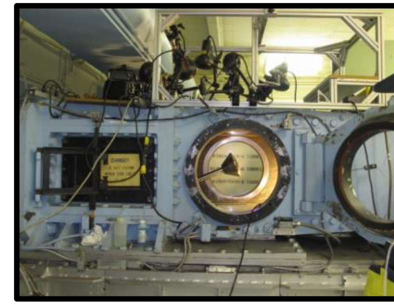
Experimental Hypersonics at the NASA Langley Research Center

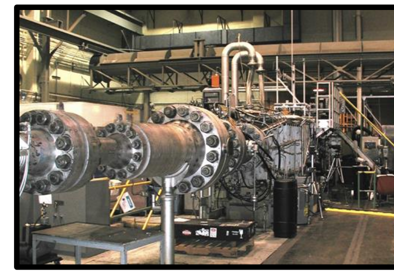
By

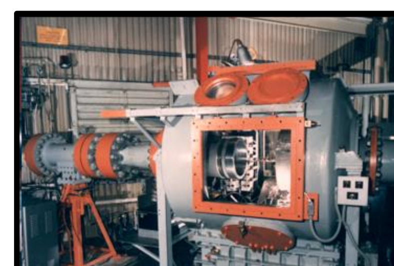
John R. Micol

Overview of Experimental Hypersonics at the NASA Langley Research Center

- **Aerothermodynamics Challenges**
- **Experimental Facilities**
- **Computational Fluid Dynamic Code Calibration**
- **Flight Experiments**



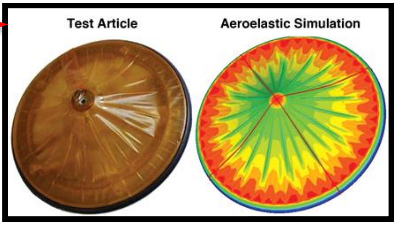




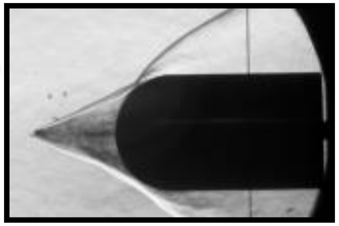
10 Challenging Problems in Hypersonics that Require Experimental Data for Vehicle Design or CFD validation

- Aeroelasticity
  - Large, inflatable/deployable aeroshells for high-mass Mars missions
  - Flow-field / structural interactions produce surface deformations that affect integrated aerodynamics and boundary-layer transition
- Retro-Propulsion and Stagnation Region Injection
  - Retro propulsion for high-mass Mars missions enables deceleration and precision landing; stagnation region injection for DoD missions produces lowered aerodynamic drag & heating
  - Complex, dynamic interactions occur between injected fluid, boundary-layer, and bow-shock wave
- Wake Flow Physics
  - Capsules produce large regions of separated, unsteady, turbulent wake flow
  - Large uncertainties in flow reattachment and shear-layer impingement locations on payload drive up TPS requirements
- RCS and Thruster Performance
  - RCS employed for entry vehicles; maneuvering thrusters for DoD missiles & strike vehicles
  - Complex, dynamic interactions occur between jets and external flow and surfaces producing non-linear effects on jet performance and generating local heating augmentation
- Turbulent Heating Augmentation from TPS Roughness
  - Random Heating Augmentation, i.e., resulting from distributed roughness produced by ablation of materials and/or patterned roughness produced by tiled TPS materials
  - Roughness promotes early transition onset, generates turbulent heating above smooth levels

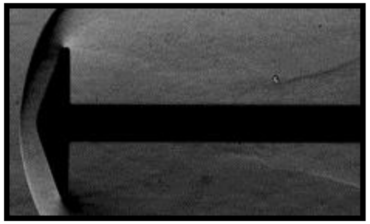
Deflections of flexible aeroshells



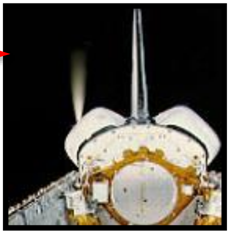
Stagnation-point injection



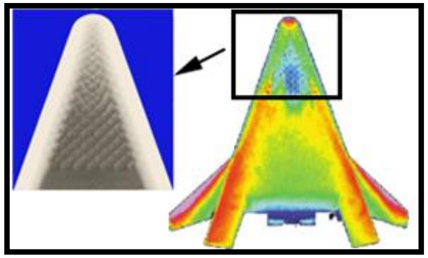
Unsteady capsule wake flow



Shuttle RCS

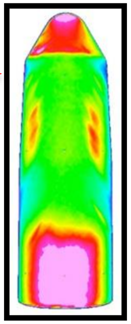


X-33 bowed-panel roughness heating

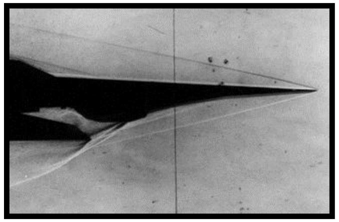


10 Challenging Problems in Hypersonics that Require Experimental Data for Vehicle Design or CFD validation (Concluded)

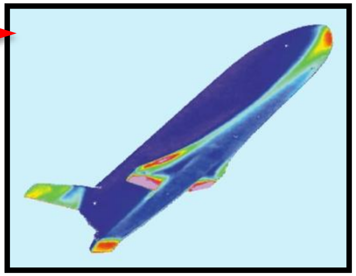
- Boundary-Layer Transition (BLT)
  - BLT is highly-dependent on vehicle configuration, e.g., flow processing over blunt capsules, lifting-bodies, slender cones and missiles, inlets, etc.
  - Characterization of transition behavior will enable reduced design margins; may be a requirement to ensure transition for air-breather inlets
- Stage, Payload, and Shroud Aerodynamic Interactions
  - Dynamic interactions are highly-dependent on speed-range, configuration, and proximity
  - Aerodynamics must be thoroughly characterized to prevent re-contact or loss of control
- Aerodynamic Control-Surface Performance
  - Performance of control surfaces (tabs, flaps, rudders, etc.) and effects on configuration aero/aerothermodynamics performance must be characterized across range of deflections
  - Boundary-layer and shock interactions with control surfaces produce pressure and heating spikes, BL transition, and flow separation
- Aerothermodynamics of Complex Topological Features
  - Compression pad cavities, tile steps & gaps, fairings, instrumentation ports, windows, etc on vehicles, i.e., these geometric features produce re-circulating flows, shock-interactions, BL transition.
  - Features also produce heating augmentation above baseline TPS environments
- Shock-Shock Interactions
  - Inlets, wings, control surfaces and towed ballutes can produce shock-shock interactions
  - Interactions affect aerodynamics, produce heating spikes and promote boundary-layer transition



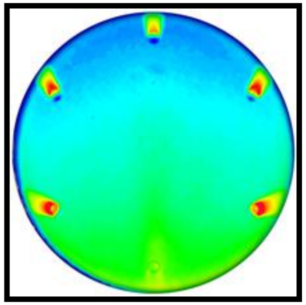
Ellipsled centerline and cross-flow transition



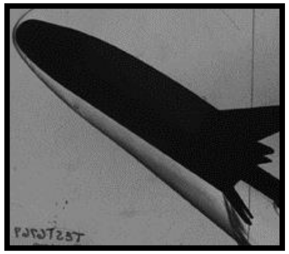
Hyper-X / Pegasus Separation Interactions



X-37 deflected controls heating effects



CEV compression pad heating



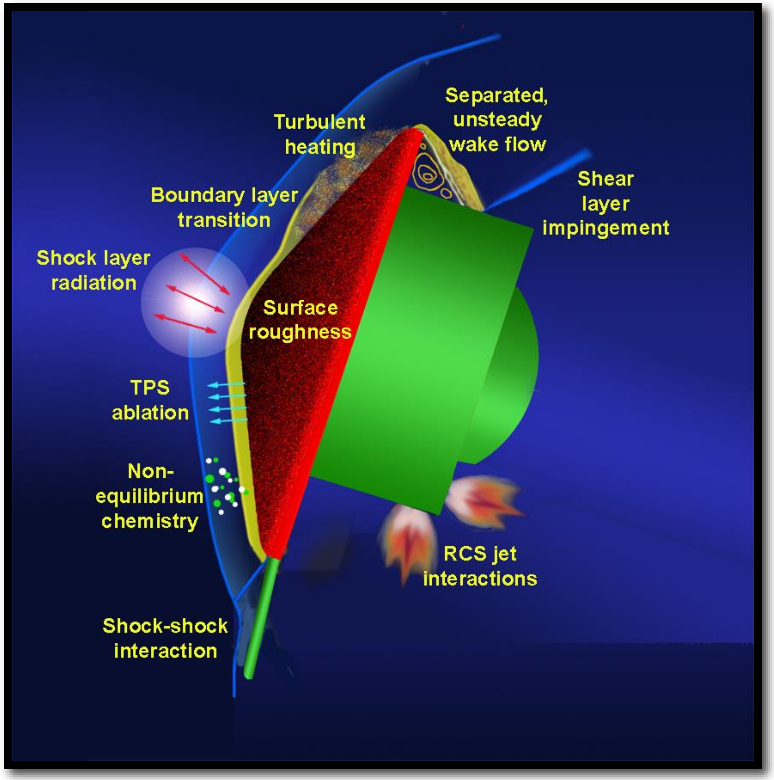
X-33 Bow-Shock / Flap-Shock Interaction

21st-Century Aerothermodynamic Challenges

- After more than 50 years of progress in the field of aerothermodynamics, many challenging problems still remain in the design of aerospace vehicles
  - Every hypersonic vehicle is different and presents unique aerothermodynamic challenges
  - Many gaps exist in CFD predictive capabilities that lead to decreased performance margins and/or mass gain
  - CFD, ground-testing, and flight-testing must all contribute to vehicle development

- Experimental data are still required to further the understanding of aerothermodynamic phenomena
  - Shock/shock and shock/boundary-layer interactions
  - Gas / fluid injection for aerodynamic or aeroheating modulation
  - Axial and cross-flow boundary-layer transition
  - High Reynolds number turbulent heating augmentation
  - Surface roughness effects on transition and heating
  - RCS jet interactions on aerodynamics & heating
  - Heat-shield penetrations, gaps, protrusions and damage
  - Aeroelasticity of deployable structures
  - Separated and unsteady wake flows
  - Stage and shroud-separation interactions & dynamics
  - Ablation blowing and recession
  - Radiation transport
  - Non-equilibrium chemistry

Aerothermodynamic phenomena of atmospheric entry & Hypersonic Flight



LaRC hypersonic tunnels provide experimental data for parametric design & optimization of vehicles, CFD validation & uncertainty assessment, flight database construction and technology development

Recent Failures and Successes in Hypersonic Flight – Why the Need for Experimental Data?

In light of the trend toward down-sizing of infrastructure, is there a future need for experimental hypersonics at NASA?

Recent experience suggests that despite great advances, CFD and other analysis tools cannot solve all aerothermodynamic problems.

In order to ensure mission success and survivability, the answer is undoubtedly ***yes***.

Consider recent flight program *failures* due to lack of experimental testing / development / validation:

- (1994) Pegasus XL first flight carrying NASA STEP-1 satellite: failure due to "errors in predictions for vehicle response to various aerodynamic forces" - *NASA Anomaly Investigation Team*
- (2001) Hyper-X Launch Vehicle on first flight of X-43: failure due to "modeling inaccuracies in the aerodynamics" - *X-43A Mishap Investigation Board*
- (2010) Falcon HTV-2 partial failure: "The Air Force wanted to do more testing. DARPA pushed back, claiming there was no point to further testing. They thought they had the performance fully characterized. They flew it, and it didn't work" - *Mark Lewis, Air Force Chief Scientist*

Or, consider positive contributions from testing to *successful* missions:

- Space shuttle orbiter: Boundary-layer tool developed (in part) from LaRC hypersonic test data used in decision-making process for tile repair on all shuttle flight (including STS 114 repair)
- X-37 / X-40 OML redesign: successful first flight in 2010 with configuration redesign (addition of body flap, change in strake angle) largely based on LaRC hypersonic test data
- Genesis & MSL Cruise-Stage Attachment Cavities: LaRC hypersonic test data used to size & place attachment-point cavities on Genesis forebody (heat-shield survived 2004 re-entry) and justify cavity relocation to aftbody on MSL (to fly in 2011)
- X-43 Hyper-X trip design: boundary layer trip design for turbulent inlet flow based on LaRC hypersonic test data – successful Mach 7 and Mach 10 flights in 2004.

Back-Up Slides