Shock Interactions in Nonequilibrium Hypersonic Flow

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Anatomy of Shock-Shock and Shock Boundary Layer Interaction in High Temperature, Hypersonic Flow

STATUS QUO

Double-cone/wedge configurations are sensitive test cases for thermochemical models in hypervelocity flows.

• Correct prediction of the high heat transfer rates in shock-boundary layer interaction is also in itself critical to vehicle survival.

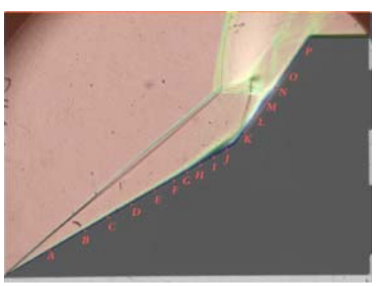
State-of-the-art simulations are currently limited by proper characterization of incoming flow.

• Current experiments are based on a novel method of gas acceleration that minimizes free stream dissociation while producing a broad range of hypervelocity flows.

NEW INSIGHTS

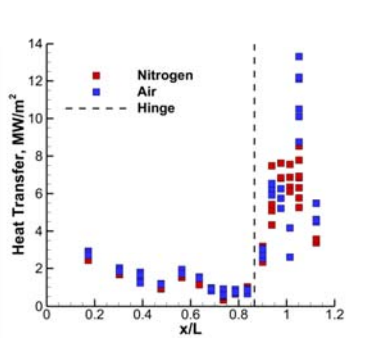
Experimental Study with "Tunable" Freestream

• Turn on/off the nonequilibrium: N_2 to air, low enthalpy to high. Quantify the response of the shock configurations, separation zone length scaling, and surface heat transfer. Collaborations with simulations of Prof D. Levin (Penn State).



Experiments and DSMC simulation of shock structure in very good agreement.

MAIN ACHIEVEMENTS:



Significant differences in heat transfer between air and N2 flows. (both Mach 7 and H_o = 8 MJ/kg)

•**Varying O2 content in freestream shown to impact viscous and inviscid flow features • Heat transfer and shock configuration data obtained for 8 test cases • Flow establishment and possible unsteadiness investigated using high-speed movies. • Spectroscopic measurements in progress**

HOW IT WORKS:

•Flexibility of expansion tube operation allows for a broad range of test conditions. Goal: Turn thermochemistry on/off while maintaining other critical freestream conditions constant..

ASSUMPTIONS AND LIMITATIONS:

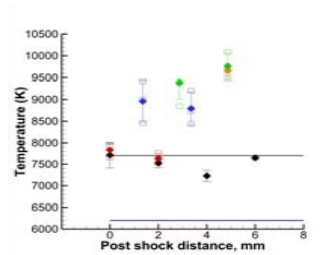
• Low Reynolds number conditions are chosen such that effects of some variation in Re between test conditions is minimized.

• Cordin system (1µs interframe) is being set up for higher resolution over selected time periods.

QUANTITATIVE IMPACT

Current Impact

• Observable differences in surface heat transfer between Air and N2 • Matched literature scaling in N2 at matched test conditions • Experimental measurements of viscous and inviscid flow establishment times show differences to simulations. •Spectroscopic measurements of naturally-occurring species in progress • Overlays of chemiluminescence and schlieren images indicate regions of thermochemical activity



Experimental NO vibrational temperature measurements behind the bow shock.

END-OF-PHASE GOAL

Planned Impact

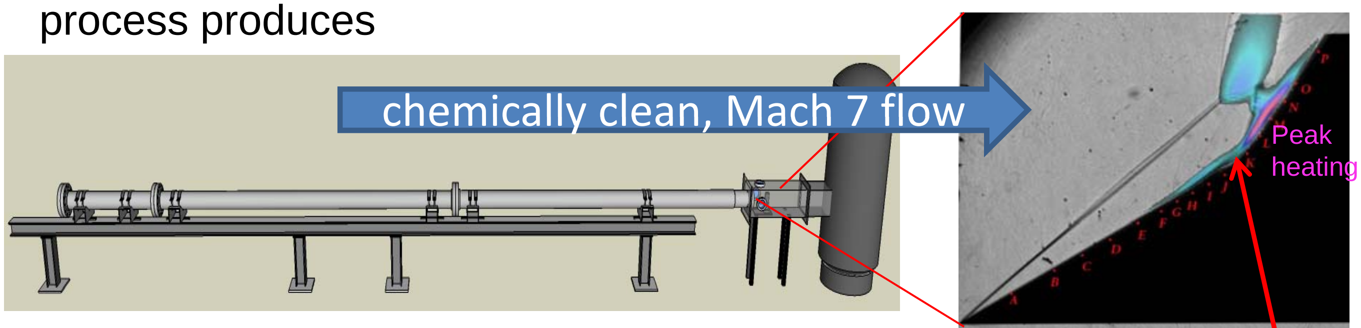
• Spectroscopic measurements of naturally-occurring specie continuing • Continued comparisons with DSMC calculations (Prof. Levin) to resolve unsteadiness discrepancy and including possible 3D issues.

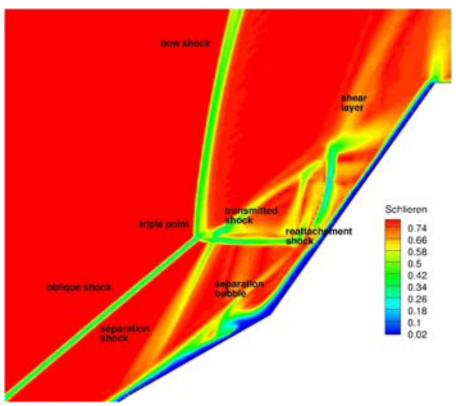
Research Goals

• Map of SWBLI configurations as function of thermochemistry. Including response of separation region to triple point location, reattachment shock angle, relaxation zone behind bow shock, deflection angle at which onset of unsteadiness is predicted.

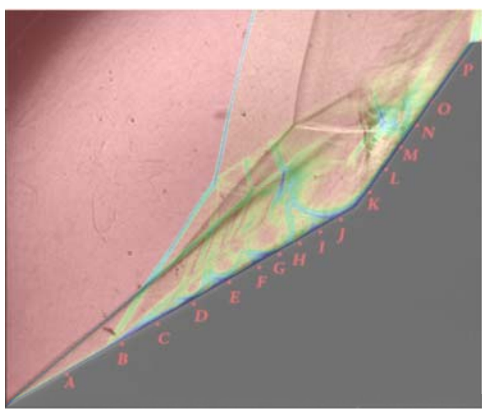
Joint experiments and simulations reveal new insight into laminar shock-shock interactions in “simple”, non-reacting flows, N_2 flows.

HET facility: Novel gas acceleration process produces

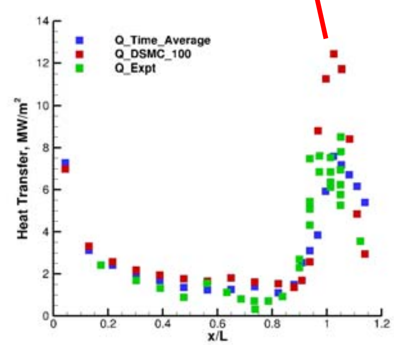




DSMC Simulations predict correct SSIs for HE case



LE case predicted SSI structure poor.



Time-averaged DSMC Simulations predict good heat flux profiles for HE case.

Joanna Austin

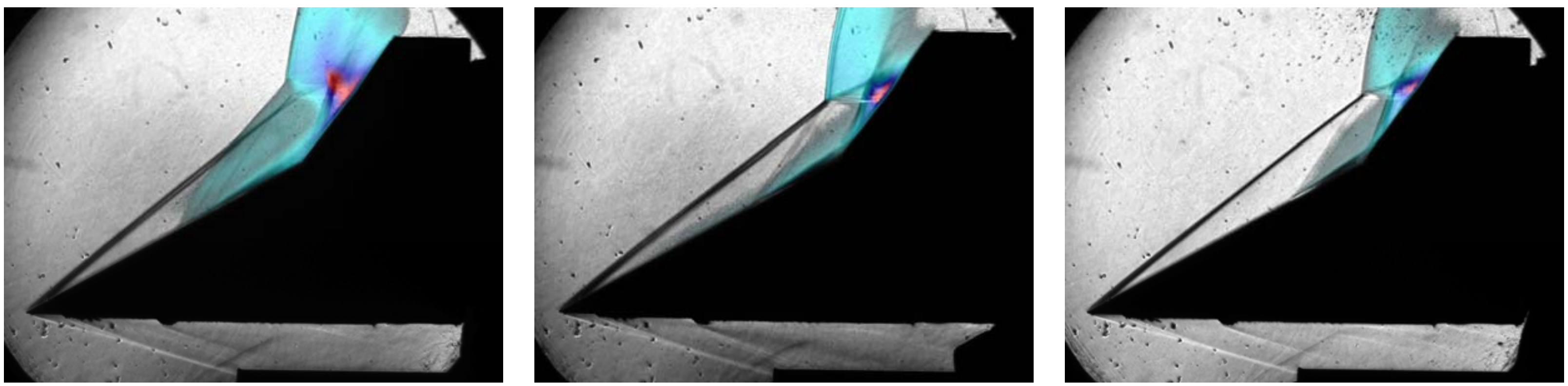
- •AFOSR YIP
- •NSF CAREER
- •Assoc. Fellow, AIAA
- •AIAA Best Paper
- •Xerox Award for research

Deborah Levin

- •PES Premier Research Award
- •AIAA Assoc. Fellow,
- • AIAA Best Paper
- •JTHT Associate Editor

Dissecting the Anatomy of Shock-Boundary Layer Interaction in Hypervelocity Flow

Quantifying the response to increasing freestream O_2 →



Experimental measurements provide direct validation for thermochemical models.

Including:

- Species temperature
- Time-resolved data

Swantek, Knisely, and Austin, Int. Shock Wave Symp., July 2013