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Sandia National Laboratories

Material Testing in Sandia's Hypersonic Shock Tunnel

Preheating System Design Overview and Current Results

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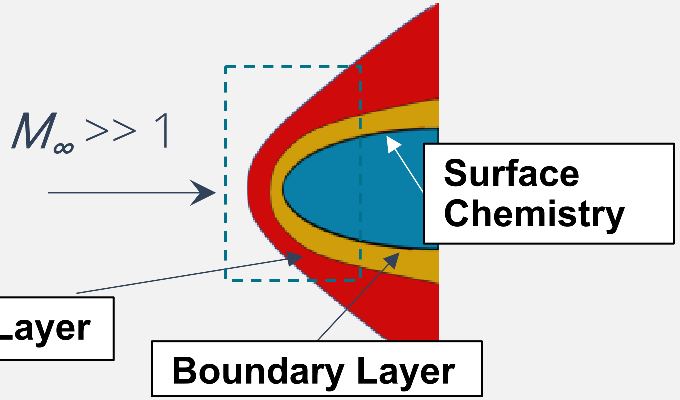
Motivation: Ablation & Gas-Surface Interactions



Shock Layer (Gas Chemistry)

- Species dependent thermodynamic nonequilibrium
  - Vibrational temp ≠ rotational temp ($T_V \neq T_R$)
- Dissociation produces atomic N and O and formation of nitric oxide (NO)

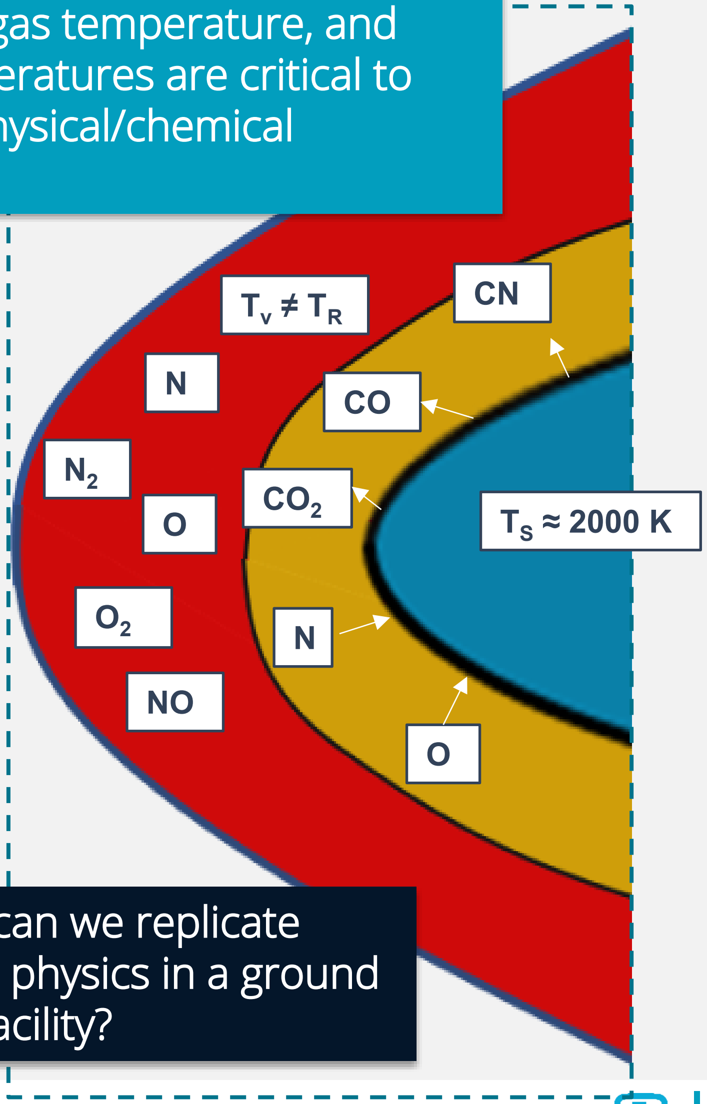
Surface Chemistry

- N and O interact (adsorb) with surface.
- Oxidation and nitridation
- CO, CO_2 production.

Boundary Layer

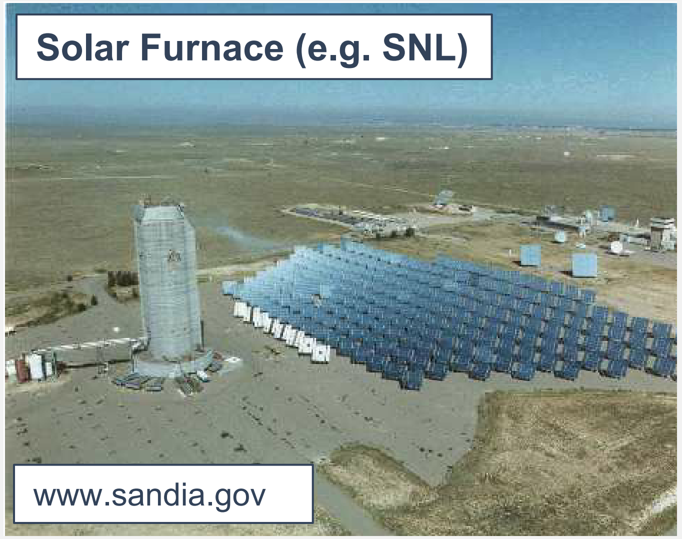
- Diffusion of oxidization products
- Air chemistry
- Vibrationally excited species (N_2 , O_2)

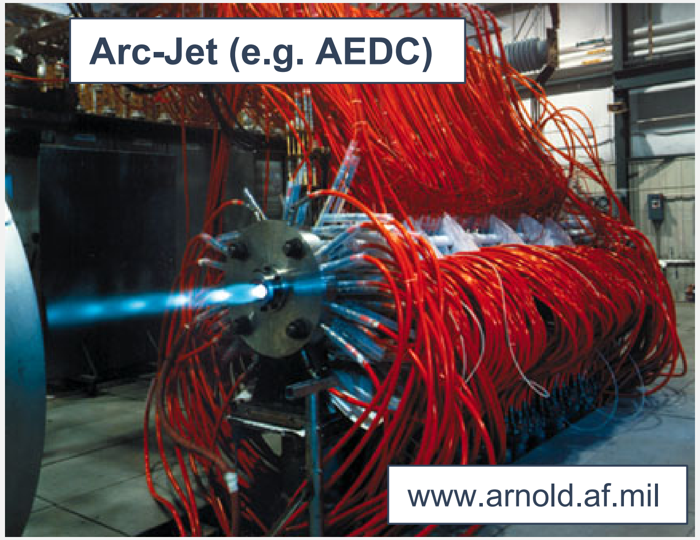
Hypersonic flow, high gas temperature, and elevated surface temperatures are critical to enacting the proper physical/chemical mechanisms

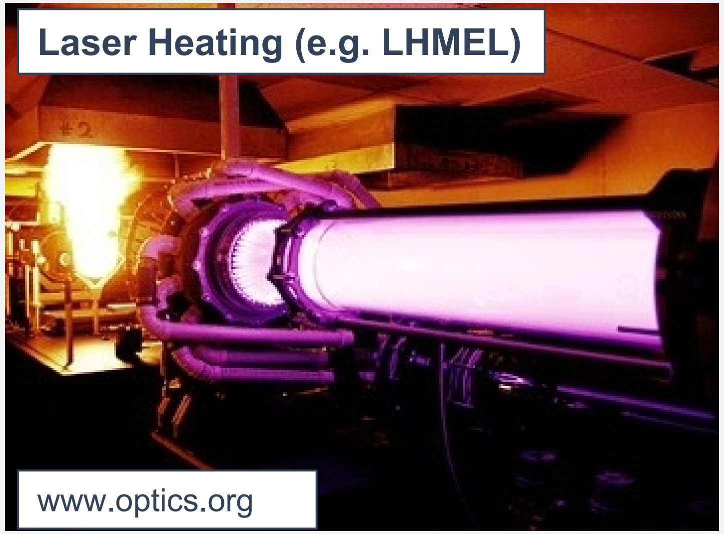


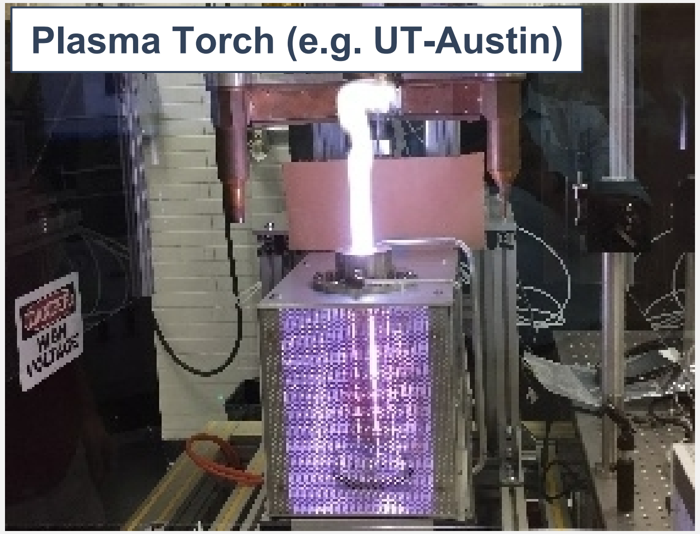
How can we replicate these physics in a ground test facility?

Established Methods for TPS Characterization







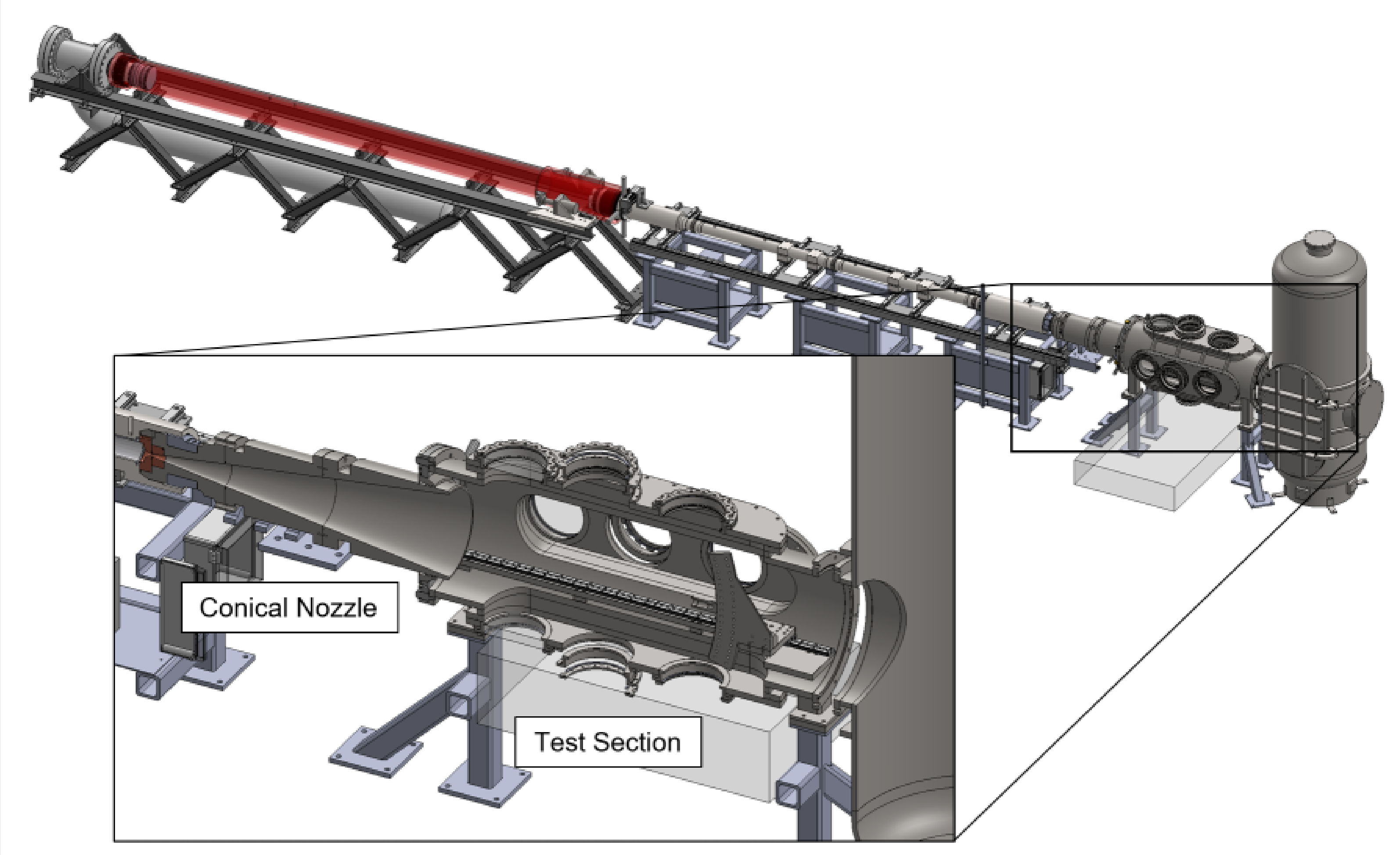


Summary

- Each method produces the correct heating over run times of several minutes.
- These facilities cannot reproduce flight velocity, aerodynamic heating and the correct air chemistry concurrently.

In hypersonic flight, fluid mechanics, gas chemistry and surface chemistry are critical to ablation and they are coupled!

A Compliment to Traditional Material Characterization Facilities: Sandia Hypersonic Shock Tunnel (HST)



Tunnel Specifications

- Nozzle Exit Dia. = 0.36 m
- Test section diameter 0.5 m
- Run times of a few milliseconds

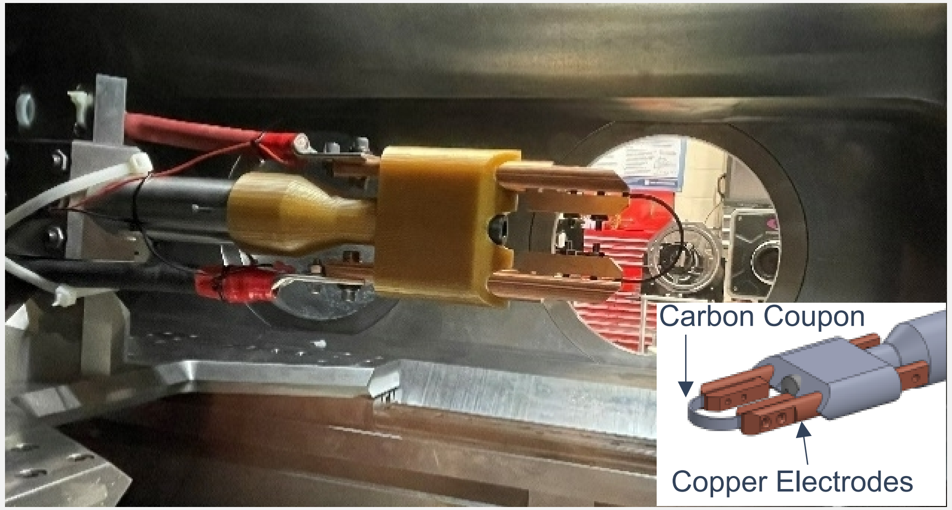
U_∞ (m/s)	H_0 (MJ/kg)	T_0 (K)
2840	4.0	3360
4060	8.8	5440

Target applications include high-temperature surface chemistry and hypersonic thermochemistry.

Quick Review: Historical Attempts at Material Characterization in Ground Test Facilities

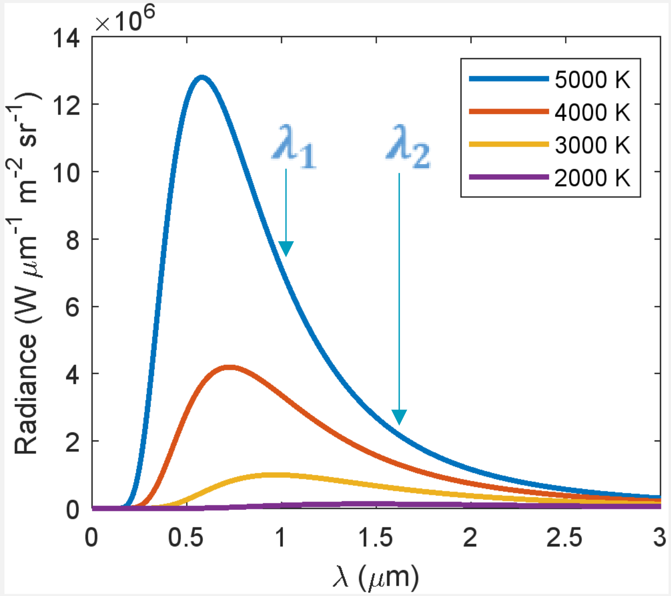
- Free stream condition achieved in HST
- How to achieve realistic T_w?
- Impulse facilities
  - Short test time
  - Must preheat model
  - Nominal past success before ~2010
    - Embedded resistance heaters
    - Induction
    - Radiative heaters
  - Unable to achieve realistic T_w

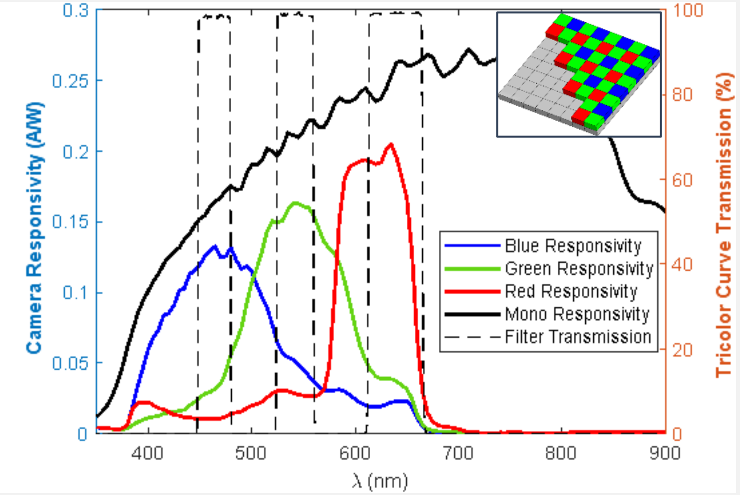
- Resistively heat models
  - *Hot Wall Re-entry Testing in Hypersonic Facilities*, Zander et al. 2013 (others)
- $T \propto I_{supply}^2 R_{Mat'l}$
- Graphite Coupons
  - Good surrogate for wall mat'l.
  - Easily scalable



Surface Temperature Characterization: Pyrometry

- How to Measure T_w? : Thermal Radiation
  - Some real surfaces (like graphite) are similar to a blackbody
  - Ratio of signal from discrete wavelengths: $\frac{S_{\lambda_1}}{S_{\lambda_2}} = f(T_{object})$
    - Unique to a particular BB temperature
    - Also true if emitter is a gray body (constant emissivity)
  - Measuring 2 discrete wavelengths is challenging
  - Measure wavelength bands instead (more signal, better for cameras)
  - Use color camera (Phantom V1212)
  - Increase temp. sensitivity with tri-color filter

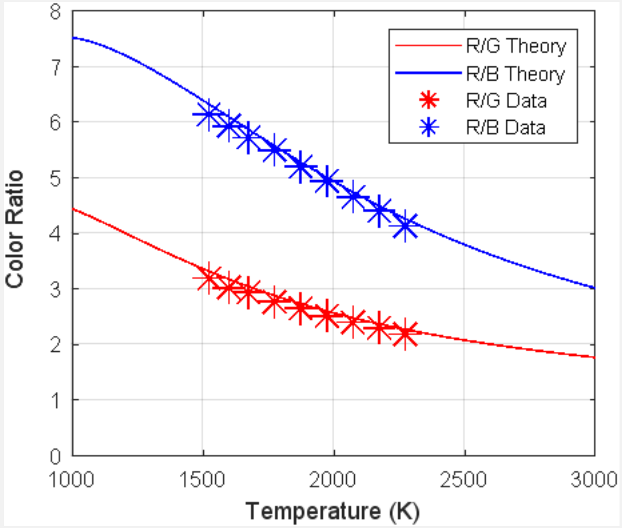




Pyrometry Calibration

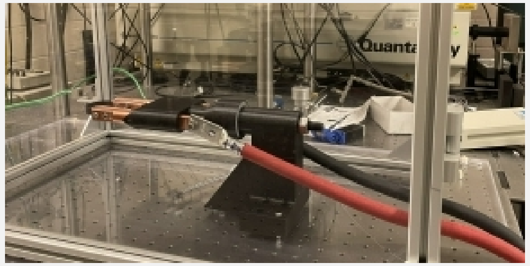
- Calibration Source:
  - Use blackbody source for calibration
  - Temperature range 1200 C – 2700 C
    - Same as that of model T_w
- Ratio Calibration:
  - Data (*) of R/G and R/B ratios compare well to theoretical values (line) for calibration range
    - 1250 C – 2000 C shown at right
  - Additional calibration data up to 2700 C recorded

$$I_{ratio} = \frac{\int_0^\infty E(\lambda, T_{obj})\, \tau_{filt}\, \tau_{lenses}\, S_{\lambda_1,cam}\, d\lambda}{\int_0^\infty E(\lambda, T_{obj})\tau_{filt}\, \tau_{lenses}\, S_{\lambda_2,cam} d\lambda}$$



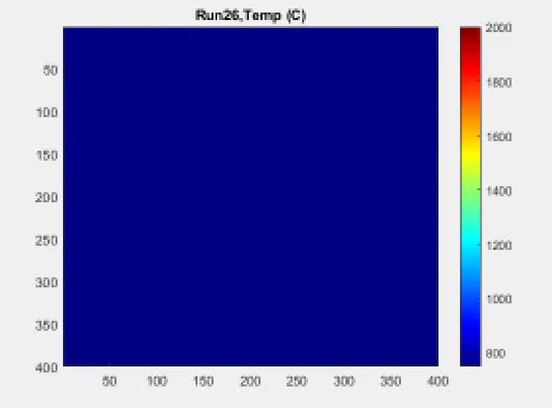
Benchtop Testing & Pyrometer Validation

- Testing and Validation:



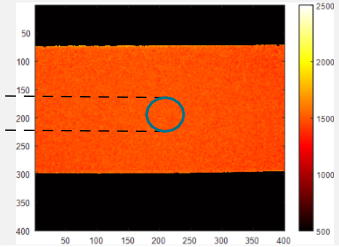
Benchtop heating using Color Pyrometer:

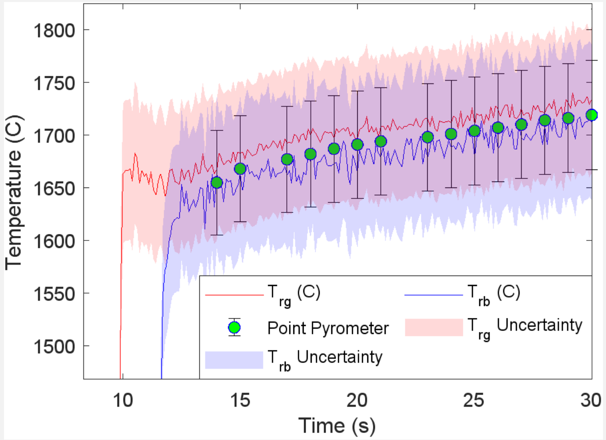
$$t_{0,video} = t_{0,current}$$



- Video: pyrometer cannot capture entire heat-up duration
  - Not enough visible signal at lower temps and near-saturation at higher temps
  - Pixels with intensity < 5% of saturation or >86% of saturation are removed from analysis
- Average 100 pixels at center of color pyrometer frame vs time
  - T_{rg} : temp from the R/G ratio T_{rb} : temp from the R/B ratio
  - 2D pyrometer compared to IR point pyrometer

Handheld pyrometer focuses on a point at center of strip

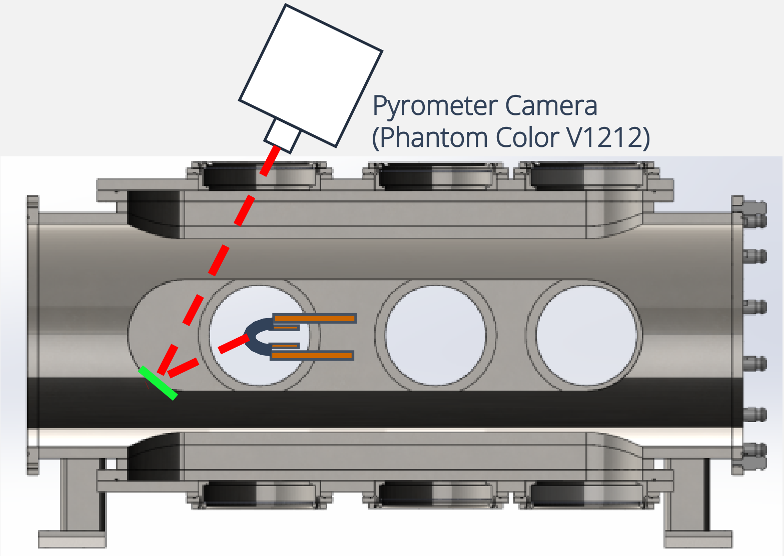


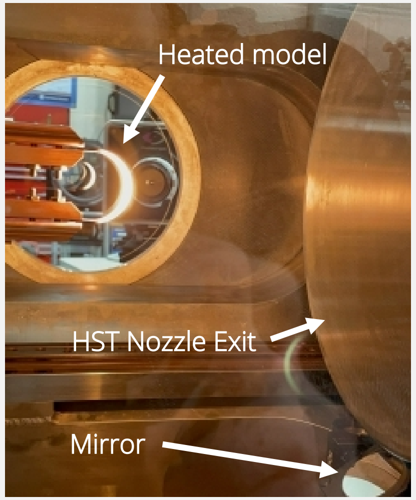


Tunnel Experiments: Mounting and Pyrometer

- Model Mounting Within HST
  - High-temperature 3D printed plastic
    - Electrical isolation of electrodes

  - Mirror mounted within test section to provide better viewing angle of model front surface



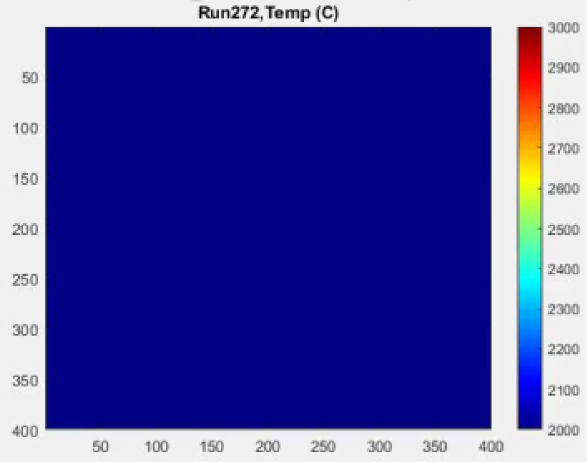


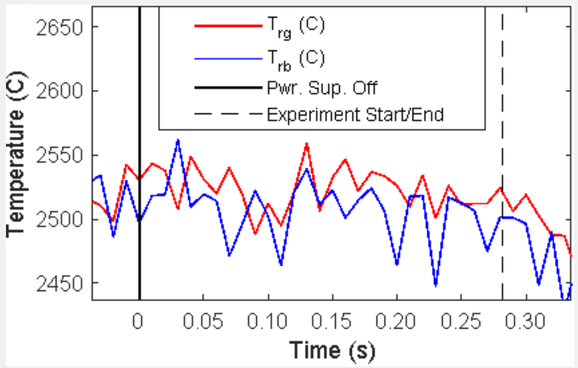
Heating process prior to an experiment

- Pyrometer Prior to Experiment

Lower Temp ~800-1000 K, no filters

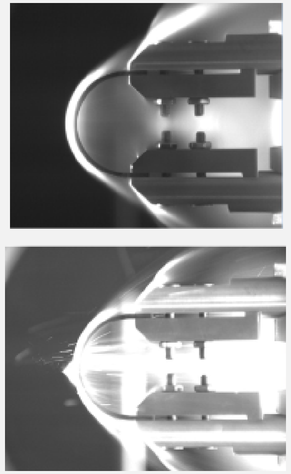
Higher temp w/filters: ~2550 C ≈ 2825 K



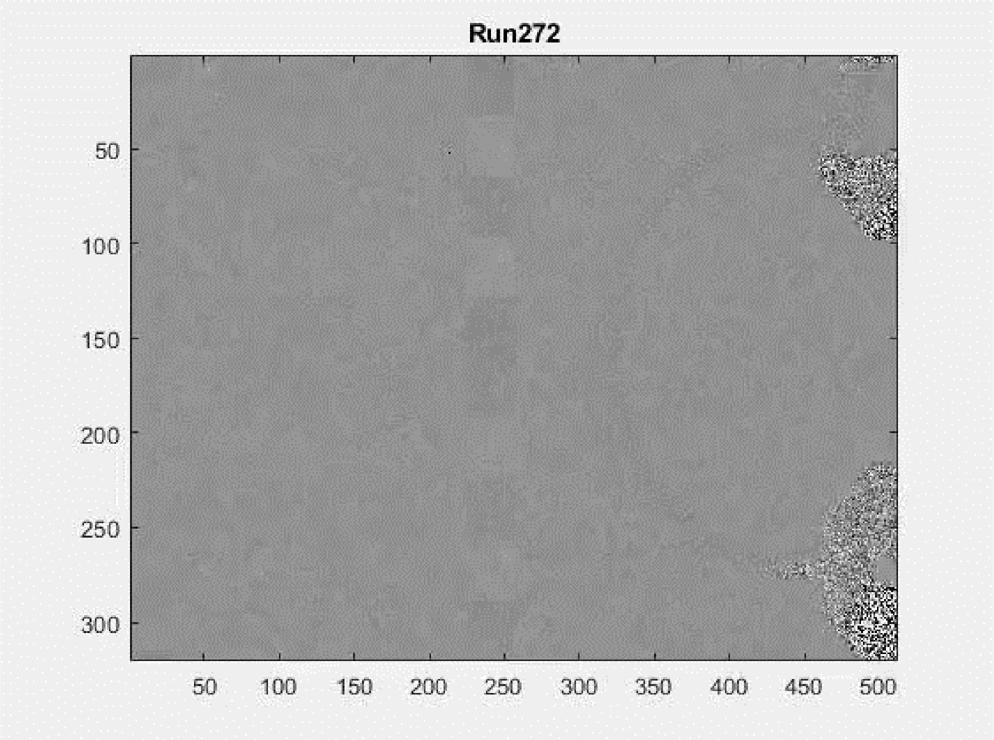


Tunnel Experiments: High Speed Video & Schlieren

- High Speed Video (Run HST-277)
  - Model has no preheating for better viewing of shock layer

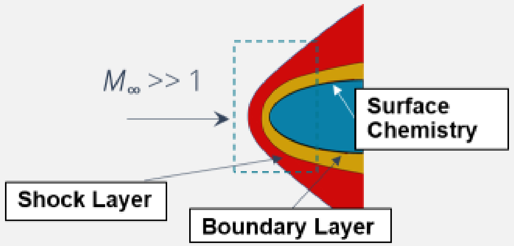


- Schlieren (Run HST-272)
  - Prior to backlighting, model is visible in the frame due to high temperature
  - Shock standoff ~2.8mm (with / without heating



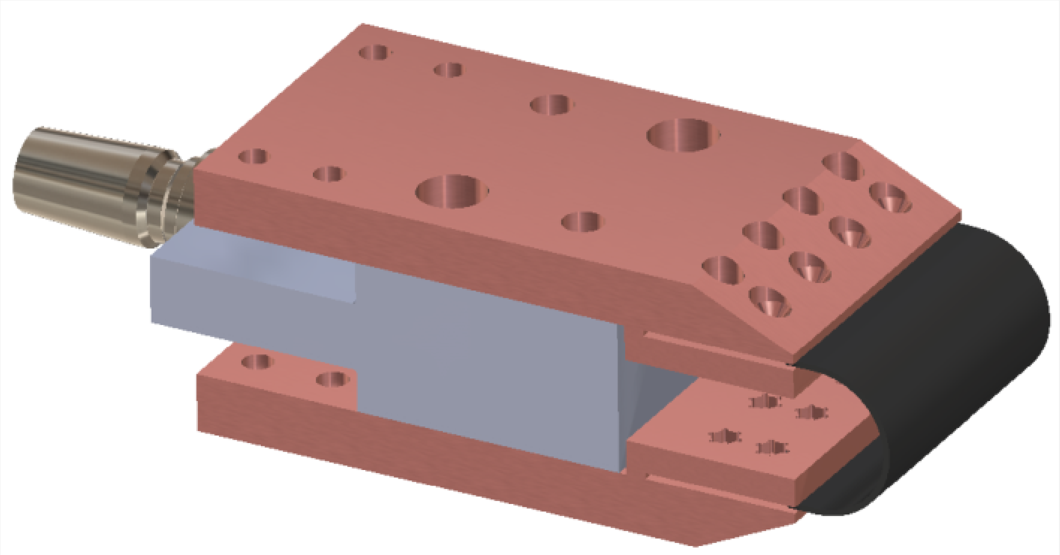
Conclusions

- How can we replicate hypersonic flight conditions?



  - HST replicates flow
  - Preheating replicates T_w
- Pyrometer developed to measure T_w
- Benchtop validation performed
- Successful incorporation into HST

- Stay Tuned:
  - Extend model to 4″ span



  - Perform optical emission spectroscopy (OES) measurements