The Lyndon B. Johnson Space Center (JSC) has been a critical element of the United State’s human space flight program for over 50 years. It is the home to NASA’s Mission Control Center, the astronaut corps, and many major programs and projects including the Space Shuttle Program, International Space Station Program, and the Orion Project. As part of JSC’s Engineering Directorate, the Applied Aeroscience and Computational Fluid Dynamics Branch is charted to provide aerosciences support to all human spacecraft designs and missions for all phases of flight, including ascent, exo-astmospheric, and entry.

The presentation will review past and current aeroscience applications and how NASA works to apply a balanced philosophy that leverages ground testing, computational modeling and simulation, and flight testing, to develop and validate related products. The speaker will address associated aspects of aerodynamics, aerothermodynamics, rarefied gas dynamics, and decelerator systems, involving both spacecraft vehicle design and analysis, and operational mission support.

From these examples some of NASA leading aerosciences challenges will be identified. These challenges will be used to provide foundational motivation for the development of specific advanced modeling and simulation capabilities, and will also be used to highlight how development activities are increasing becoming more aligned with flight projects. NASA’s efforts to apply principles of innovation and inclusion towards improving its ability to support the myriad of vehicle design and operational challenges will also be briefly reviewed.
NASA Aerosciences Activities to Support Human Space Flight

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Presented at JAXA Tsukuba Space Center
November 21, 2011
NASA Centers and Mission Directorates

- Ames Research Center
- Jet Propulsion Lab
- Dryden Flight Research Center
- Glenn Research Center
- Goddard Space Flight Center
- NASA Headquarters
- Langley Research Center
- Marshall Space Flight Center
- Kennedy Space Center
- Glenn Research Center
- Aeronautics Research
- Human Exploration and Operations
- Science
Johnson Space Center

Apollo

Space Shuttle

International Space Station

Mission Control

Astronauts

Orion
NASA/JSC Aerosciences

Aerodynamic Characterization
Rarefied Gas Dynamics

Aerothermodynamic Heating
Decelerator Systems

Ground Testing
Modeling and Simulation
Flight Testing
NASA/JSC Aerosciences

Aerodynamic Characterization
Rarefied Gas Dynamics

Aerothermodynamic Heating
Decelerator Systems

Ground Testing
Modeling and Simulation
Flight Testing
Primary CFD Codes Used at JSC

Overflow
Overset grid Navier-Stokes
NASA Langley Research Center

Cart3D
Cartesian inviscid compressible
NASA Ames Research Center

DPLR  (Data Parallel Line Relaxation)
Multi-block hypersonic non-equilibrium
NASA Ames Research Center

DAC  (DSMC Analysis Code)
Rarefied gas dynamics solver
NASA Johnson Space Center
Space Shuttle Overset CFD Development

Early 80’s
3 Grids
0.3 million volume cells

Late 80’s
14 Grids
1.6 million volume cells

Early 90’s
113 Grids
16.4 million volume cells

STS-107
267 Grids
34.8 million volume cells
605 Overlapping Grids
96.4M Volume Cells
Validation and Ground to Flight Traceability
Experimental Validation and Traceability

IA700 Wind Tunnel Test
Mach = 1.55
Re = 2.5E6/ft
Flight Data Validation

STS-50 Orbiter Wing Running Loads
Mach 1.25, Alpha -3.3, Beta 0.0, $\delta_{e_i/o} = 10.5/6.25$, $Q_{bar} = 640.7$ psf

Shear Force

Bending Moment

Torsion

Flight Data
1994 CFD
2004 CFD
Pre-Columbia Debris Transport Analysis

Post Flight Damage Assessment

Liberation Source Identification
Post Columbia Accident DTA
Bipod Redesign Environment Updates

Old Configuration
Bipod Ramps

New Configuration
Bare Spindle
Shock Boundary Layer Interaction

Orbiter

Orbiter Bow Shock

Separated and Unsteady Flow

Lox Feedline

Bipod Spindle

External Tank
Mission Support / Damage Assessment

Vehicle Inspection

STS-118 Deep Tile Damage

Baseline Heating

STS-114 Protruding Gap Filler
Boundary Layer Transition Flight Experiment

Modified Tile

CFD prediction

Turbulent flow from wing protuberance

Radiometrically Calibrated Temperature Image
Frame averaging applied

HYTHIRM
Hypersonic Thermodynamic InfraRed Measurements
NASA Langley Research Center

STS-119
Mach ~ 8.5
Mar 28, 2009
Space Launch System / Orion

- Space Launch System
- Tower Jettison Motor
- Primary Abort Motor (4 Nozzles)
- Attitude Control Motor (8 Nozzles)
- Fairing / Boost Protective Cover
- Orion Crew Module
Orion Project Elements

**Crew Module**
Crew and Cargo Transport

**Launch Abort System**
Emergency Escape During Launch

**Service Module**
Propulsion, Electrical Power, and Fluids Storage
Orion Aerosciences Trajectory Space

Transonic, Supersonic
High Q, High Drag Abort
Mach 0.9 to 4, 30k to 80k ft alt

Hypersonic Abort
LAT Sep
After control motor burnout
Forward Heat Shield Sep
Parachute System Deploy
Heat Shield Sep

Entry Heating Phase
Service Module Jettison

LAT Sep
Plume Heating
Skip Entry

Ascent Abort Separation Environment
1st Stage Abort
2nd Stage Abort

Atmospheric Entry Environment
Skip Entry
Direct Entry
Mach 25
Entry Heating Phase

Main Chutes
Mach ~0.1

LAT Nominal Jettison
Mach ~7.5, ~200k ft alt

On-Orbit Plumes Environment

Pad Abort

Recovery Systems Deploy

Turn-around maneuver

Turn-around maneuver
LAS Freestream – Jet Interaction

- Attitude Control Motor (ACM) Jets
- Abort Motor (AM) Plumes
- ACM/AM Jet Interaction
CFD “Schlieren” of Plume Interaction

Launch Abort Vehicle
Time = 0.0963 sec
Stuart Rogers/NASA/ARC/TNA, Thu Apr 22 13:18:23 PDT 2010
Integrated Abort Vehicle Wind Tunnel Test
CFD vs. Pressure Sensitive Paint

Simulation – Computational Fluid Dynamics

Mach 1.3 Pressure Distribution

Experimental - Pressure Sensitive Paint
CFD vs. PSP vs. Pressure Tap
Entry Physics

- Bow Shock
- Viscous Interaction
- Shock Layer Radiation
- Dissociation & Ionization
- Surface Recombination
- Ablation & Recession
- Boundary Layer Transition
- Shear Layer
- Ablation Product Contamination
- Separation
- Afterbody Heating
- RCS Interaction
- Recompression
- Continuum Breakdown
Crew Module Backshell

Docking Windows
Roll Jets
Pitch Jets
LAS Attach Well (1 of 6)
Yaw Jets
### Orion Heating Environments

<table>
<thead>
<tr>
<th>Smooth Body Convective</th>
<th>Laminar</th>
<th>Turbulent</th>
<th>Compression Pad CFD</th>
<th>Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>V = 10.98 km/sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H = 60.75 km</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>α = 157°</td>
<td></td>
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</tr>
</tbody>
</table>

- **Single Roll jet, α = 18°**
  - Jet Momentum Ratio ~ 1.2 x 10^-4
  - run 48, Re = 0.21E6
  - Jet Momentum Ratio ~ 3.6 x 10^-4
  - run 47, Re = 0.21E6
  - run 49, Re = 0.73E6

- **RCS Interaction**

- **Ascent**
Characterized by Knudsen number: \( Kn \equiv \frac{\lambda}{L_{\text{Ref}}} \)

- Continuum Flow: \( \sim 0.01 \) Kn
- Transitional Flow: \( \sim 100 \) Kn
- Free Molecular Flow: Kn
RGD Flow Regimes

Computed Using NASA’s Direct Simulation Monte Carlo (DSMC) Analysis Code (DAC) Software

Near Continuum                      Transitional                      Free Molecular

Undisturbed freestream molecules

Molecules that have collided with the surface

Molecules that have been indirectly influenced by the surface
Rendezvous and Docking Plume Impingement

Scarfed Jet
solid surface
solid surface
Unscarfed Jet

Plume Source Boundaries
Additional DSMC Applications

ISS On-orbit Aerodynamics

Hubble Servicing Mission

Interplanetary Aerobraking Aerodynamics

X-38

Genesis
Stardust
Mars - Pathfinder

NASA
Orion Parachute System Development
Capsule Wake Modeling

Reynolds Averaged Navier Stokes

Detached Eddy Simulation
NASA’s Top Aerosciences Challenges

Aerodynamic Predictions
- Aero-plume interactions
- Massively separated flow behind bluff bodies
- Strong shockwave boundary layer interactions
- Aeroacoustic and buffet environments
- Fluid-structure interactions

Aerothermodynamic Predictions
- Boundary layer transition
- Protuberance and cavity heating
- Ablative thermal protection system performance
- Shock layer radiative heating

Uncertainty quantification and validation remain generic foundational challenges!
Forcing Function

- Transition from steady to unsteady simulations
- Increased parametric analysis
- More complex geometries
- Increase computational capacity

Anticipated Response

- Time accurate, low dissipation, higher order methods
- Higher order turbulence modeling
- Automated surface and volume grid generation
- Adjoint methods for parameter sensitivity and solution adaptation
- Coupled multi-physics simulations
Shift in Modeling Maturation

Develop → Validate → Apply

Pros:
• Logical
• Systematic
• Ensures end-users have a product that is ready for release

Cons:
• Developers can be separated from users
• Always a struggle to advocate for resources to proceed in this mode

Develop → Apply → Validate

• NASA has seen explosive growth in the application of CFD
• Extremely difficult to be fully validated for every application
• Insufficient validation leads to large data uncertainties and design margins
• Acquiring test data to validate analysis becomes a project priority
• Roadmaps for future modeling and simulation development become more clear
Innovation and Inclusion

Visions of the Future

Does it WORK?

Is it Flight-Ready?

TRL – Technology Readiness Level
We Must Not Ever Forget…

Space Shuttle Challenger Crew
Lost January 28, 1986

Space Shuttle Columbia Crew
Lost February 1, 2003
Thank you.