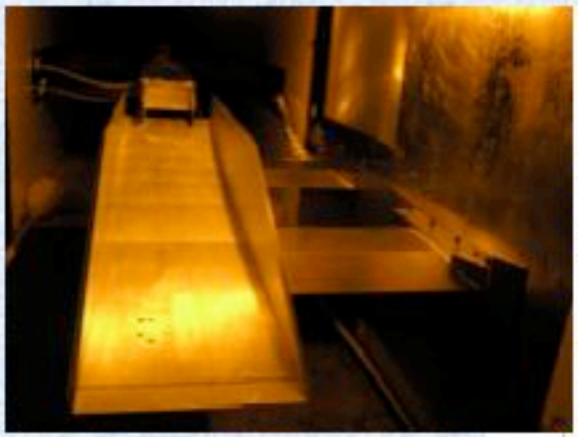
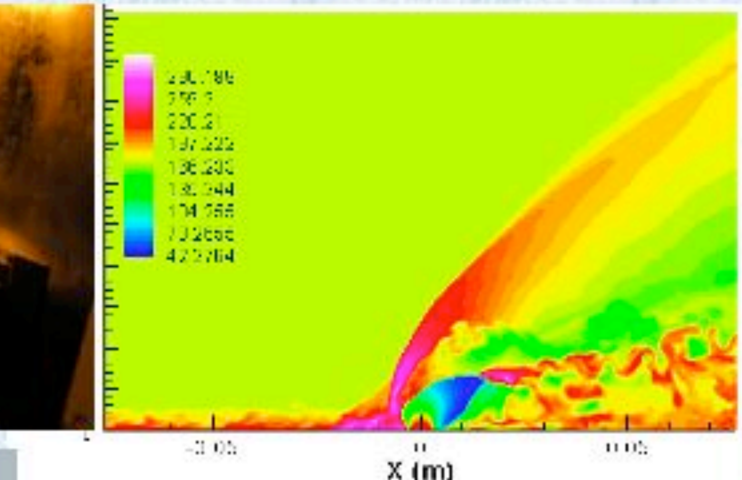
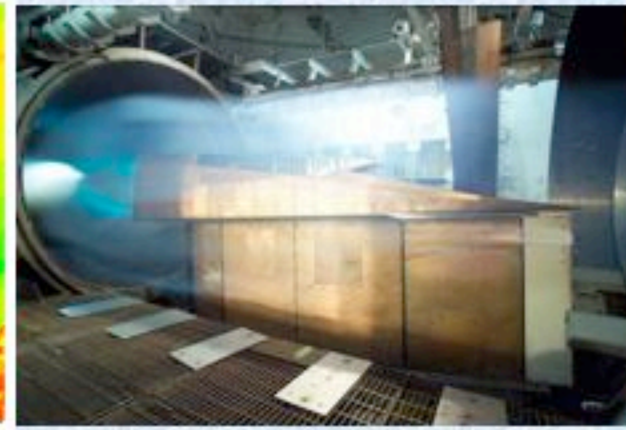
An Overview of the Hypersonic Airbreathing Propulsion Technical Discipline







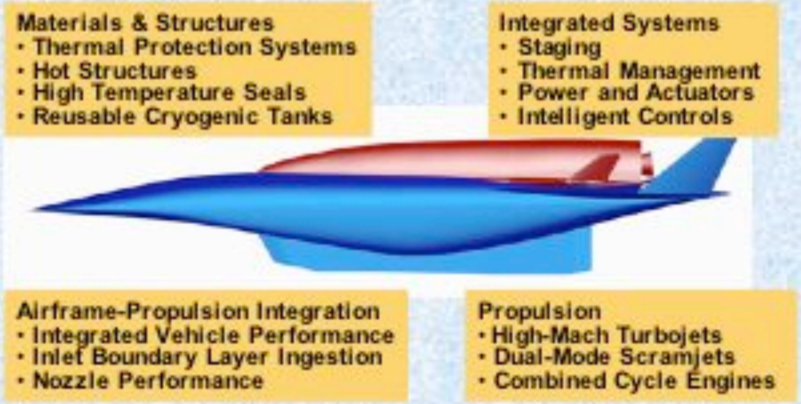
Dr. Aaron H. Auslender (API)
Mr. James F.Walker (APM)

Agenda and Opening Comments

- Discipline Objectives
- Propulsion Roadmap
- Propulsion Partnerships
- Propulsion Physics
- Propulsion Technology
- Propulsion NRA(s)
- Concluding Remarks

Mission Statement:

Conduct fundamental and multidisciplinary research to enable airbreathing access to space (and entry into planetary atmospheres)



Highly Reliable Reusable Launch Systems (HRRLS) (and High Mass Mars Entry Systems (HMMES))

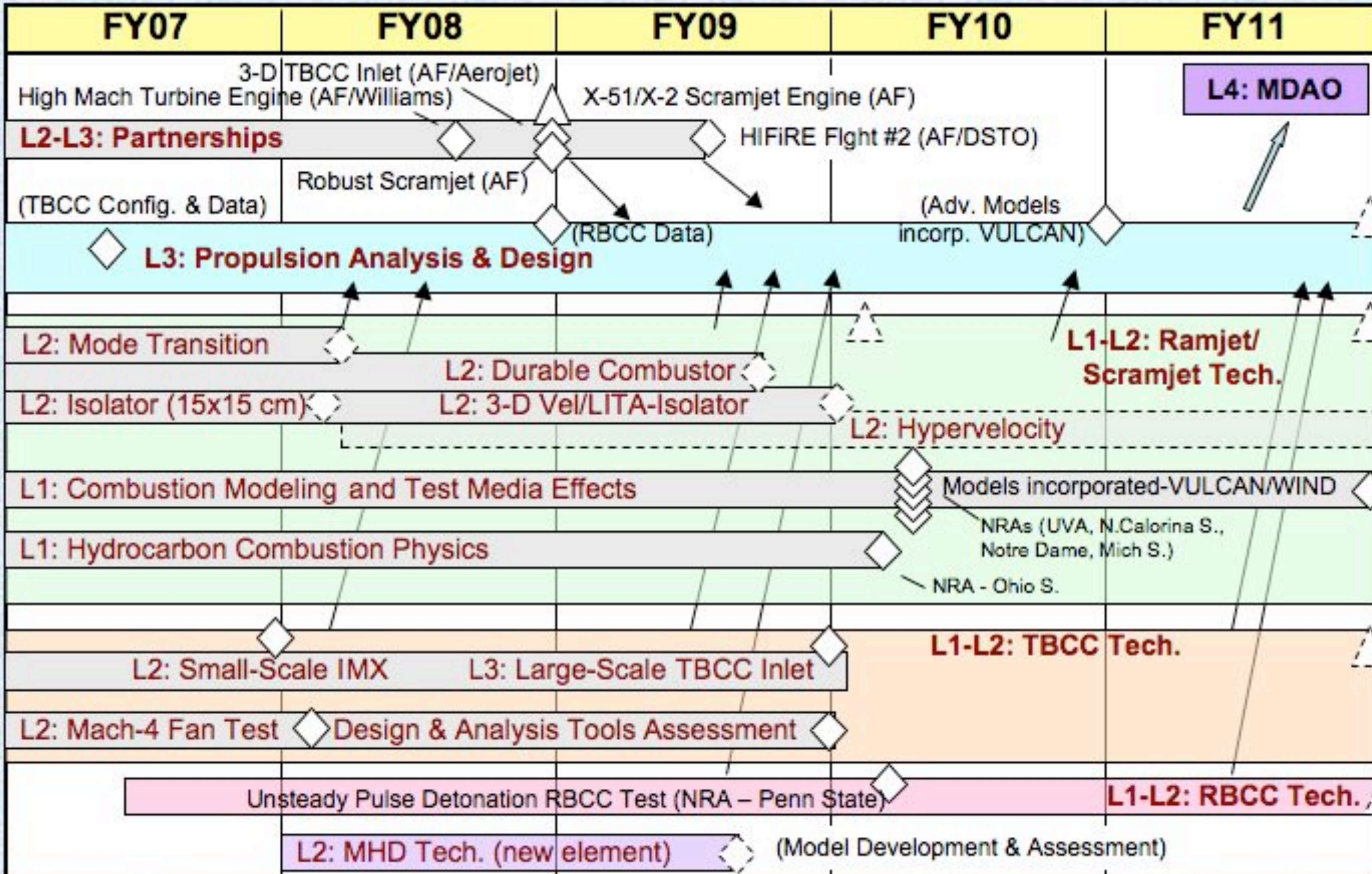
Discipline Objectives

- Advance the state-of-the-art propulsion design and analysis tools and quantify predictive capabilities:
  - Combustion Modeling and Test Media Effects
  - Hydrocarbon Combustion Physics
- Mature HRRLS propulsion cycles:
  - Ramjet/Scramjet Technology Development
  - TBCC Technology Development
  - RBCC Technology Development
  - MHD Technology Development
- Leverage technology impacts via Partnerships
- Utilize NRA process to infuse program with novel concepts

Note: The National Academies, "Decadal Survey of Civil Aeronautics - Foundations for the Future," June, 2006, stressed conducting research in hydrocarbon-fueled scramjet technology and combined-cycle hypersonic propulsion systems, inclusive of mode transition.

Roadmap - Propulsion Discipline

△ Project Level Milestones
◇ Discipline Level Milestones



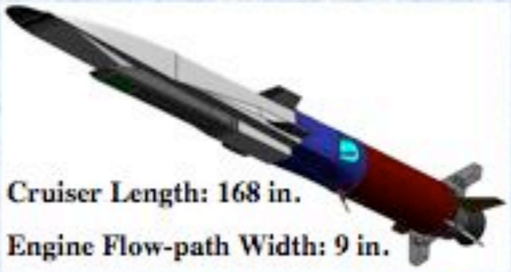
Propulsion Partnerships

Technology Impact	Title	NASA and Organizations	NASA Activity and Tech-Transfer
Ramjet/Scramjet	X-51A	AFRL/DARPA/ BOEING/PWR/ AFFTC/ASC/ NAVAIR	8'HTT and Unitary Testing
Mode Transition	HIFIRE	AFRL/DSTO/UQ	Flight#2 - Payload Development
TBCC	RATTLRS	NAVY	Program Participation
	RCT	ATK/AFRL	Unitary Testing and Analysis
TBCC	3-D Inlet	AEROJET/AFRL	Unitary Testing and Analysis
TBCC	High-Mach Turbine	DOD	Testing (Mach-3 Engine & Mach-3 Fan)
TBCC	FALCON	DARPA	SMEG Participation

- Level-1/2 Task --- Proprietary Data Agreement (5-yr restricted distribution)
- Level-3 Task --- Propulsion Technology Integration Partnership(s)

Propulsion Partnerships

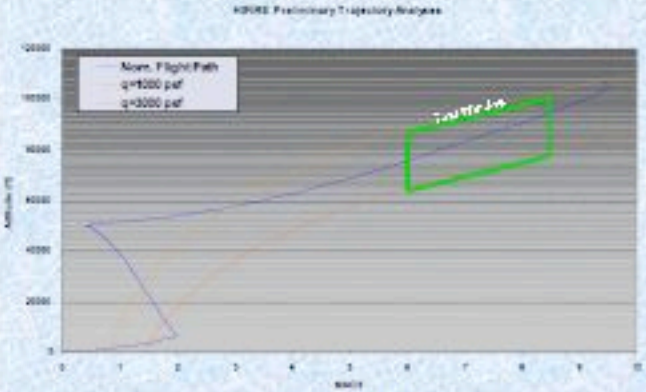
X51A



X-51A Development Engine
SJX61-1 (Flight Weight)
(8'HTT - July 2007)

- Full forebody and full nozzle tested
- JP-7 cooled (closed loop fuel system)

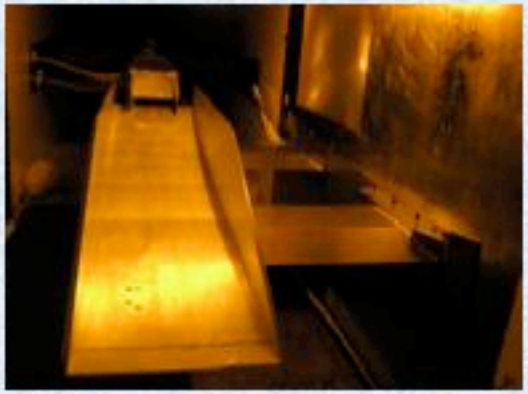
HIFIRE



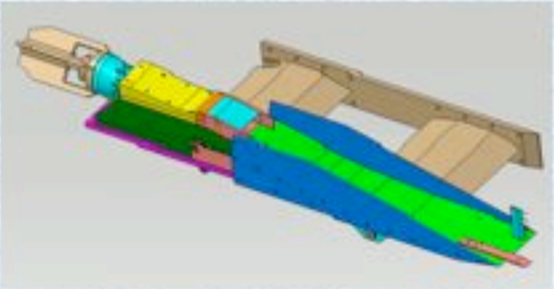
HIFIRE

- Validation of high enthalpy scramjet prediction tools
- Suppressed trajectory of a Terrier-Oriole
- 2-D Flow-path configuration
- Fixed geometry 2-D inlet (Total-CR=14.4, Internal-CR=1.2)
- Demonstrate dual-mode operation transitioning to scramjet (M 6 – 8+)
- Surrogate gaseous hydrocarbon-fuel representative of cracked JP-fuel
- 02/08 – Ground test (LaRC-AHSTF)
- 10/09 – Launch date

RCT



Rectangular-To-Circular Inlet

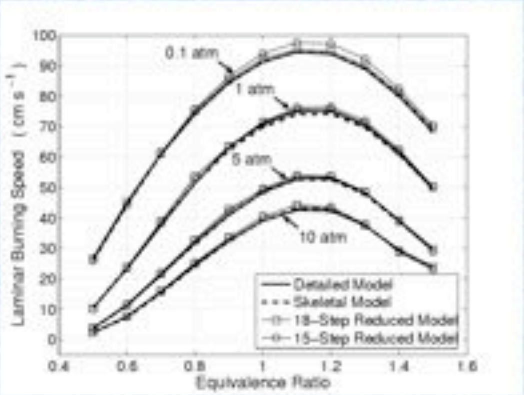


AFRL Robust Scramjet Task
ATK - Work Order #3
(Unitary - October 2007)

- 2-D forebody and initial 2-D capture
- Isolator transitions to circular geometry

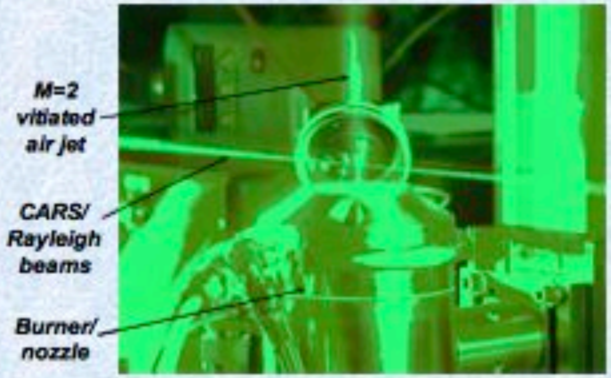
Combustion Modeling and Test Media Effects

Goal(s):
- **Develop enhanced physics-based codes with increased capability to model turbulence, turbulent mixing, and kinetics to address flameholding, vitiate testing effects and high-speed turbulent-combustion processes**
- Develop new kinetics models
  - –Reduce the complexity of the chemistry by up to a factor of 100
  - –Identify and verify primary chemical interactions through sensitivity studies and experimentation
- Improve diagnostic capabilities for measuring mean and fluctuating temperature, velocity, and chemical species
  - –Increase precision of the existing temperature and species measurements and add a 3-component velocity measurement capability, to fully characterize a supersonic combusting environment



Chemical Kinetics Modeling

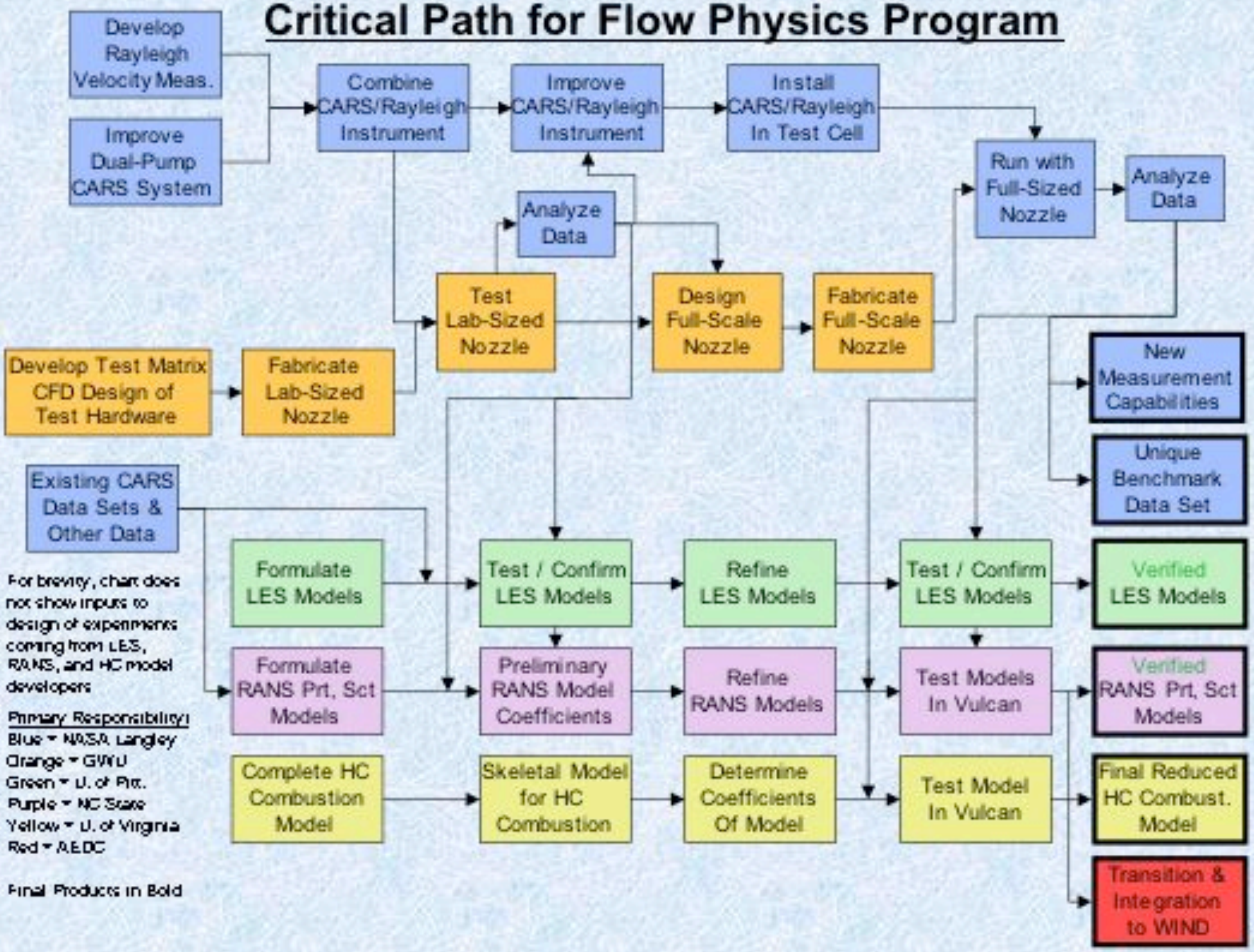
Task(s):
- Conduct experiments using simplified geometry and collect critical data for modeling improvements
- Increase diagnostic capability to collect mean and fluctuating data (velocity, temperature, and species)
- Improve fidelity of simulation tools (VULCAN and WIND codes) with improved phenomenological models
  - – Turbulence
  - – Chemical Kinetics
  - – Interactions between these phenomena
- Support the development of advanced simulation tools including large eddy simulation and hybrid RANS-LES capabilities for component and flow path design



"Unit" Experiments for Data Acquisition

Combustion Modeling and Test Media Effects

Critical Path for Flow Physics Program



Hydrocarbon Combustion Physics

- **Goal(s):** Advance the physical understanding of hydrocarbon-fuel injectors and flame-holding devices

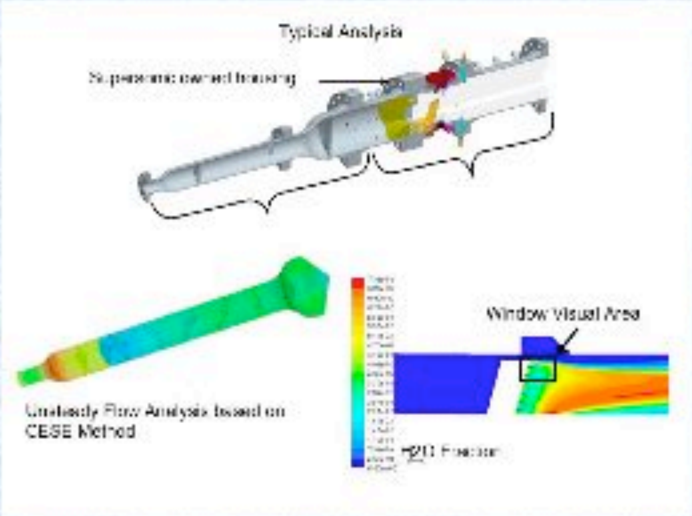
- **Diagnostic Tasks:**
  - Obtain detailed flowfield information using optical diagnostics
    - Explore and quantify the limitation of the diagnostic techniques
  - Obtain both lean and rich blowout limit data.
    - Engineering and SOA analytic model development
  - Characterize pilot and primary-flame zone interaction
  - Characterize the impact of elevated fuel temperature on the combustion process
- **Analysis Tasks:**
  - Quantify the current state-of-the-art analysis limitations
  - Perform CFD analysis to guide the experimental program
  - Unitized numerical simulations to explore fundamental limitations of traditional flame holder designs
  - Characterize the facility and combustor via measurements and CFD analyses
- **Associated NRA Tasks:**
  - Non-equilibrium Ignition and Flameholding in High-Speed Reacting Flows --- Ohio State University
  - Advanced Multi-Scale Computational Methods for Hypersonic Propulsion --- University of Notre Dame

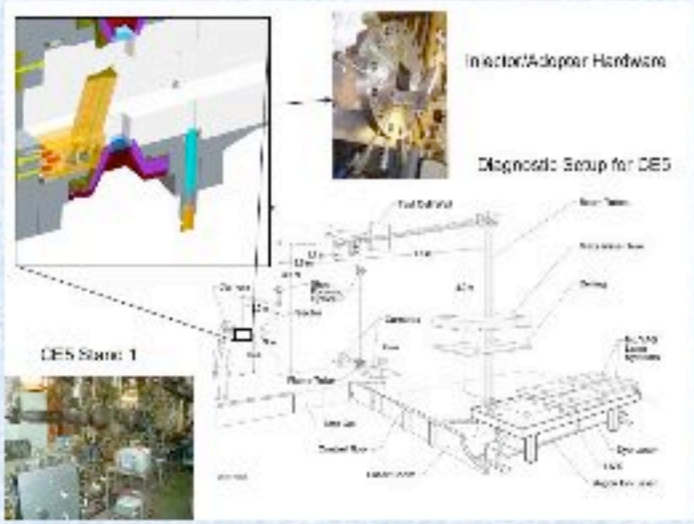
Hydrocarbon Combustion Physics

- **Diagnostic Tasks:**
  - OPO system repaired/Upgraded to allow for the pulse rate to be doubled and wavelength fine tuned so that Raman spectroscopy can used to measure temperature and major combustion species such as CO, CO_2, O_2, N_2, CH_4, H_2O, and H_2. This capability is also useful in making laser-induced fluorescence (LIF) measurements.

- **Analysis Tasks:**
  - Transient analysis was conducted to characterize the flow conditioner in CE5
  - Test matrix developed
  - CFD analysis is being conducted on the flame holder designs (note: some conditions will not "light")

- **Associated Tasks (Facility and Hardware):**
  - FY08 test entry scheduled (utilizing Jet-A fuel)
  - Injector hardware fabricated and leak checked
  - Generation-2 Injector with elevated temperature capability has been fabricated (check-out in progress)
  - Instrumentation being addressed
  - Modified fuel system hardware has been fabricated
  - Environmental/Operational requirements are being addressed



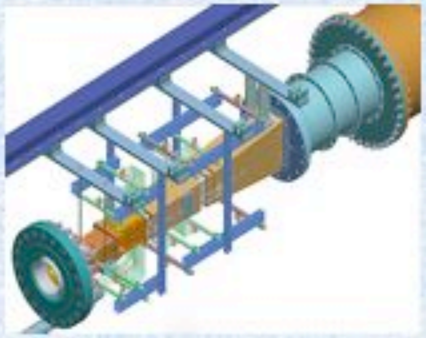


Ramjet/Scramjet Technology Development

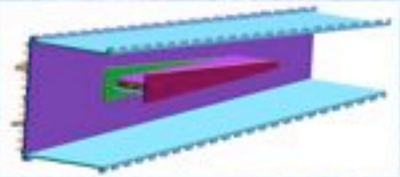
Durable Combustor Rig

- Durable Combustor Rig (DCR) - **fuel-cooled**, flight-like combustor model designed to function for many long duration tests. Used to demonstrate an ability to design and fabricate robust, actively-cooled, flight-like structures.
- Heavy-Weight Heat-Sink DCR - constructed for more traditional RJ/Scramjet and **mode-transition (Q3 FY08)** tests.
- Dynamic Seal Module (DSM) - used to evaluate hot surface sealing technologies in severe environments.
- Composite Demonstration Panel (CDP) - used to evaluate two actively cooled composite panels in severe combusting environments. (Collaborative Task with M&S Discipline)

Heavy-Weight Heat-Sink DCR
(To-be Installed in DCSCTF)



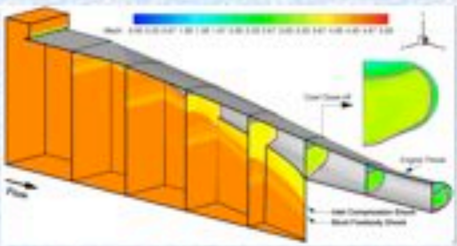
Dynamic Sealing Rig



CDP and Holder

Mode-Transition Test(s)

- Obtain **ramjet/scramjet mode transition data** sets (combustion back-pressure) on same geometry at (nearly) constant conditions to support tool development. Minimum requirement: steady-state data on two end states (ram & scram) (either direction, i.e. ram-to-scram or scram-to-ram) achieved with "open-loop" forcing function, e.g. fueling, test condition with the desire of resolving the transient mode-transition (~10 Hz) process.
- Goal is to investigate and identify pre-cursor "measurements /signals" for the application in **engine-flight control laws** (sensing and/or controlling) (mode transition and potential inlet unstart).



VULCAN CFD Solution
(AHSTF Mach-5 conditions)

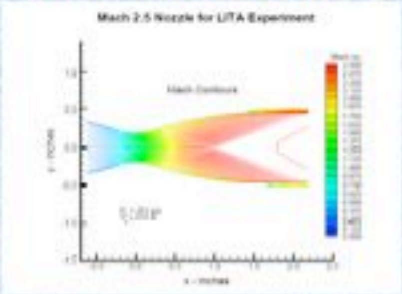
REST Engine
(Installed in AHSTF)

Ramjet/Scramjet Technology Development

Goal: Obtain Data to Quantify Isolator Environment and Analytic Capability

3-D Vel/LITA Experiment(s)

- Obtain **three-dimensional velocity measurements** (three orthogonal individual components) of Mach-2.5 unheated air in a sub-scale mechanically back-pressured isolator using the **LITA technique** (which provides via an instantaneous-local Mach-Number/Speed-of-Sound measurement the instantaneous-local velocity component).
- Obtain **PIV (velocity)** and Raman (density) measurements
- Obtain Schlieren data of the shock structure
- Obtain **Kulite (high-frequency wall static pressure)** data
- Obtain skin-friction measurement (MEMS gauge)
- Obtain "standard" **wall-static-pressure measurements**
- Use data to characterize the Reynolds stress tensor
- Use data to enhance CFD predictive capability



Nozzle Design

Partial Isolator Layout

15x15cm Isolator Experiment(s)

- Utilize facility as a "platform" for **shock control sensors and mass-flux measurement** "device/sensor" development
- Obtain **isolator performance data** (for analytic comparisons)
- Obtain data for shock control strategies (GN&C interactions)
- Obtain shock stability data (for analytic model development)
- Implement "advanced-diagnostic-techniques" to characterize the isolator flow-field parameters

15x15 cm Tunnel (schematic and photographs)

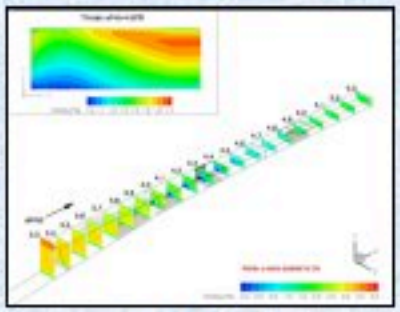
TBCC Technology Development

Goal(s): Addresses Key Hypersonic Combined-Cycle Technology Requirements

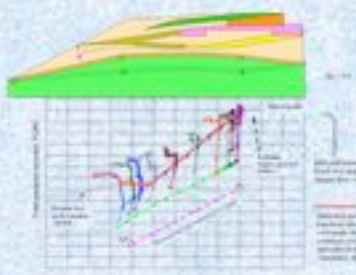
- **Multi-Mach Combustor (Mach 3-7)**
- **High Mach Wide Operability Turbine Engine**
- **Dual Integrated Inlet Operability and Performance (Unstart, Distortion, Bleed and Controls)**
- **Mode Transition between Turbine and Scramjet Configurations (Variable Geometry)**
- **Turbine Engine Transients during Transition and including High Altitude Re-Light**

Screening Effort
(Small Scale - IMX)
(1'x1'- SWT)
June 2007 - Testing

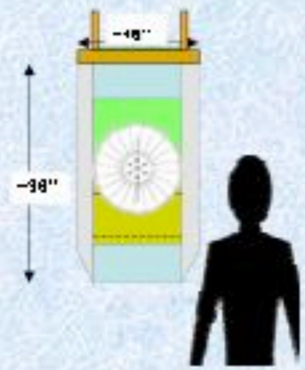
Baseline 2-D Design



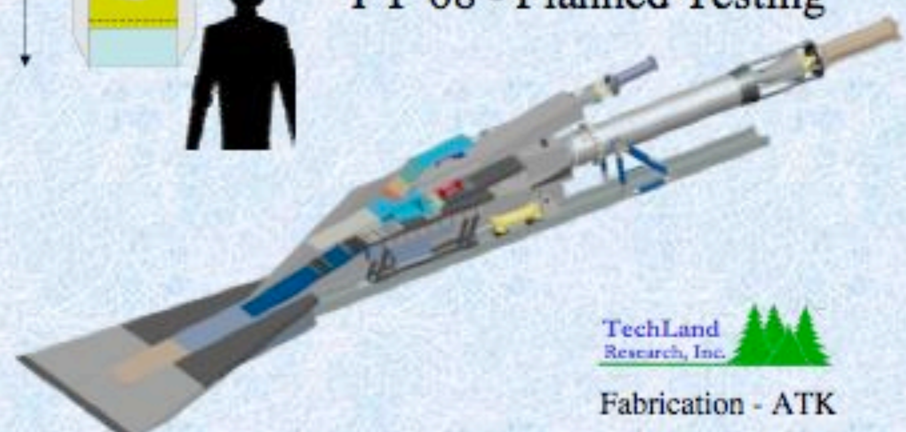
CFD - Results
Mach Contour (Planes)



Mode Transition Experimental Results
Pressure recovery versus Mass-flow Ratio



"Developmental" Platform
(Large Scale - IMX)
(10' x 10' Tunnel)
FY'08 - Planned Testing



TechLand Research, Inc.

Fabrication - ATK

Note: Williams Int'l 12"-HiSTED Turbine (Baseline)

TBCC Technology Development

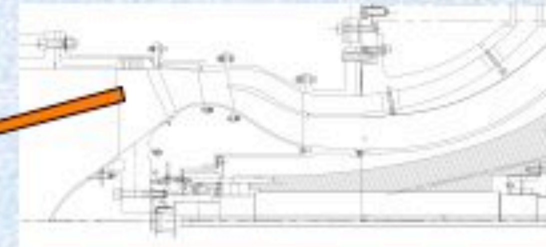
Aerodynamic/Aeromechanic Experimental Data of a Mach 4+ Fan Stage

Description:

- Characterize a TBCC engine fan stage aerodynamic and aeromechanic performance and stability limits, over a wide operating rang, including power-on and hypersonic-unique windmill operation.
  Assess/Verify SOA turbo-machinery design and analysis tools for TBCC propulsion.

Accomplishment(s):

- Completed **aeromechanical data collection** and have identified "safe"operating modes over the test envelop for Baseline configuration with **uniform inlet flow**.



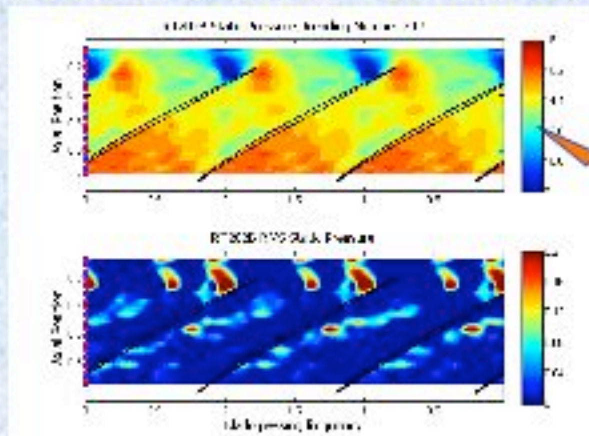
10x variation in bypass ratio (full power to windmill operation)
variations: 8x in rotor speed, 8x inlet pressure, 3x inlet temperature

RTA: GE / NASA
Mach 4 capable
TBCC engine

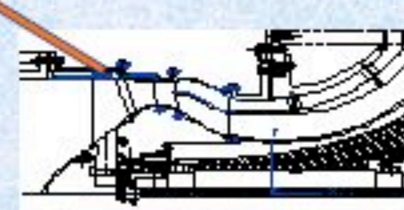
Aerodynamic/Aeromechanic CFD of a Mach 4+ Fan Stage

Accomplishment(s):

- Pre-Test **CFD simulation of the fan stage performance and operability** is complete at 100%, 50%, and 37% of fan corrected speed.
- Preliminary aerodynamic **mapping of compressor performance** (15%-100% speed) acquired during aeromechanical assessment for the baseline configuration.



Preliminary - Kulite data (rotor tip)



RBCC Technology Development

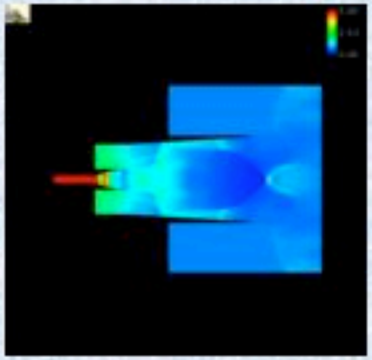
RBCC-Cycle Development and Simulation

Objectives:

- Provide high fidelity performance estimates for classical and novel, new approaches to low speed RBCC cycles
- Evaluate new approaches to improve vacuum mode performance of RBCC propulsion systems
- Improve capability to model steady and unsteady RBCC cycles

Task Element/Status:

- Modeling of pulsed and steady low speed cycles
- Modeling of Penn-State-NRA tests
- Modeling of vacuum-mode
- Provide propulsion data for system analysis (Level-4).



Unsteady Pulsed-Detonation RBCC Simulation. 2-D finite-rate, time accurate, pressure contours

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RBCC-Cycle Experimental Validation

Objectives:

- Develop and validate RBCC low speed and vacuum cycles
- Develop mode transition schemes and enabling technologies for low speed ramjet operation
- Provide validation data for cycle prediction and CFD model

Candidate Facilities: ASCR, PSL-4

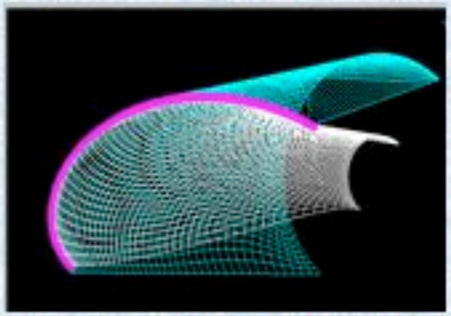
Candidate Facilities: RCL-11, RCL-22, RCL 32

Propulsion Analysis and Design

Rapid High-Fidelity Geometry and Mesh Generation

Objective
- Develop rapid engine design/analysis capability without sacrificing fidelity.
- Speed increase from rapid geometry generation and mesh generation
- Leverage Level 4 work in the Advanced Vehicle Integration & Synthesis Environment (AdVISE).

Task/Element/Status
- 2-D class vehicle developed including engine/vehicle parameterization for rapid geometry generation.
- Contract begun with TechnoSoft Inc. to develop automated structured gridding scheme for 2-D and 3-D forebodies/inlets. Investigating GridPro.



Interactive Analysis for Propulsion-Airframe Integration

Objective and Status:

- Develop an interactive computer program for the preliminary design and aerodynamic evaluation of three-dimensional forebody-inlet configurations. The approach will be to use a marching technique to solve the Parabolized-Navier-Stokes (PNS) equations for parameterized geometry. COTS software will be used for geometry manipulation, mesh generation, and post processing. Preliminary beta-version in test.

MHD Technology Development

Goal(s): Extend the "Russian-AJAX" concept to a turbojet by evaluating the utility of electromagnetically extracting a portion of the turbojet-inlet-air kinetic energy; thereby, (potentially) extending the operating range of conventional turbojets (and turbofans) from about Mach-3.5 to Mach-7

Figure 1b: MHD/Turbojet Engine Concept

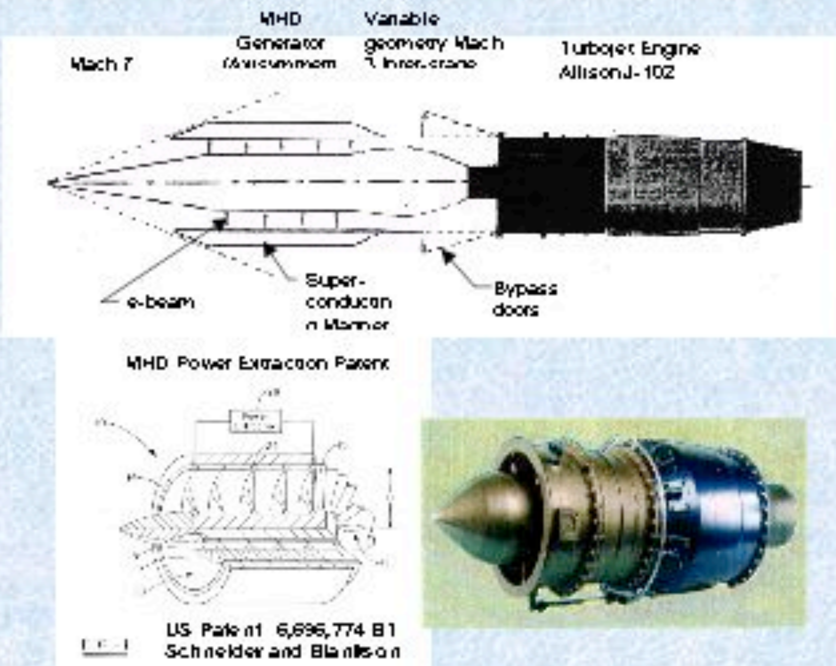
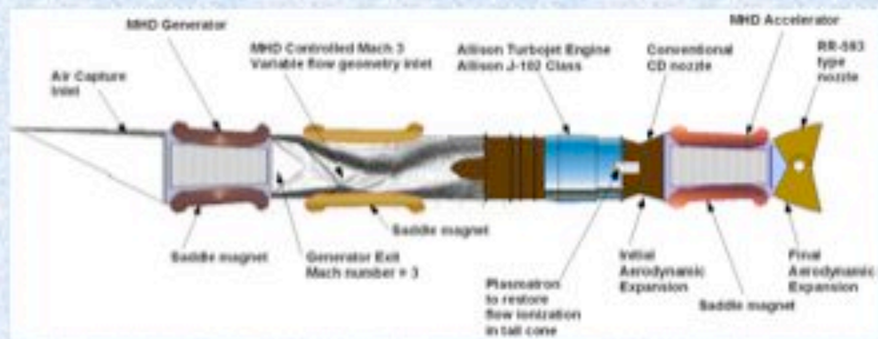


FIGURE 1A: GENERAL ARRANGEMENT MHD CONTROLLED TURBOJET HIGH-SPEED PROPULSION



Ref(s): [1] I.V. Adamovich, J. W. Rich, S. Schneider, I. M. Blankson, "Magnetogasdynamic Power Extraction and Flow Conditioning for a Gas Turbine," AIAA-2003-4289
[2] I.M. Blankson, and S. Schneider, "Hypersonic Engine using MHD Energy Bypass with a Conventional Turbojet," AIAA-2003-6922

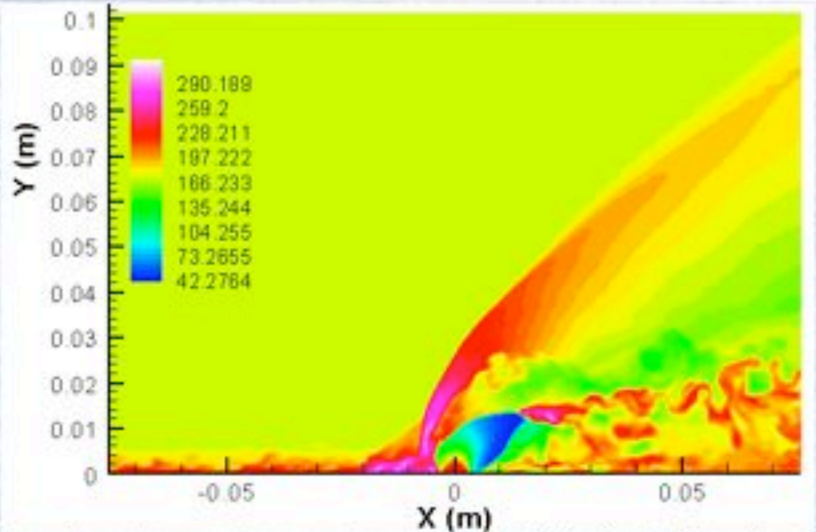
Propulsion NRA Awards (Round #1)

A.5.2 - Topic(s) Propulsion	Develop advanced modeling (and simulation) capabilities, and supporting fundamental experimental databases, addressing combustion physics and engine fluid dynamics and performance.	Proposals Awarded
Subtopic 1: Advanced Analytic Methods	Develop significant advances in **analysis techniques** to achieve a robust design and predictive, hypersonic-propulsion analysis capability. Emphasis is placed on the analytic characterization of the fundamental governing physical mechanisms relevant to combustion physics and associated engine/propulsive fluid-dynamic mechanisms.	J. Edwards NCSU LES/RANS F. Jaberi MSU LES/FMDF/DES J. Powers ND Wavelet-ILDM
Subtopic 2: Combustion, Fluid Dynamics and Performance Experiments	Validate analytic methods by obtaining experimental data (with quantified uncertainties in the measured and the derived quantities) addressing: combustion, fluid dynamic and performance of a combined-cycle propulsion engine. **Characterize fundamental combustion processes** (such as ignition, flame holding, flame propagation and turbulent combustion); examine facility induced performance effects (such as vitiation effects), and the quantification of fluid-dynamic-governed mechanisms (such as engine-unstart , mode-transition, operability margins/constraints, control margins/constraints, and performance) inherent to HRRL combined-cycle engines.	H. Chelliah UVA Reduced Kinetics I. Adamovich OSU Ignition C. Goyne UVA Vitiate Effects R. Santoro PSU Unsteady-RBCC

J. Edwards - Development of Hybrid Large-Eddy / Reynolds-Averaged Navier-Stokes Methods for High-Speed Internal Flows

Objectives

- Development and refinement of hybrid large-eddy / Reynolds-averaged simulation (LES/RANS) methods for high-speed turbulent flows
- Applications to sonic injection into a supersonic cross-flow, crossing-shock interactions, and shock-train propagation
- Implementation of LES/RANS methods into NASA's VULCAN code
- Development of automatic block-splitting / partitioning algorithms for structured meshes and implementation into VULCAN (subcontract to Corvid Technologies)



Center-plane temperature contours: LES/RANS simulation of sonic air injection into Mach-2 cross-flow

Approach

- Development of improved RANS-to-LES blending functions that transition in outer part of log layer
- Development of methods for controlling turbulence energy distribution
- Development of generalized recycling / rescaling methods for arbitrary mesh topologies
- Development of Fortran 95 block-splitting / merging algorithms and coupling with MeTIS for load-balancing
- Testing for problems mentioned above and implementation into VULCAN (collaboration with NASA Langley)

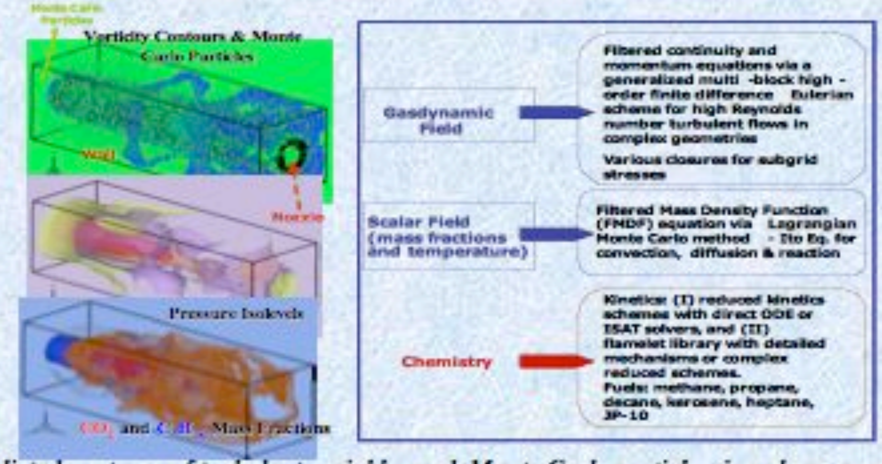
FY 2007/08 Key Milestones (to date)

- Improved **RANS-to-LES blending functions and methods** for controlling turbulence energy distribution developed and demonstrated
- LES/RANS simulations of air-air sonic injection experiments of Gruber, et al (AFRL) completed; helium-air simulations to be performed next
- Analysis of LES/RANS data to calculate turbulent Schmidt / Prandtl number variation underway
- Generalized recycling / rescaling module for structured meshes written and being debugged and tested
- Beta version of block-splitting / merging codes developed and delivered to NASA

F. Jaberi - A High Fidelity Model for Numerical Simulations of Complex Combustion and Propulsion Systems

Objectives

- Develop validated high-fidelity numerical models for high speed turbulent reacting flows.
- Study "laboratory combustors" of interest to NASA for various flow and combustion parameters via numerical models.
- Improve basic understanding of turbulent combustion in supersonic and hypersonic flows.



Predicted contours of turbulent variables and, Monte Carlo particles in a dump combustor.

FY 2007/08 Key Milestones

- Development and implementation of high-order numerical schemes for flows with shock waves.
- Extension of existent LES/FMDF submodels to compressible flows.
- Simulations (DNS and LES) of compressible non-reacting turbulent flows in realistic systems via new numerical schemes and subgrid models.
- Development of a stochastic formulation for compressible velocity-scalar FMDF.

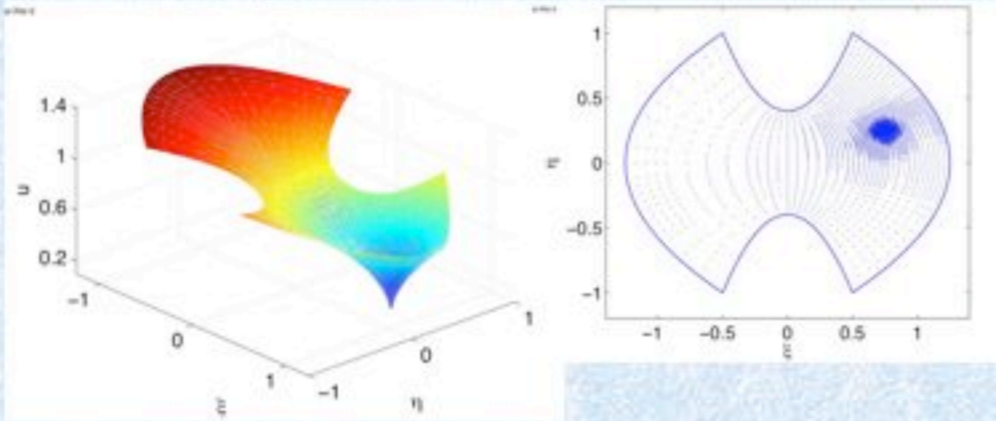
Status and Progress

- Existent subgrid models and numerical methods have been modified and extended to account for **compressibility effects**, specifically: (1) Stable high-order finite difference compact, WENO and MP schemes have been developed for flows with discontinuities. (2) Compressible dynamic subgrid models have been implemented. (3) The modified flow solver has been (and is being) applied to various 1D, 2D and 3D laminar and turbulent problems.
- Direct numerical simulations of supersonic channel flow have been conducted and work is in progress on the application of the DNS to supersonic boundary-layer flow over a flat plate.
- Work is in progress to develop a stochastic compressible subgrid model based on velocity-scalar-pressure correlations.

J. Powers and S. Paolucci - Advanced Multi-Scale Computational Methods for Hypersonic Propulsion

Objectives:

- Extend the use of wavelet-based analysis environment for compressible reacting flows.
- Develop an analytical environment for full three dimensional reacting flow analysis.
- The adaptive wavelet collocation spatial discretization to be used to capture multi-scale flow physics for the flow solver.
- Manifold methods are to be used to equilibrate fast chemical reactions.



Images of idealized solution on an irregular adoptive mesh

Approach:

- Extend the current three dimensional incompressible flow wavelet based solver to compressible environment with domain decomposition for complex geometry handling and combine with a manifold technique to handle reacting flows.

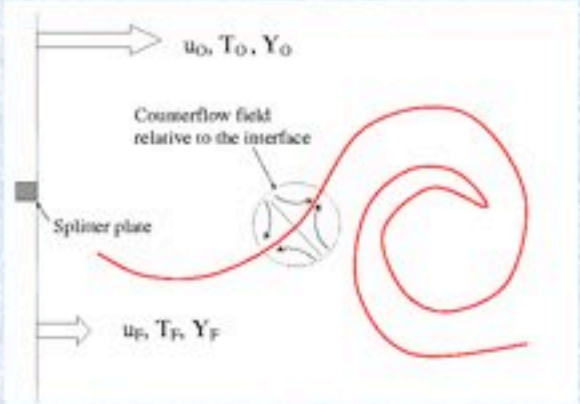
FY 2007/08 Key Milestones/Progress to date:

- Dr. Wirasaet is beta testing the newly developed **3-D compressible flow solver based on adaptive wavelet** method.
- Project re-scoped to add a post-doctoral participation (D. Wirasaet)
- General geometry environment has being developed to handle more complex combustor geometry.
- Continued technical discussions with NASA
- 3-D incompressible non-reacting and 1-D compressible reacting flow models have been demonstrated

H. Chelliah - Reduced Reaction Models for Hypersonic Reacting Flow Simulations

Objectives

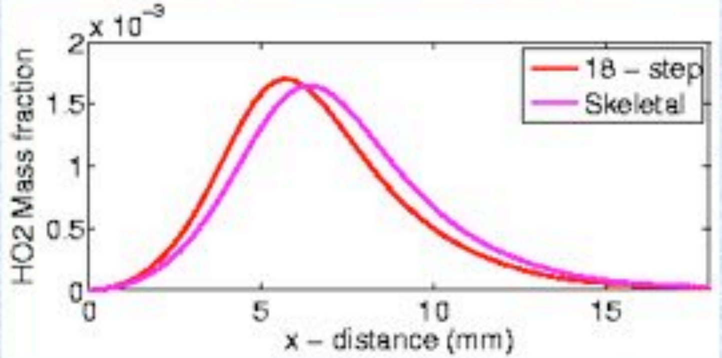
- Develop analytical tools to evaluate the detailed kinetic models for all fuels of interest (eg. "cracked" fuel mixtures, surrogate fuels, etc.)
- Develop and validate **reduced reaction models** by considering the relevant physical and chemical time scales in typical combustor flow path. These models will be implemented in SPARK and other NASA codes to investigate mixing and reaction in typical hypersonic flow fields.



Objective is to extend reduced reaction models developed based on counterflow field to realistic multi-dimensional high-speed reacting flow fields.

Status and Progress

- Computations:
  - Selected two high-speed shear flow cases to validate reduced reaction models.
  - Analysis of C2H4/Air ignition results indicates the need to validate the models at much higher equivalence ratios.
- Experiments:
  - New counterflow burner has been designed.
  - Initial tests with SiC heating element has shown the viability of approach adopted, with flow strain rates reaching up to 800 1/s.

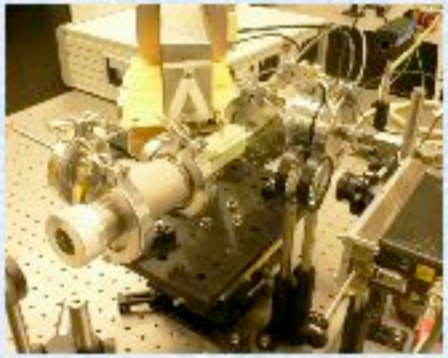


Differences between the C2H4 reduced model And the skeletal model along the flow path of a 2D Shear layer.

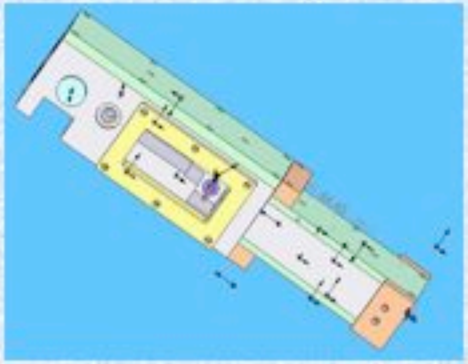
I. Adamovich - Nonequilibrium Ignition and Flameholding in High-Speed Reacting Flows

Objectives:

- Extend the use of non-equilibrium plasma ignition / flame holding to higher static pressures, higher flow velocities, and non-premixed flows
- Study the effect of the pulsed discharge plasma on coupling of flame sustained in a cavity flame holder to the main flow
- Determine spatially resolved temperature and concentrations of key radicals



Photograph of nanosecond discharge / TALIF cell for O-atom concentration measurements



SolidWorks design of the Combustion test section

Approach:

- Use stable, large-volume, short pulse duration, repetitively pulsed plasmas in high-pressure combustible flows (40 kV peak voltage, 5 nsec pulse duration, 100 kHz pulse repetition rate) to generate active radicals
- Use non-intrusive optical diagnostics (Two-Photon Absorption Laser Induced Fluorescence, Tunable Diode Laser Absorption Spectroscopy) to measure radical concentrations

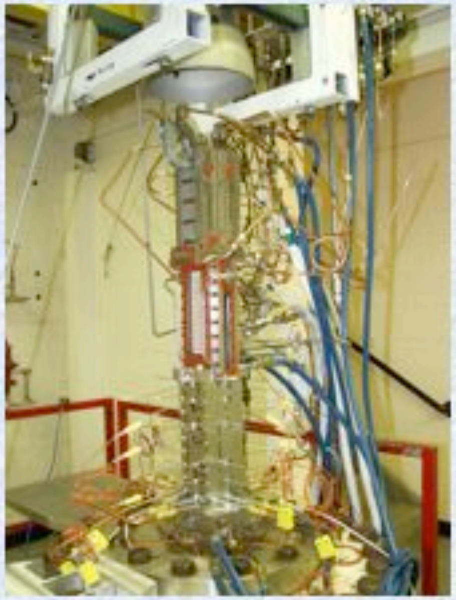
FY 2007/08 Key Milestones:

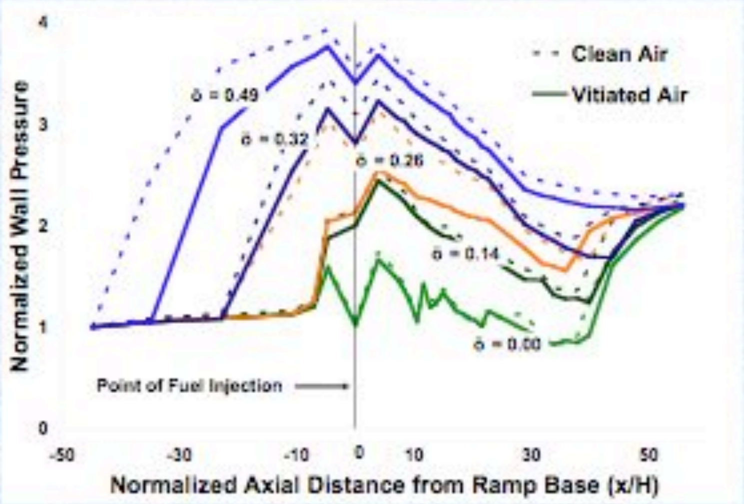
- Design and manufacturing of a new high-speed **plasma ignition / combustion test section**
- O atom concentration measurements in a nanosecond pulse discharge
- Development of a **kinetic model of a nanosecond discharge plasma in a combustible mixture**

C. Goyne - Test Media Effects (Vitiate Effects)

Status and Progress

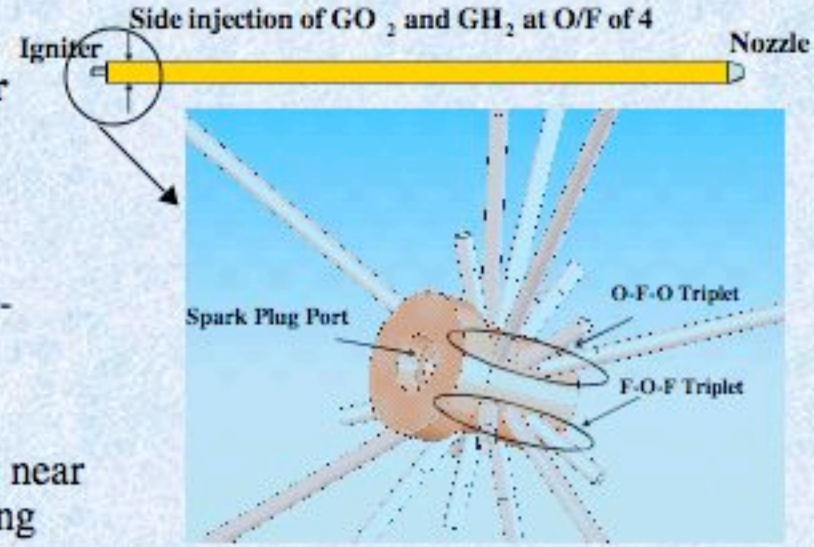
- Clean-air and methane-vitiated test series recently completed
  - Vitiate levels of 8% H_2O, 4% CO_2
  - **Effects of vitiates evident in results**
  - Data analysis is underway
- CFD Analyses using WIND and GASP code are proceeding:
  - Sensitivity of results to wall temperature boundary conditions and chemical kinetics model is being assessed
- PIV Measurements at nozzle exit being planned
- Facility steam pre-heater in preliminary design
  - Required to prevent condensation at water vapor levels approaching that of H2-vitiated facility at Mach 5



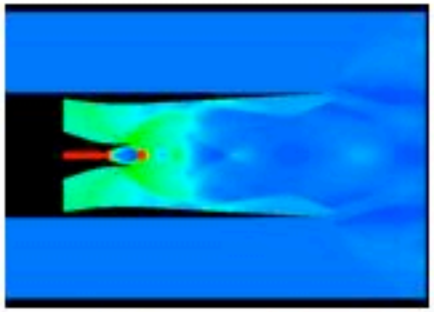


R. Santoro - Performance Studies of the Ejector Mode of an Unsteady Pulse Detonation RBCC Engine

- Objectives
  - To demonstrate the increased propulsive **performance for the ejector mode of a pulse detonation rocket-based combined cycle** (PD-RBCC) engine
  - To understand the fundamental processes that lead to the experimentally demonstrated increased performance of a PD-RBCC engine
- Status, progress and accomplishments:
  - Status and Progress: The design of the GO_2/GH_2 PDRE is near completion based on analysis at Penn State and CFD modeling input from NASA GRC (Mr. D. Perkins and Dr. S. Yungster). The geometry and flow conditions for PDRE operation have been jointly finalized.
  - Accomplishments: The design of the most critical component of the PDRE, the injector, has been completed.
- Plans for the remainder of first year of effort:
  - Currently the PDRE design is being finalized for fabrication
  - Conduct first test campaign to verify PDRE stand alone operation at frequencies of 140 Hz and above for pressures up to 290 psia
  - Complete analysis and document PDRE operational results



PD Rocket Injector



2-D Simulation of PD-RBCC

Propulsion NRA Awards (Round #2)

A.5.2 - Topic(s) Propulsion	Primary technical challenges for the Propulsion Discipline include the need to enhance basic understanding of the flow-path physics, as well as the ability to accurately predict and quantify the propulsive environment and relevant fluid dynamics.	Proposals Awarded
Subtopic 1: Turbulent Combustion	Develop novel physical models, computational and/or experimental methods that **elucidate the fundamental governing mechanisms of turbulent combustion physics** and associated fluid mechanisms in the combustor environments of hypersonic engines.	TBD
Subtopic 2: Hypervelocity (Mach 10+) Propulsion	The advanced technology that supports HRRLS requires the development of air-breathing propulsion systems for the **hypervelocity regime**. To this end, enhancements in the state-of-the-art are solicited in engine design, performance, operability, performance assessment and validation databases that will yield advancements in analysis and simulation methods.	TBD
Subtopic 3: Advanced Propulsion Concepts and Analysis Algorithms	Innovative research efforts addressing **novel propulsion cycles**, or novel modifications to existing propulsion cycle designs applicable to the HRRLS missions are highly encouraged, as are advancements in the capability to accurately, and in a timely manner, **assess propulsion system performance**.	TBD

Concluding Remarks

- The Propulsion Discipline has formulated numerous research tasks to enhance the state-of-the-art in propulsion analysis (tools), and combined-cycle technologies (that will enable HRRLS).

- The Propulsion Discipline actively seeks external-partnerships and NRA-collaborations, in order to broaden and infuse the research efforts.

- The Propulsion Discipline is continuously seeking "good-ideas" for incorporation within the NASA-FA-Hypersonics Program.