



# 2009 MURI Topic #11: Chemical Energy Enhancement by Nonequilibrium Plasma Species

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

**“Fundamental Mechanisms, Predictive Modeling,  
and Novel Aerospace Applications of Plasma Assisted Combustion”**

## **Program Overview**

**W. Lempert**

**Departments of Mechanical Engineering and Chemistry**

**The Ohio State University  
Columbus, OH**

**MURI Kick-Off Meeting  
November 4, 2009**

## Report Documentation Page

*Form Approved*  
*OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE <b>04 NOV 2009</b>	2. REPORT TYPE	3. DATES COVERED <b>00-00-2009 to 00-00-2009</b>			
4. TITLE AND SUBTITLE <b>Program Overview</b>		5a. CONTRACT NUMBER			
		5b. GRANT NUMBER			
		5c. PROGRAM ELEMENT NUMBER			
6. AUTHOR(S)		5d. PROJECT NUMBER			
		5e. TASK NUMBER			
		5f. WORK UNIT NUMBER			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Ohio State University, Nonequilibrium Thermodynamics Laboratories, Columbus, OH, 43210</b>		8. PERFORMING ORGANIZATION REPORT NUMBER			
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)			
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)			
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>U.S. Government or Federal Rights License</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>16</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			



# MURI Team Members

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

## U. S. Institutional co-PIs

- **Walter R. Lempert, Igor V. Adamovich, J. William Rich, Jeffrey Sutton**  
**Ohio State University – Program Lead Institution.**
- **Yiguang Ju, Richard B. Miles, and Mikhail Shneider**  
**Princeton University.**
- **Andrei Starikovskii, Alexander Fridman**  
**Drexel University.**
- **Richard Yetter**  
**Pennsylvania State University.**
- **Vigor Yang**  
**Georgia Institute of Technology**



# MURI Team Members

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

## International Collaborators

- **Christophe Laux (Ecole Centrale - Paris)**  
**Experimental Kinetics , Plasma Enhanced Mixing/Combustion.**
- **Boris Potapkin (Moscow State University)**  
**Modeling of fundamental processes and mechanism development.**
- **Sergey Leonov (Joint Institute of High Temperature, Moscow)**  
**Mixing Enhancement**
- **Svetlana Starikovskaya (Ecole Polytechnique, Paris)**  
**Experimental Kinetics, Discharge Physics**
- **Nickolay Aleksandrov (Moscow Inst. of Physics and Technology)**  
**Modeling of fundamental processes and mechanism development.**
- **Aleksander Konnov (Vrije Universitat Brussels)**  
**Modeling of fundamental processes and mechanism development.**
- **Fei Q (Univ. of Sci. and Tech, China)**  
**Modeling of fundamental processes and mechanism development.**



# Program Principal Objective and Primary Deliverables

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

## PRINCIPAL OBJECTIVE

**“Develop experimentally validated kinetic mechanisms and modeling codes capable of predicting the impact of nonequilibrium plasmas on reactive processes, particularly on ignition, chemical energy release, and flameholding in combustors of flight vehicle engines.”**

## PRIMARY DELIVERABLES

- Extensive new experimental data sets of non-equilibrium plasma chemical energy conversion kinetics over a wide range of initial temperatures (300 – 1800 K) and pressures (0.1 – 70 bar), in a variety of complementary new test facilities, specifically designed and fabricated for this program.
- Detailed non-equilibrium plasma chemical energy conversion kinetic mechanisms, validated over a wide range of conditions, using data from multiple facilities.
- Extensive experimental data sets on ignition delay, flameholding and laminar flame speed augmentation by nonequilibrium discharges, including nsec pulsed, DC/RF, and microwave.
- High fidelity multi-dimensional plasma combustion modeling codes, validated in a series of model flows, with emphasis on the high subsonic to supersonic flow regimes.



# Principal Thrust Areas

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

- Thrust 1. Experimental studies of nonequilibrium air-fuel plasma kinetics using advanced non-intrusive diagnostics** (*leader: Richard Miles, Princeton*).
- Thrust 2. Kinetic model development and validation** (*leader: Richard Yetter, Penn State*):
- Thrust 3. Experimental and modeling studies of fundamental nonequilibrium discharge processes** (*leader: Alexander Fridman, Drexel*).
- Thrust 4. Studies of diffusion and transport of active species in representative two-dimensional reacting flow geometries** (*leader: J. William Rich, OSU*).

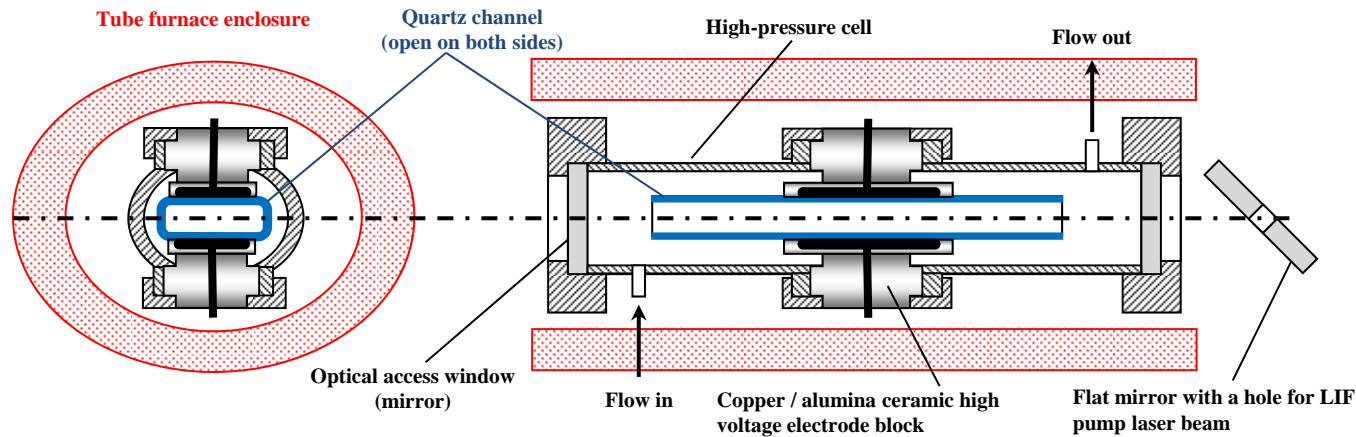
# Thrust 1 Overview I:

## Low to Moderate ( $T=300=800\text{K}$ ) Temperature Facilities

The Ohio State University

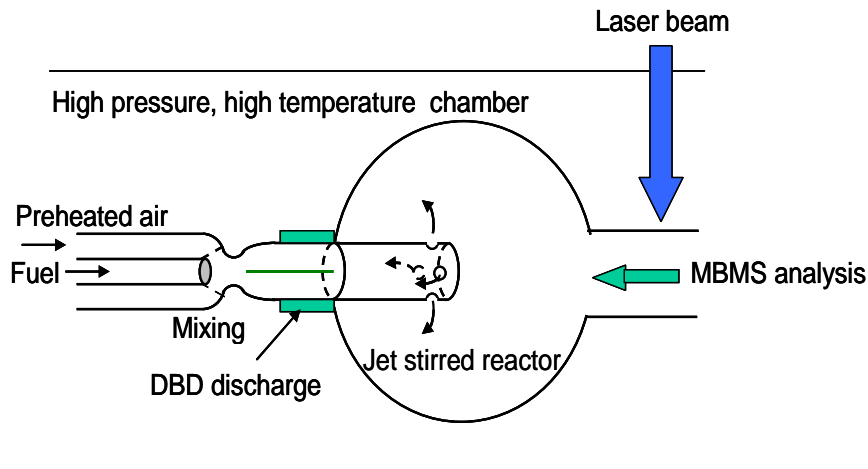
Nonequilibrium Thermodynamics Laboratories

OSU Optical access Furnace (P to ~2-3 Bar) – Extensive Optical Diagnostics (LIF, CRDS, CARS, etc)



Princeton plasma jet stirred reactor (P to ~5 Bar)

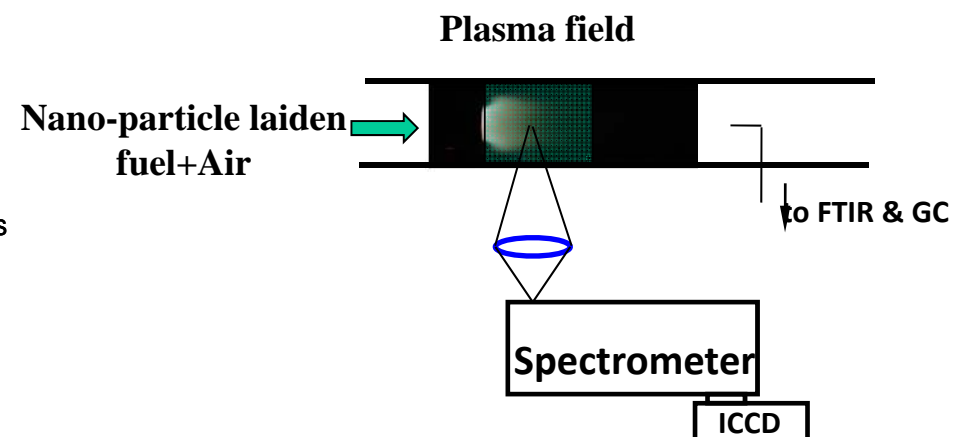
Molecular Beam Mass Spectrometer



PSU Laminar Flow Reactor

(FTIR, GC – P to 10 Bar)

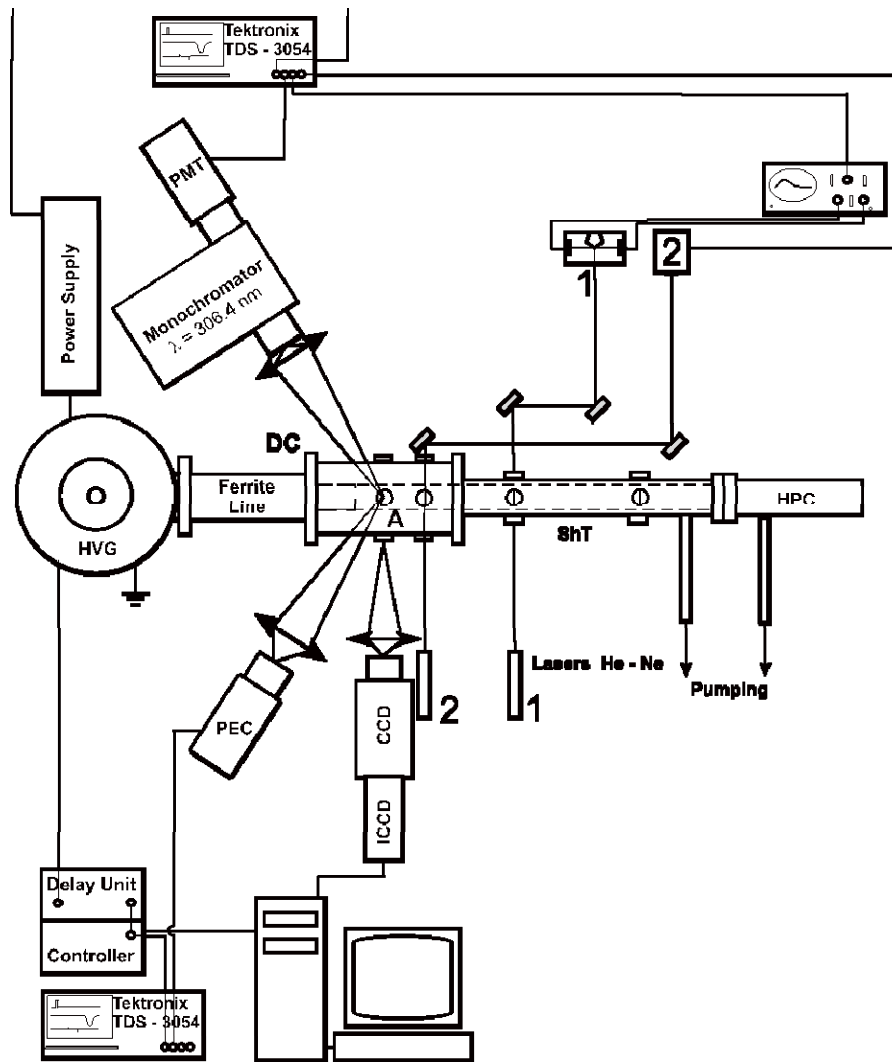
Nanoparticle Effects



# Thrust 1 Overview II: Moderate-to-high (T=800 – 1800 K) Temperature Facilities

The Ohio State University

Nonequilibrium Thermodynamics Laboratories



## Drexel Discharge Shock Tunnel facility

- i. Shock Pre-Heated Fuel/Air Mixture .
- ii. Plasma Initiated by FIW.
- iii. Extensive Diagnostic Suite.



# Thrust 1 Overview III: Drexel High Pressure (Up to 70 Bar) Facility

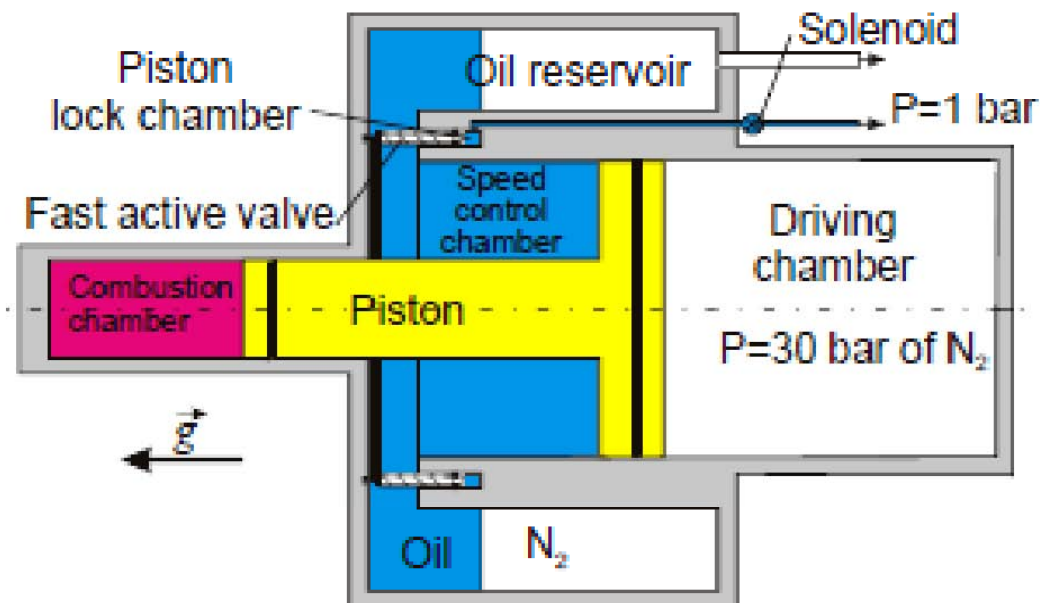
The Ohio State University

Nonequilibrium Thermodynamics Laboratories

## Drexel Rapid Compression Machine

**Nsec pulser – DC sustained (non-self-sustained) discharge.**

**Enables wide E/n range.**



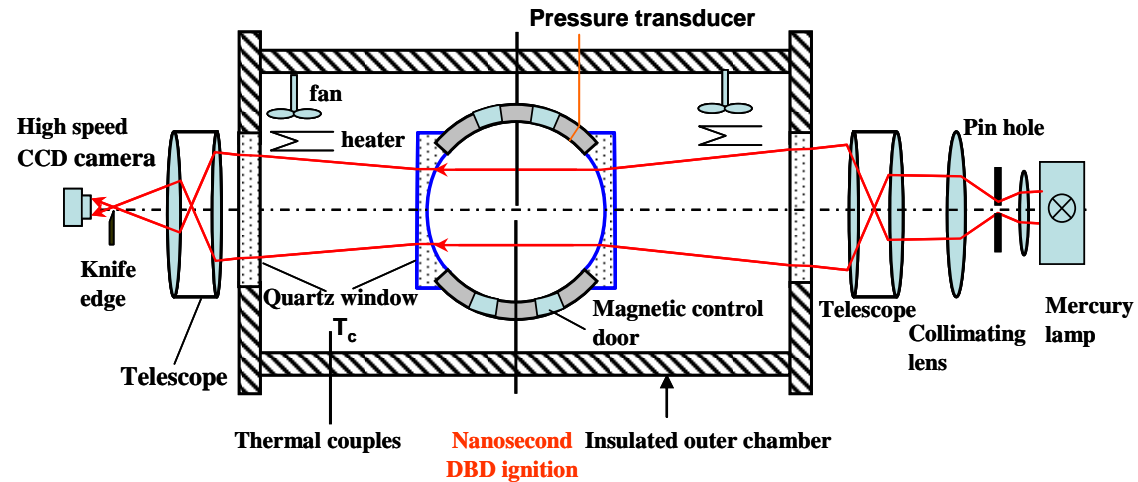
# Thrust 1 Overview IV: Ignition and Flame Speed Enhancement

The Ohio State University

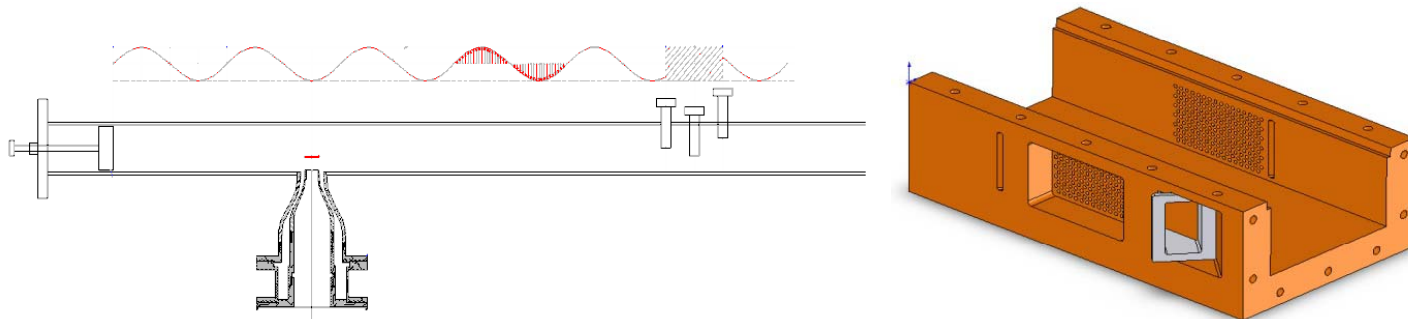
Nonequilibrium Thermodynamics Laboratories

## Princeton high pressure combustion chamber

(Transport and volume effects on ignition delay and minimum ignition energy)



## Princeton Resonant Microwave Cavity - co-Flow Burner





# Thrust 2 Overview

## Kinetic model development and validation

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

- **Development and validation of a predictive kinetic model of non-equilibrium plasma fuel oxidation and ignition, using kinetic data sets generated in Thrust 1.**  
(Task co-Leaders: R. Yetter, Y. Ju, I. Adamovich).
- **Mechanism Reduction and Dynamic Multi-time Scale Modeling of Detailed Plasma-Flame Chemistry.**  
(Task Leader: Y. Ju. Principal Collaborator: V. Yang).



# Thrust 3 Overview

## Discharge Properties

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

### (i) Key parameter measurements

**Electric Field by CARS**

**Electron Density - Temperature (EEDF?) by Thomson scattering and Radar REMPI**

**VDF of Major Species by CARS**

### (ii) Structure of Ionization Waves

### (iii) Electron Impact and Photo Ionization

### (iv) Integration with Thrusts 1/2 for nsec pulsed plasma code development / validation.

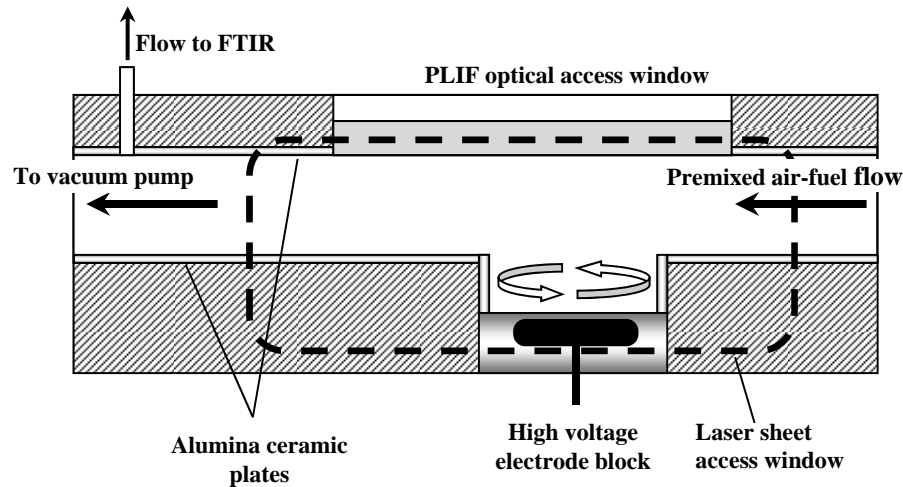
# Thrust 4 Overview I:

## Ignition / Flame Holding in Cavity and High Speed Flows

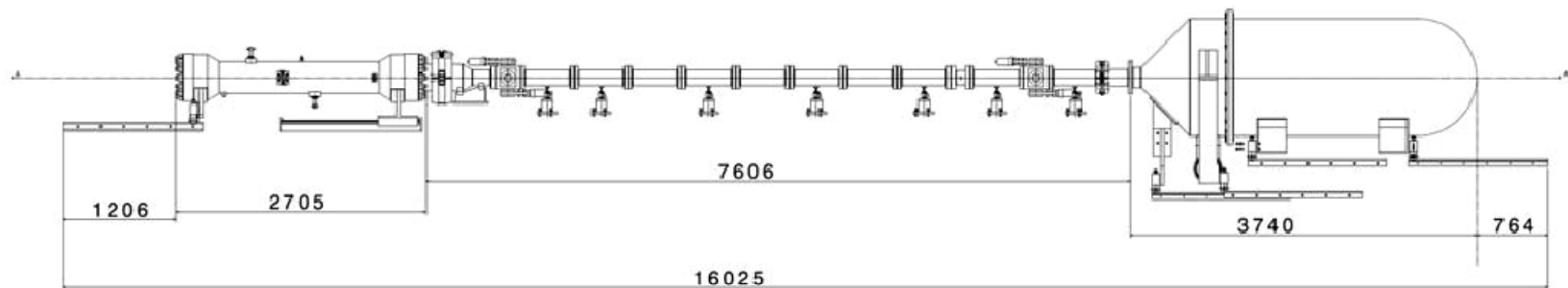
The Ohio State University

Nonequilibrium Thermodynamics Laboratories

### OSU Plasma cavity flow ignition experiment.



### Drexel Shock Tunnel



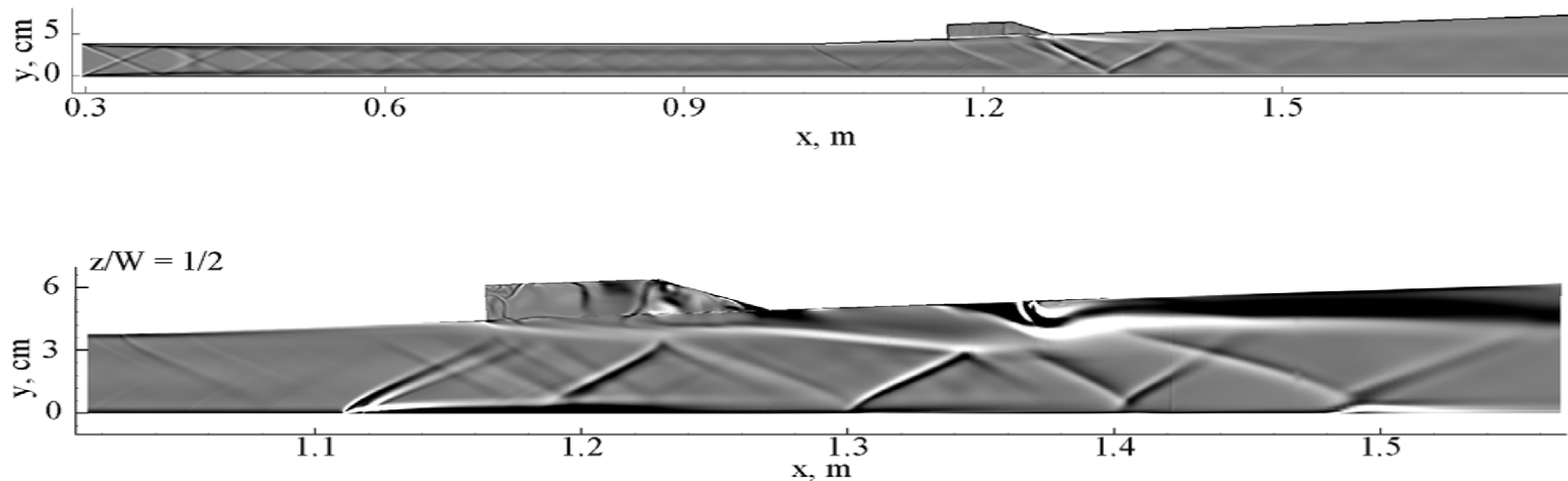
## Thrust 4 Overview II:

### High Fidelity Modeling of Complex Environments and Flow Paths

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

### Computational shadowgraph of flowfield in AFRL scramjet combustor test facility.





# Role of International Collaborators

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

- **Direct participation during visits to MURI team member institutions (15K / yr provided in institutional cost share).**
- **Attendance at planned workshops (at AIAA meetings).**
- **Informal consulting (including other meetings attended by MURI team members).**

## **Thrust 1 (primarily)**

**Christophe Laux, Svetlana Starikovskaya**

## **Thrust 2 (primarily)**

**Boris Potapkin, Nickolay Aleksandrov, Aleksander Konnov, Fei Q**

## **Thrust 4 (primarily)**

**Sergey Leonov**



# Program Management

The Ohio State University

Nonequilibrium Thermodynamics Laboratories

- **Periodic (monthly) teleconferences.**
- **Twice Yearly Informal Workshops**  
(in conjunction with Aerospace Sciences and PD&L AIAA meetings).
- **Formation of Government/Industrial Advisory Board.**





The Ohio State University

Nonequilibrium Thermodynamics Laboratories

**Questions / Discussion?**