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

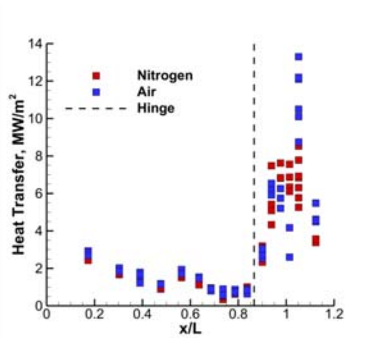
Experimental Study with "Tunable" Freestream

• 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.

Sample Test Cases (N_2 and Air limits)

Freestream Parameters	M5_4	M7_2	M7_8	M4_3.6
Mach Number	5.12	7.11	7.14	4.01
Static temperature, K	676	191	710	853
Static pressure, kPa	8.13	0.391	0.78	18.3
Velocity, m/s	2664	1972	3812	2340
Density, kg/m^3	0.042	0.0071	0.0038	0.0747
Test Time, μs	361	327	242	562
Unit Reynolds Number, $10^6/m$	3.42	1.10	0.435	4.64
Stagnation Enthalpy, MJ/kg	4.2	2.1	8.0	3.6

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.

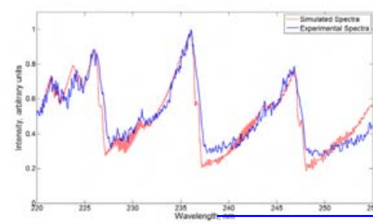
• Cordin system (1µs interframe) is being set up for higher resolution over selected time periods.

QUANTITATIVE IMPACT

Current Impact

• Observable differences in surface heat transfer between Air and N2 • Matched literature scaling in N2 at matched test conditions • Extended database of types of SWBLI beyond literature results • <u>Current data sets selected for NATO RTO AVT 205 group simulations.</u> • <u>Student presented two conferences papers; journal paper in progress</u>

Experimental and simulated spectra obtained behind the bow shock used to make NO vibrational temperature measurements.



END-OF-PHASE GOAL

Planned Impact

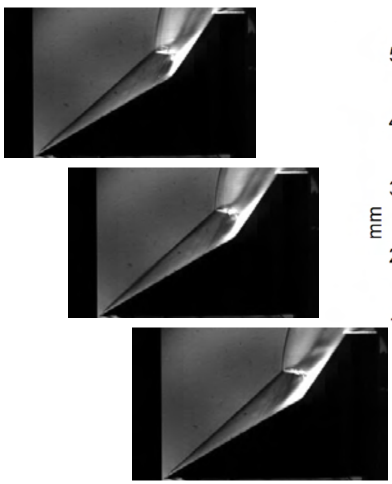
•Spectroscopic measurements of naturally-occurring species superimposed on schlieren images •Validation quality database •Comparisons with DSMC calculations (Levin- PSU)

Research Goals

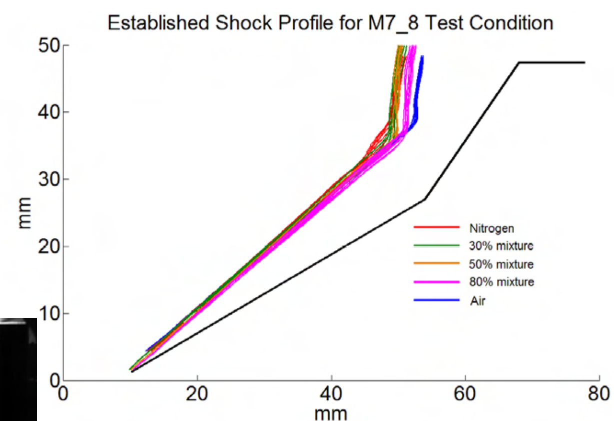
• Map of SWBLI configurations as function of thermochemistry. Including **response of separation region to triple point location, reattachment shock angle, relaxation zone behind bow shock, deflection angle at which onset of unsteadiness is predicted.**

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

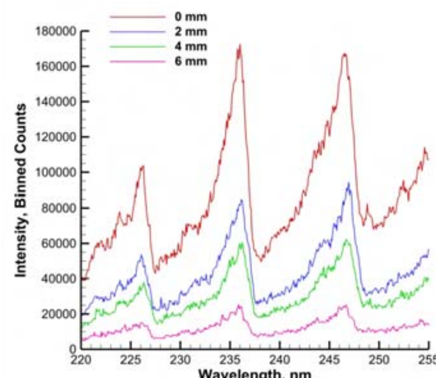
Double wedge: sensitive test case for thermochemical models. Goal: “Tune” the thermochemical activity to identify critical transitions between perfect/ real gas flows.



Time-resolved data



“Tuning” freestream O_2



Species & temperature measurements

- Previously, only single-shot images & only selected conditions.
- Lack of predictive capabilities for complex chemistry revealed.
- Current dataset chosen for simulation by NATO RTO AVT 205 group.

Swantek and Austin, Int. Shock Wave Symp., July 2011
Swantek and Austin, AIAA ASM Meeting, Jan. 2012

Joanna M Austin

- AFOSR Young Investigator Program Award
- NSF CAREER Award
- Associate Fellow, AIAA
- AIAA Fluid Dynamics Best Paper Award
- Xerox Award for Faculty Research Excellence

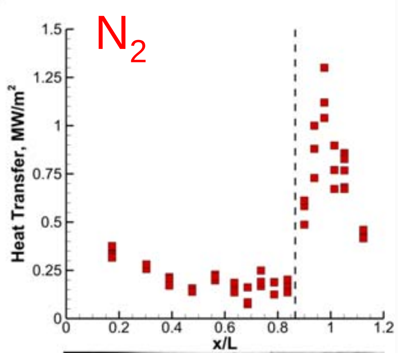
Mach 7.1

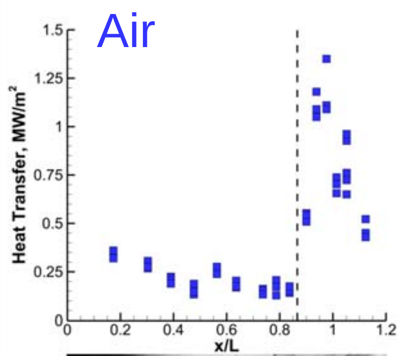
Low Enthalpy (2MJ/kg)

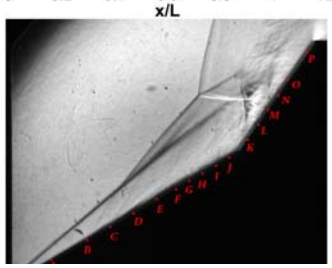
Increasing thermochemical complexity →

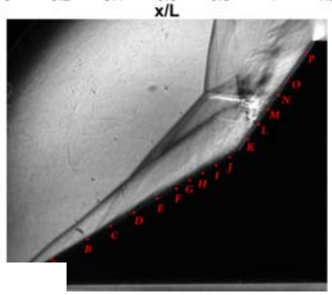
Mach 7.1

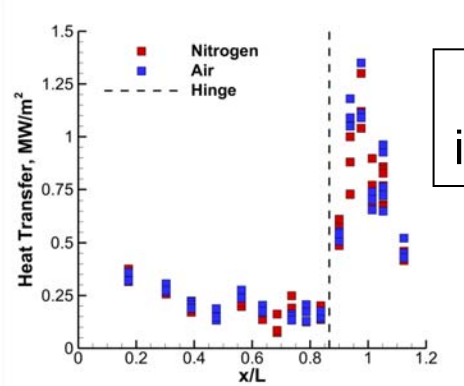
High Enthalpy (8MJ/kg)



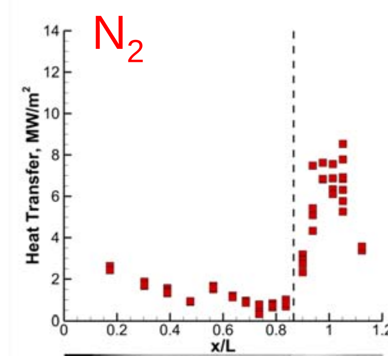


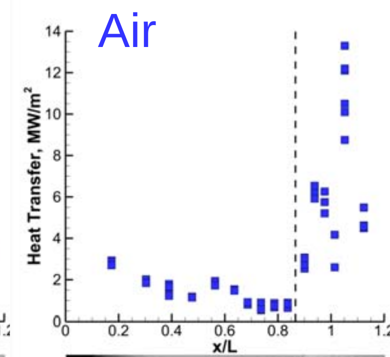


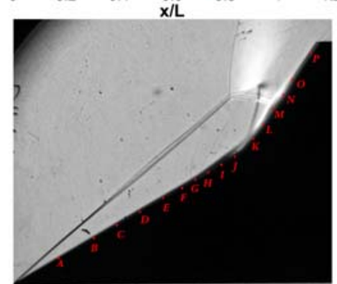


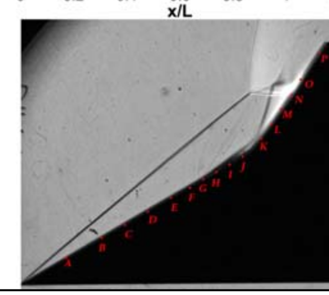


N_2 and Air data in good agreement.









Increasing enthalpy (other parameters matched) reveals significant differences between N_2 and Air heat transfer.

Swantek and Austin,Int. Shock Wave Symp., July 2011
Swantek and Austin, AIAA ASM Meeting, Jan 2012