Hypersonics Project Overview

Fundamental Aeronautics Program

Dr. James L. Pittman, Project Manager, Langley Research Center
Mr. John M. Koudelka, Deputy Project Manager, Glenn Research Center
Dr. Michael J. Wright, Project Scientist for EDL Technologies, Ames Research Center
Mr. Kenneth E. Rock, Project Scientist for Airbreathing Technologies, Langley Research Center

2011 Technical Conference
March 15-17, 2011
Cleveland, OH
Hypersonics Project Goal

Develop tools and technologies to *enable* airbreathing access to space and large-mass entry into planetary atmospheres.
Airbreathing Technical Challenges

- Develop airbreathing propulsion technology for Two-Stage-to-Orbit Vehicles
  - Propulsion Discipline – Dr. Rick Gaffney, Wed 8AM
  - Turbine Based Combined Cycle Discipline – Mr. Scott Thomas, Wed 11AM
- Develop integrated light-weight, reusable airframe and propulsion structures
  - Materials & Structures Discipline – Dr. Anthony Calomino, Wed 2PM
- Develop physics-based integrated multi-disciplinary design tools
  - MultiDisciplinary Analysis & Optimization Discipline – Mr. Jeff Robinson, Tues 2PM
  - Guidance, Navigation & Control Discipline – Mr. Don Soloway, Thurs 3:30PM
Entry, Descent & Landing (EDL) Technical Challenges

- Decrease uncertainty in aeroheating prediction by 50%
  - Aero, Aerothermo & Plasmadynamics Discipline – Dr. Deepak Bose, Wed 4PM
- Develop tools and technologies to enable large-mass planetary entry
  - Atmospheric Decelerator Technology Discipline - Mr. Chuck Player
  - Materials & Structures Discipline – Dr. Anthony Calomino
    - EDL Overview, Dr. Mike Wright, Thurs 8AM

[Images: NASA Human Mars Lander Concept, Inflatable Reentry Vehicle Concept]
Airbreathing partnerships

- **X-51A**
  - AFRL/DARPA flight tests
  - 1st flight May 26, 2010
  - NASA ground tests, CFD studies

- **Two-Stage-to-Orbit Study**
  - AFRL RBCC Concept
  - NASA TBCC Concept

- **HIFiRE Flight Tests**
  - Sounding rocket payloads
  - Flow physics, scramjet payloads

- **Science Centers**
  - Flow physics, Propulsion, Materials
  - Joint with AFOSR
EDL partnerships

• Shuttle Flight Tests
  • Boundary layer transition due to discrete roughness
  • Hypersonics Project ground tests, CFD studies

• MEDLI
  • ESMD responsible for hardware development and installation
  • Hypersonics responsible for modeling and pre/post flight data analysis

• HIADs, SIADs
  • IRVE flight tests & large scale SIADs transferred to OCT
  • Hypersonics Project develops advanced Flexible insulative TPS, aerothermoelastics models

• Exploration EDL Project
  • Supersonic Retro Propulsion (identified as high payoff by EDL-SA)
  • Work closely to ensure a well integrated complimentary portfolio across both projects
Airbreathing Hypersonics
Hypersonic Airbreathing Technology Roadmap

<table>
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<tr>
<th>Vehicle Scale</th>
<th>1X</th>
<th>10X</th>
<th>100X</th>
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<tr>
<td>User</td>
<td>DoD</td>
<td>DoD</td>
<td>NASA</td>
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<tr>
<td>Application</td>
<td>Weapon</td>
<td>DoD-ISR, Strike</td>
<td>Access to</td>
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<td></td>
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<td>Space</td>
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<td>Year Technology Achieves TRL 6</td>
<td>2020</td>
<td>2030</td>
<td>2040</td>
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Long-term, sustained commitment required to achieve airbreathing access to space technology
Air Force/DARPA objective: Demonstrate controlled, sustained, accelerating hypersonic airbreathing-powered flight from Mach ~4.5 to 6+.

NASA/AFRL research value: Extensive ground tests in vitiated air, flight tests in clean air, CFD increase understanding of vitiation effects on scramjet performance & operability.
HIFiRE Flight 2

Hypersonic International Flight Research Experiment

- Collaborative effort
  - USAF (AFRL)
  - Australian Defense Science and Technology Organization
  - NASA (Flight #2)
- High speed hydrocarbon combustion test
  - Ramjet to scramjet mode transition (Mach 5.5 to 8+)
  - Flight Test – Sounding rocket with a suppressed trajectory
- Ground tests of flowpath tested in LaRC AHSTF
- Flight & ground test data, CFD support vitiation studies
Large-scale Scramjet Engine Test Technique (LSETT)

- Objective: Develop test techniques for large scale (up to 10X) scramjet testing
- Utilize multiple facilities
  - ATK-GASL (Direct Connect)
  - ATK-GASL (Semi-Freejet)
  - LaRC 8-Ft HTT (Freejet)
- Use the ATK ALRJ-51-4 flowpath
- Use the existing X-51 forebody
- Team members: OSD, AFRL, NASA and ATK
Truncated Inlet Test (TRINT)

- Objective: Develop a design methodology to generate a reduced length inward turning inlet having similar properties to a full length inlet
- Method developed by JHU under AFRL contract
- Hardware constructed and will be tested in the GRC 1’ x 1’ supersonic wind tunnel in 2011 to validate the methodology
  - Small scale full length inlet
  - Small scale short length (truncated) inlet
- Tests partners: NASA, AFRL, OSD and JHU
Turbine Based Combined Cycle Test Program

Test Approach - 4 Phases

1. Inlet performance and operability characterization, Mode Transition Sequencing

2. System Identification of inlet dynamics for controls

3. Demonstrate Control strategies for smooth & stable mode transition without inlet unstart

4. Add turbine engine / nozzle for integrated system test with simulated Scramjet

Testbed Features
- Variable Low Speed Cowl
- Variable High Speed Cowl
- Variable Ramp
- Variable Compartmented Bleed (13)
- Low Speed Mass flow / Backpressure Device
- High Speed Mass flow / Backpressure Device
- Inlet Performance Instrumentation (~800)
- Engine Face: Flow Characteristics (AIP)
CCE Inlet Installed in NASA 10’X10’ SWT
1st Wind Tunnel Run March 7, 2011
Reversible Airframe Thermal Protection Options
Vehicle Acreage

- **Improved Shuttle tile or blanket insulators**
  - Insulator bonded or mechanically attached to vehicle mechanical load carrying structure

- **Metallic or CMC standoff TPS**
  - TPS system isolated from airframe to prevent thermal loads from reaching the vehicle mechanical load carrying structure

- **Structurally integrated TPS (SITPS)**
  - A TPS system that has an integrated mechanical and thermal load carrying capability with the ability to share mechanical loads with the airframe

The SITPS option constructed with Ceramic Matrix Composite (CMC) materials is under development for the potential of lightest weight, highest volumetric efficiency and greatest durability.
Structurally Integrated Thermal Protection System (SITPS)

Objective: Design and fabricate SITPS panels for test under flight loads.

Status: Small rigid insulator SITPS panels built from CMC fabricated and tested. Manufacturing is currently an issue for light weight design (SITPS-1). Fabrication process modified and new panel under construction.

Fabrication demo panel (SITPS-0): 12” x 12” x 2.2” panel // 5.8#/ ft2

“Optimized” panel (SITPS-1) 12” x 12” x 2” panel // 3#/ ft2

Cracking in AETB insulator
Objective: Develop improved modeling and physical understanding of CMC behavior to improve durability and extend life.

Status: Quantitative image analysis software system under development to model CMC microstructure for finite element analysis. Results compare well to test data.
Objective: Develop airbreathing Two-Stage-To-Orbit (TSTO) reference vehicles for the same mission to evaluate design methodologies, vehicle technologies and inform technology decisions in both Agencies.

Status: Common mission ground rules and similar design methods defined to achieve more rigorous comparisons of alternate technologies.

NASA and AFRL completed vehicle concept definition at Level 1 methods fidelity and exchanged geometries for independent analysis. Study concludes in FY11.

Mission: 20K# payload, 100 nm orbit due East

Air Force rocket-based combined cycle (RBCC) orbiter (2nd stage) concept

NASA turbine-based combined cycle (TBCC) booster (1st stage) with rocket-powered orbiter
MDAO Tool & Method Development

- Integrated Design and Engineering Analysis (IDEA) Environment
  - Geometry centric, knowledge capture, AML based system
  - Common computational model
  - Generation 1 due in FY12

- High Fidelity Propulsion Methods
  - Parametric flow-path design
  - Automated structured CFD grid generation based on geometry and grid topology
  - Scramjet engine thermal & power balance.
  - Mass estimates

High Fidelity Vehicle Methods
- Coupled aero / thermal / structural analysis
- Parametric OML generation
- Coupled SITPS analysis
- Subsystem modeling
Vehicle Control System Design Tool

Control Model Environment (VSI Aerospace Inc.)

Model Generation

Generate:
- Control Design and Evaluation Models
- Sensitivity Data Base

Model Analysis

Controller Design

Parameterization

Trade Studies Generator (Optimization Algorithm)

Performance

FltZ Simulator, Evaluate Design

Given Geometry

Feedback
to
Vehicle Design Process (MDAO, Structures,...)
EDL
OCT Grand Challenges (2011)

• EDL is recognized by OCT as one of 13 NASA “Grand Challenges” for the future. EDL technologies are a NASA-unique area that requires continual improvement to the SOA to enable challenging science and exploration missions.

• Problem:
  – Entry, Descent and Landing is a challenging operation. A space system must be robust enough to accommodate a wide range of hazards associated with uncertain position and velocity knowledge, atmospheric conditions, heating, particulates, and terrain characteristics to safely arrive at a desired surface location.

• Challenge
  – Develop entry, descent and landing systems with the ability to deliver large-mass human and robotic systems to planetary surfaces.
EDL-Systems Analysis Mars Landing Architectures
(with Mars Arrival Mass underneath)

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<td>Aerocapture</td>
<td>NTR</td>
<td>Supersonic</td>
<td>Subsonic</td>
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<tr>
<td>110 mt</td>
<td>84 mt</td>
<td>265 mt</td>
<td>109 mt</td>
<td>134 mt</td>
<td>141 mt</td>
<td>107 mt</td>
<td>81 mt</td>
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40 metric tons (mt) landed mass in all cases
Inflatable Reentry Vehicle Flight Experiment (IRVE)

Objective: Demonstrate test technique, stability and survivability of an inflatable reentry aeroshell.

Status: NASA developed and flight tested the Inflatable Reentry Vehicle Experiment (IRVE-2) with Mach 6 reentry (2 watts/cm²) in August 2009.
Future IRVE Flight Experiment

Objective: IRVE-3 designed for 20W/cm² maximum heat pulse and vehicle lift control though CG offset. Launch planned May 2012.

Status: IRVE flight tests transferred to NASA Chief Technologist Game Changing Program in FY11. Hypersonics Project continues development of next generation 50W/cm² flexible insulative thermal protection system.
AAP Technical Challenge

Decrease Uncertainty in Aeroheating Predictions by 50%

Transition and Turbulence

High Enthalpy Physics

Advanced Computational Tools
Aeroheating Uncertainty Assessment

1. Compression Corner
   - Turbulent Flow
   - Mach 7 and 14
   Recommended Uncertainty: 45%

2. Impinging Shock
   - Turbulent Flow
   - Mach 7 and 14
   Recommended Uncertainty: 45% separated & 30% attached

3. High Mass Mars Entry
   - Turbulent Flow
   - Speed: 7 km/s
   Recommended Uncertainty: 50% convective & 100% radiative

4. High Speed Return To Earth
   - Turbulent Flow
   - Speed: 15-16 km/s
   Recommended Uncertainty: 60% radiative

Uncertainty assessed by a Panel of NASA Subject Matter Experts

Details will be presented at the 42nd AIAA Thermophysics Conference, Jun 27-30, Honolulu, HI
CFD Development Strategy

**Today**

**LAURA**
- Structured, Finite Volume, mostly steady-state
- Also coupled to Radiation and Ablation codes

**In 2-3 Years**

**US3D-NASA**
- FUN3D (LAURA-path)
  - Unstructured, Finite Volume, low-dissipation schemes, DES/LES, DNS capability, well-balanced schemes

**In 5-10 Years**

**DG (Discontinuous Galerkin)**
- CESE (Conservation Element Solution Element)
  - Unstructured, higher order, unsteady, beyond finite volume
Concluding Remarks

• The NASA Fundamental Aeronautics Program’s Hypersonics Project develops a broad range of enabling technologies for airbreathing access to space vehicles and for the entry and descent of large mass vehicles into planetary atmospheres.

• Partnerships within NASA and with other government agencies, industry and academia are essential to advancing hypersonic technologies.

• Future activities within the Hypersonics Project will be constrained by recent investment decisions.

• New NASA Chief Technologist is already investing in EDL technologies. This area of research may grow.

• Other NASA investments in airbreathing technologies unknown.
ACRONYMS

• AFOSR – Air Force Office of Scientific Research
• AFRL – Air Force Research Laboratory
• AHSTF – Arc Heated Scramjet Test Facility
• AIP – Aerodynamic Interface Plane
• CCE – Combined Cycle Engine
• CFD – Computational Fluid Dynamics
• CG – Center of Gravity
• CMC – Ceramic Matrix Composites
• DARPA – Defense Advanced Research Projects Agency
• DoD – Department of Defense
• DMSJ – Dual Mode ScramJet
• EDL – Entry, Descent & Landing
• EDL - SA – EDL Systems Analysis (NASA Project)
• ESMD – Exploration Systems Mission Directorate (NASA)
• GNC – Guidance, Navigation, and Control
• GRC – Glenn Research Center (NASA)
• HIAD – Hypersonic Inflatable Aerodynamic Decelerator
• HIFiRE – Hypersonic International Flight Research and Experimentation
• IRVE - Inflatable Reentry Vehicle Experiment
• JHU – John Hopkins University
• LaRC – Langley Research Center (NASA)
ACRONYMS

- OCT – Office of Chief Technologist (NASA)
- OML – Outer Mold Line
- OSD – Office of Secretary of Defense
- MEDLI – Mars Science Lab EDL Instrumentation
- M&S – Materials and Structures (Discipline)
- MDAO – Multi-Disciplinary Analysis and Optimization (Discipline)
- RBCC – Rocket Based Combined Cycle
- SIAD - Supersonic Inflatable Aerodynamic Decelerator
- SITPS – Structurally Integrated Thermal Protection System
- SOA – State Of the Art
- SWT – Supersonic Wind Tunnel
- TPS – Thermal Protection System
- TRL – Technology Readiness Level
- USAF – United States Air Force
- 8-Ft HTT – 8 Foot High Temperature Tunnel