LAS Doppler Velocimetry in a Hypersonic Wind Tunnel and 1D Non-Equilibrium Nozzle Simulations

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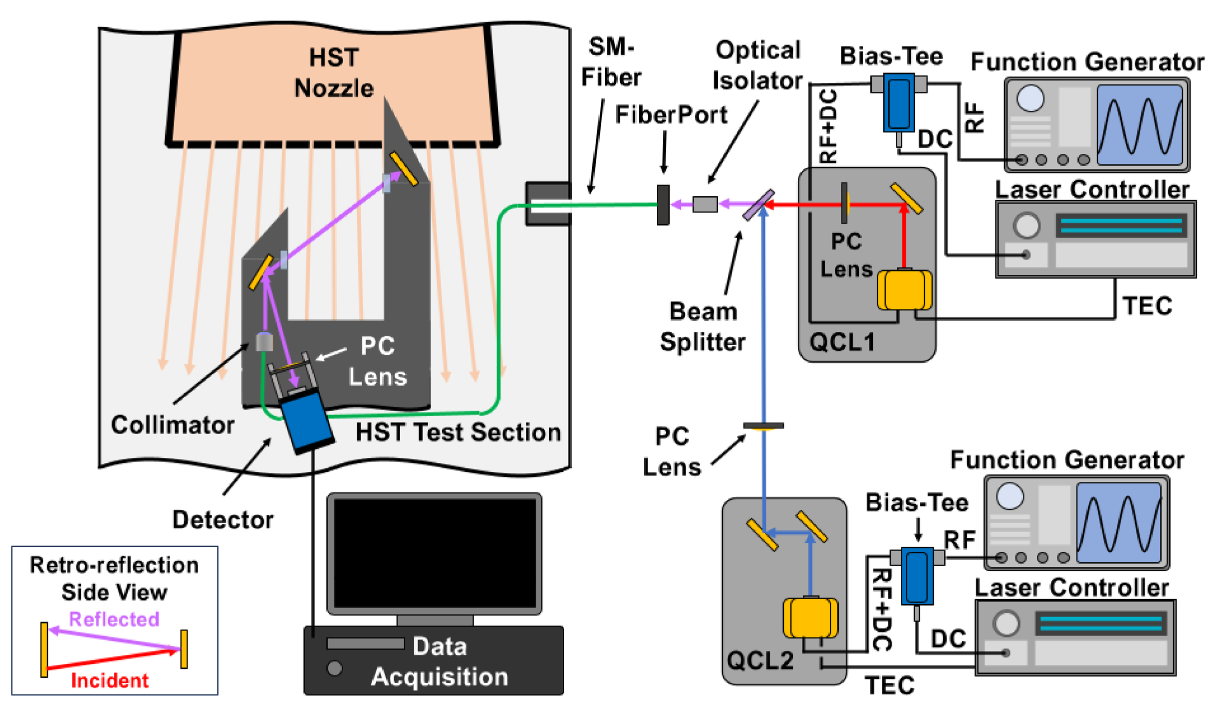
Non-Equilibrium Measurements of NO Internal Temperatures, Partial Pressure, & Velocity in a Hypersonic Shock Tunnel

Motivation

- Freestream conditions in shock tunnels are not well known and are important for understanding ablation. This work characterizes the freestream of the HST at Sandia National Laboratories by measuring internal temperatures, partial pressure, and velocity of nitric oxide.

Experimental Setup

- Used a 3D printed probe to isolate the quasi-uniform core flow. A single laser beam was propagated upstream and then reflected downstream to provide Doppler velocimetry. A 500 MHz bandwidth detector was used which allowed measurements to be acquired at 200 kHz (3 km/s tests) and 1 MHz (4 and 5 km/s tests)



Experimental Setup

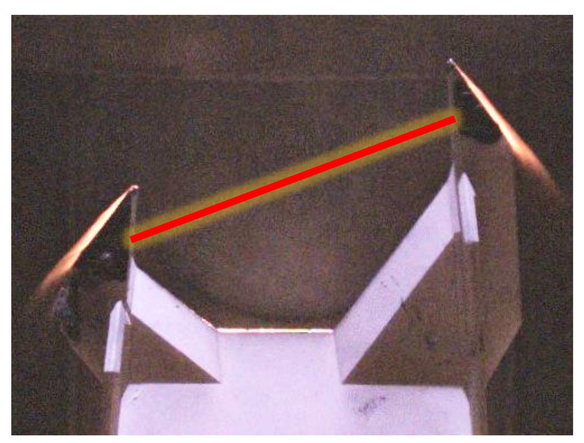
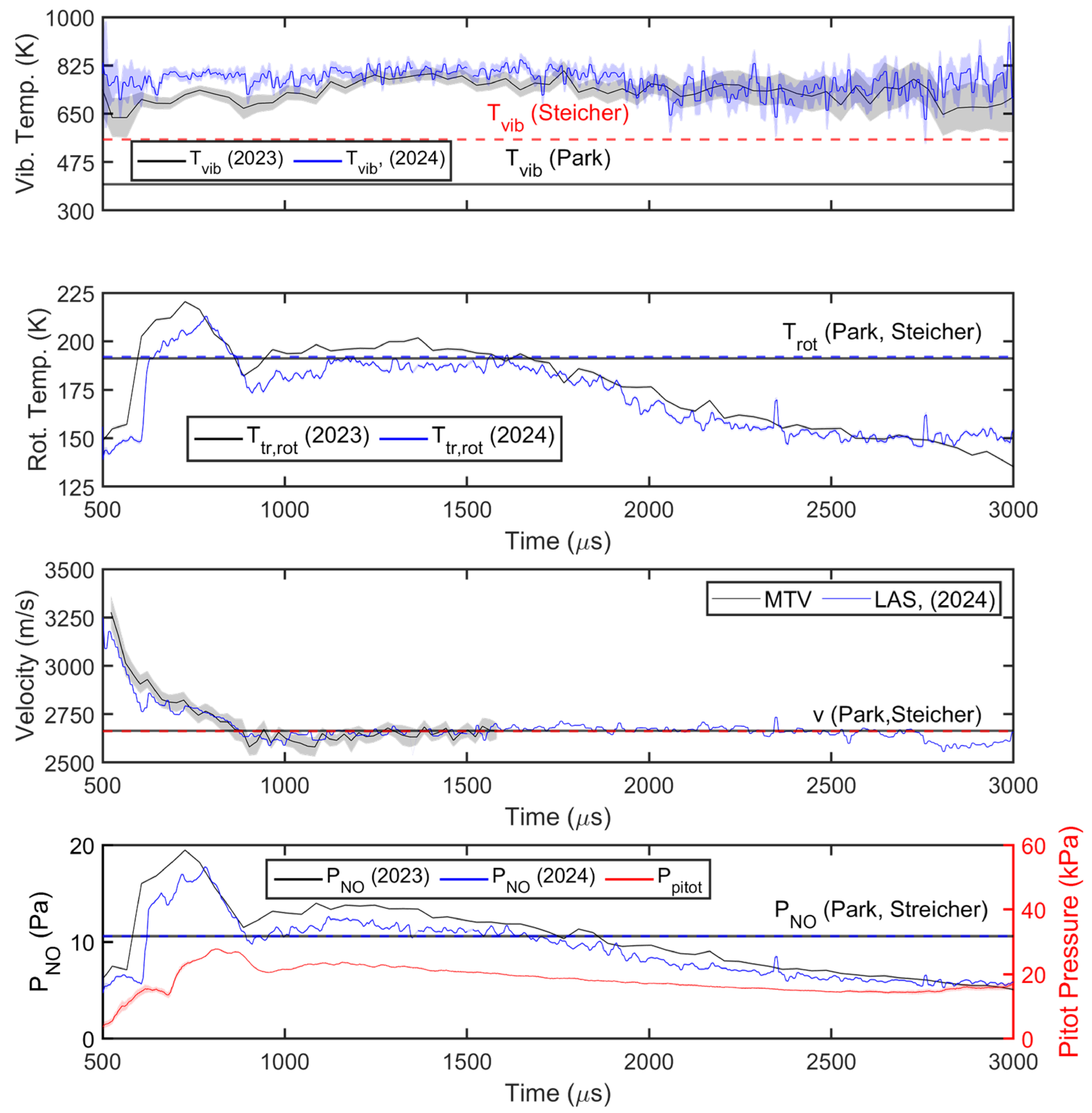


Image of Probe in HST



Time History of Measurements Acquired in the HST

Results

- Vibrational temperatures agreed within 4.4% with previously acquired measurements. Some disagreement is observed in the start up transient which could be related to spatial non-uniformity.
- Rotational temperatures agree within 5.2% with measurements previously acquired. There is a slight delay due to the subtly different measurement locations.
- The LAS velocity agreed with molecular-tagging velocimetry (MTV) within 0.44% giving confidence in both measurements.
- The partial pressure of NO agrees within 13% with previous measurements.

Key Takeaways

- High measurement rate allowed measurements of rapid transients in the freestream
- Adding razor blades to the leading edges reduced disturbance of the core flow and resulted in lower rotational temperatures and NO partial pressures
- Measured data agree relatively well with CFD predictions but highlight the transient nature of the tests.

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State-Resolved Thermochemical Mechanism for Non-Equilibrium Air Chemistry & 1D Simulations of Reacting Hypersonic Nozzle Flows

Motivation

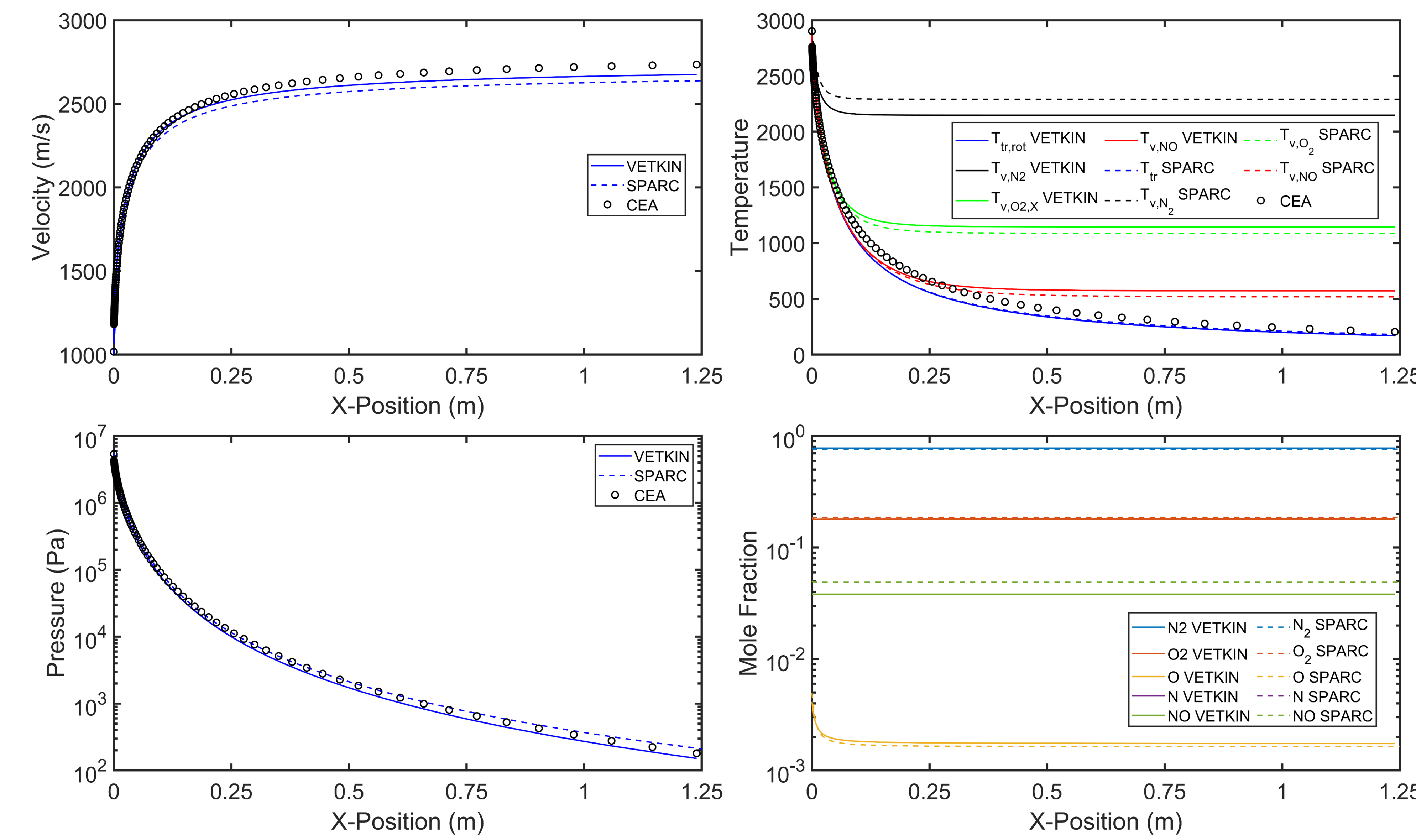
- Most models of gas chemistry and gas-surface chemistry assume thermal equilibrium and have rates which depend on a single temperature.
- Hypersonic flows are characterized by similar time scales for thermal relaxation, chemistry, and flow
- The kinetic rates for excited species can be drastically different than ground state species (e.g., O_2 in excited vibrational states will dissociate much more rapidly than the ground state)
- However, many non-equilibrium are complex and not easily distributed to researches in the field

Strategic Approach

- Use the open-source framework of Cantera to build a state-resolved chemical kinetics mechanism for thermal non-equilibrium situations
- The diatomic species are broken down to their constituent vibrational states ("pseudospecies")
  - E.g., N_2 becomes $N_2(v=0), N_2(v=1), N_2(v=2), \ldots$
- Rates are assigned to the dissociation and exchange reactions as well as vibrational-translation relaxation and inter- and intra-species vibrational-vibrational relaxation
  - E.g., $NO(v) + O \Leftrightarrow N + O_2(v')$

Application to Hypersonic Flows in Shock Tunnels

- Simulations of 1D expanding flows in the nozzle of the HST were performed
  - Reservoir conditions were set to those expected for a 3 km/s test in the HST (same for all cases)
  - The ODEs modelling the expansion of the reacting flow in the nozzle were solved using MATLAB
- Comparisons were made with 2D axisymmetric CFD simulations (Sandia SPARC code) and with NASA CEA (assuming flow is chemically frozen at the throat and thermally equilibrated during the expansion)



Simulations of Expanding Flows in the HST

Key Takeaways

- Chemical kinetic mechanism for reacting gases in thermal non-equilibrium was developed.
- The use of open-source software (Cantera) makes this work highly portable and easily customized
- 1D nozzle code provided approximate vibrational temperatures in the freestream compared to 2D CFD sims.
- The lack of inclusion of boundary layers leads to a slightly higher pressure and velocity
- Future plans involve writing this code in Python for portability and future Cantera support