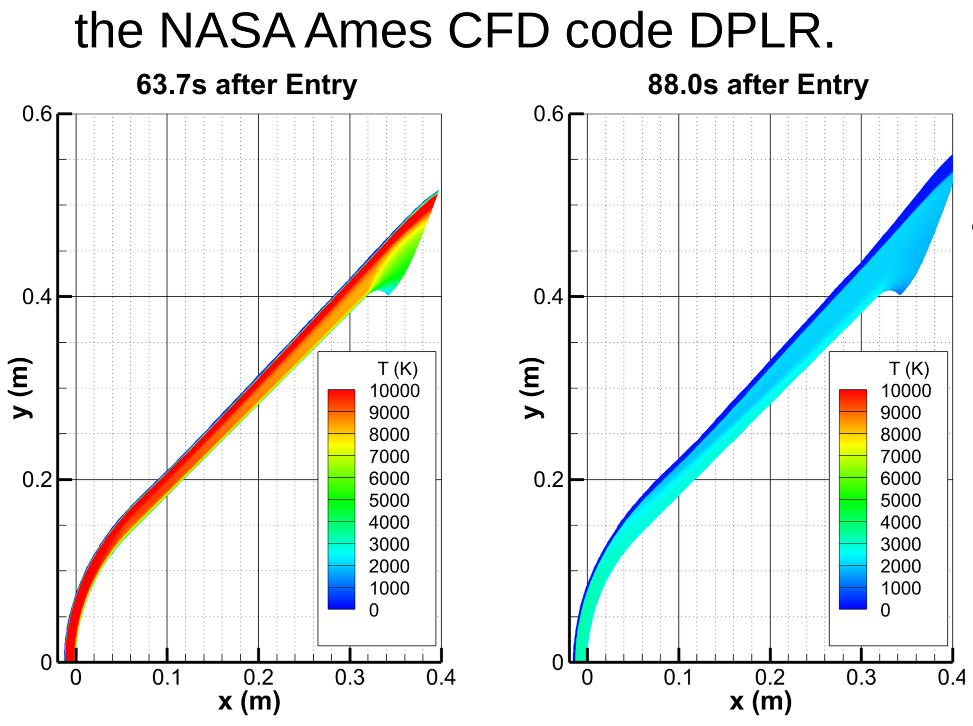

Fig. 2: Axisymmetric Flowfields During Entry Heat Pulse

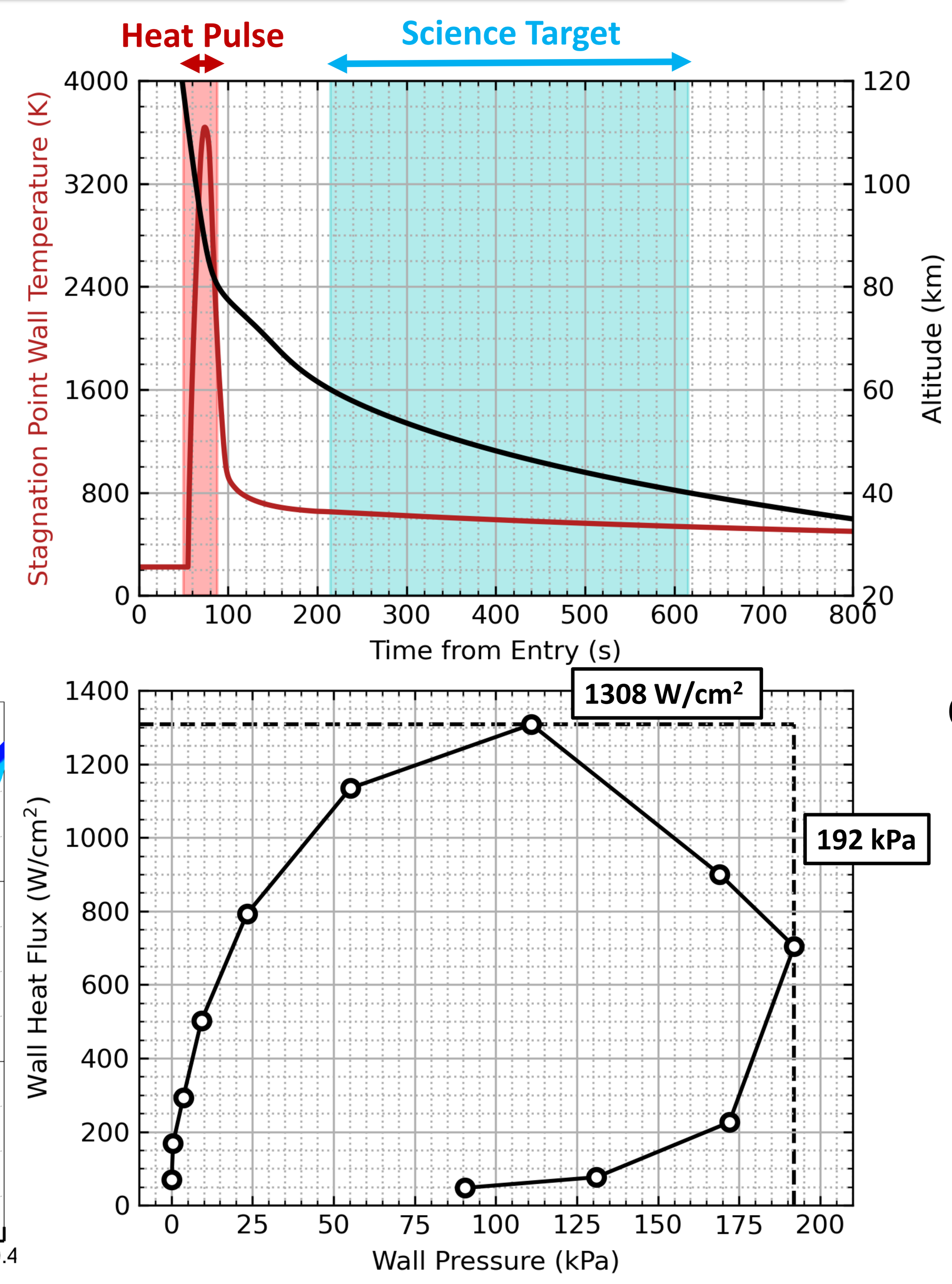

Fig. 3: Trajectory Profile (Top) and Entry Condition Envelope (Bottom)

Test Facility

Testing in the **PlasmatronX**, a 350 kW inductively-coupled plasma torch facility developed by the Center for Hypersonics and Entry Systems Studies at the University of Illinois at Urbana-Champaign [2].

- Capable of long test durations (hours).
- Supports CO_2 as a test gas – Representative for Venus.

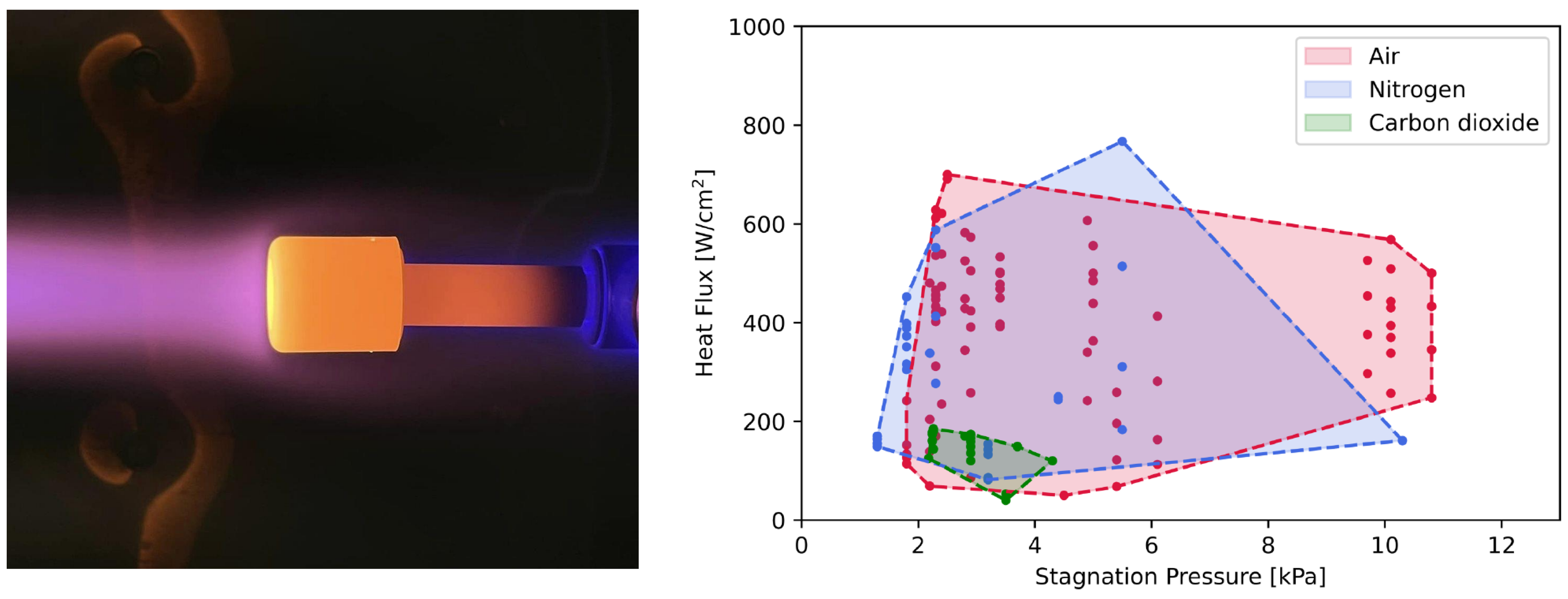

Fig. 4: Sample PlasmatronX Test Article (Left) and Test Condition Envelope (Right) [3]

Test Conditions

Performed trade study to determine ideal test gas.

- **Air** allows for a higher heat flux (~574 W/cm^2 at facility max).
- **CO_2** increases recession, but only supports lower heat fluxes (~157 W/cm^2 at facility max).

Can't match flight heat flux with either gas, but **CO_2 matches recession at survivable thermocouple temperatures**.

	Gas	Heating Duration (s)	Max Heat Flux (W/cm²)	Heat Load (kJ/cm²)	Stag. Recession (mm)
Test:	**CO_2**	85	157	13.35	**2.00**
Flight:	**CO_2**	45	1308	19.58	**1.89**

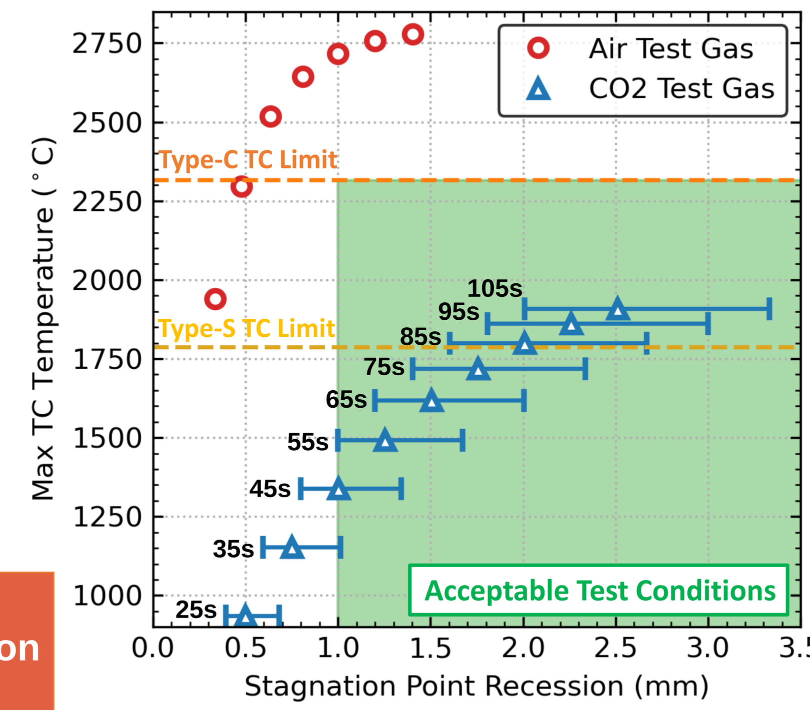

Fig. 5: Test Article Thermal Predictions at Facility Max

Test Articles

Testing **two** 1" Iso-Q article designs:

- **Open Article** – Coupon has 0.4" diameter through-hole.
- **Closed Article** – Coupon has two thermocouples at bondline.

Comparing collected test data to simulation for objectives:

- CT Scans – Goal 2.a
- Laser Scans – Goal 1.a and 2.b
- TC Data – Goals 3.a and 3.b

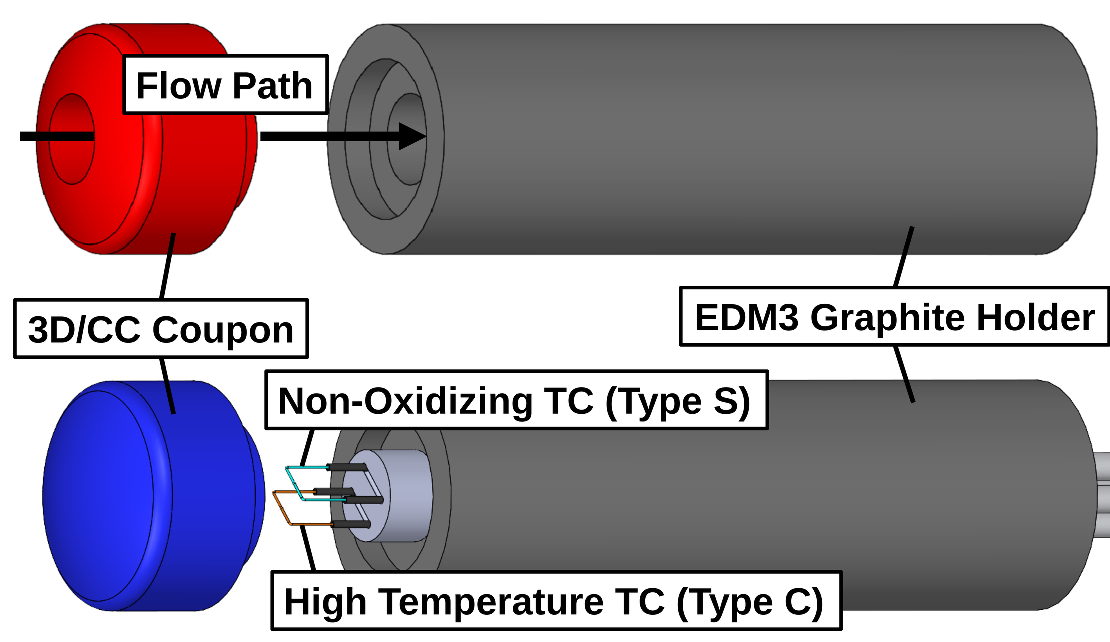

Fig. 6: Test Article Configurations – Open (Top) and Closed (Bottom).

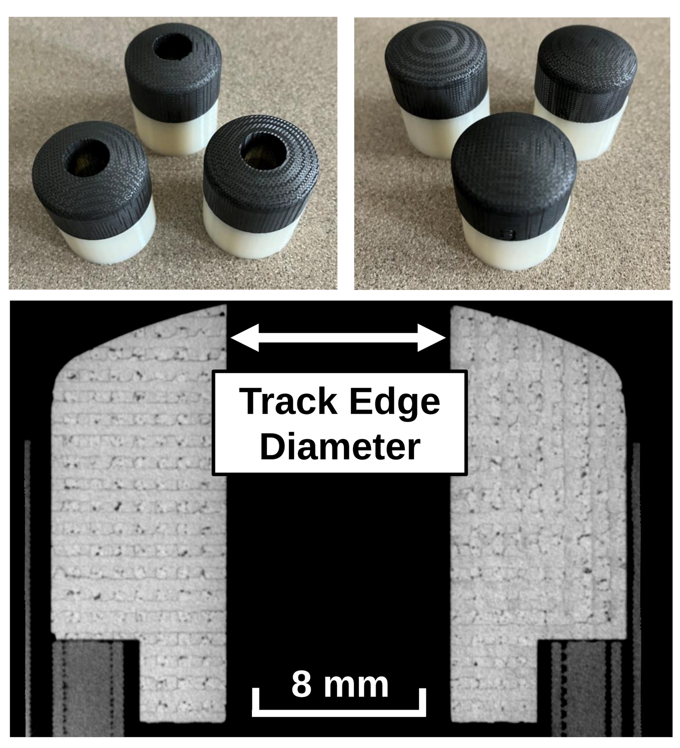

Fig. 7: 3D/CC Coupons (Top), Open Coupon CT Scan (Bottom)

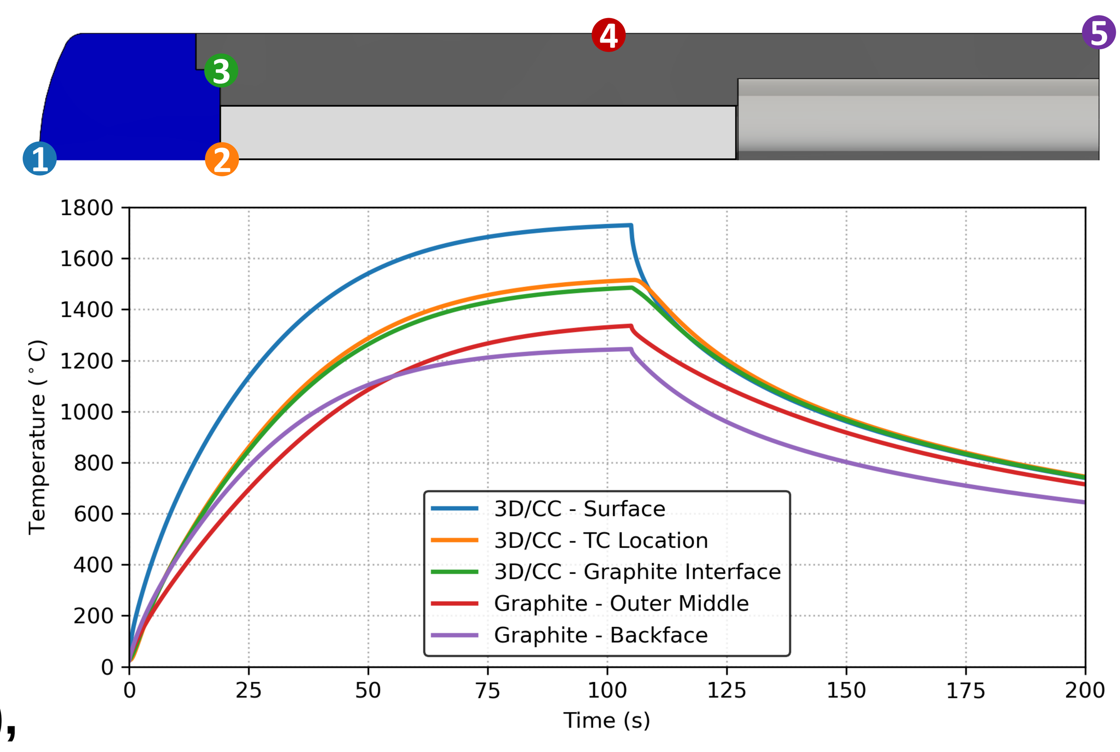

Fig. 8: Test Article Thermal Predictions

References

[1] D. Gentry et al. (2023). *AERACEPT (Aerosol Rapid-Analysis Combined Entry-Probe/sonde Technology): Enabling Technology for Missions to Venus Clouds.* [Abstract] AGU, San Francisco, CA, 2023.

[2] T. Oldham et al. (2023). *Aerothermal Chracterization of the PlasmatronX Wind Tunnel: Optical Emissions Spectroscopy and Jet Temperature Reconstruction.* AIAA Scitech, National Harbor, MD, 2023.

[3] Panerai et al. *Plasmatron X: Inductively Coupled Plasma Wind Tunnel for Hypersonic Testing*. [PPT Charts].