Aerocapture, Entry, Descent and Landing (AEDL) Human Planetary Landing Systems
Section 10, AEDL Analysis, Test and Validation Infrastructure

Presented by J. O. Arnold for the APIO Human Planetary Landing System Study Team


May 4, 2005
“Test as you fly, fly as you test”

“Train as you fly, fly as you Train”

“If you are not ready, do not fly”

“Mars Exploration program strategy must account for a reasonable number of failures and be robust against their happening”

“Programs have the responsibility to ensure that projects provide data/information for the health of future projects, e.g. flight instrumentation to understand failures and performance”

“No ground facility can simultaneously duplicate the altitude, velocity and scale of human flight vehicles/systems”

“You told the boss (1st president Bush) what it cost ($400 B) to do the human Mars mission and it cost you the program, plus there was no congressional support”

“A sustained Mars Program must sustain public interest”

“I wish I had come to the NASA Ames and Langley Research Centers earlier”

“One strike, and you are out”

---

1 Tom Young/Mars Program Independent Assessment Team (MPIAT)

2 Harrison Schmitt, Apollo Astronaut

3 Dean R. Chapman/NASA Ames/Stanford

4 Hans Mark

5 Tony Spear, Mars Pathfinder Project Manager
• Listing of critical capabilities (knowledge, procedures, training, facilities) and metrics for validating that they are mission ready

• Examples of critical capabilities and validation metrics: ground test and simulations

• Flight testing to prove capabilities are mission ready

• Issues and recommendations
## Capabilities

<table>
<thead>
<tr>
<th>Knowledge Facilities*</th>
<th>Model/codes</th>
<th>Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10.1 Systems Engineering</strong></td>
<td>Physics based/cost</td>
<td>- <strong>Intercenter teams</strong>,+ Industry + Academia</td>
</tr>
<tr>
<td>1-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10.2 G,N &amp; Control (flexibles)</strong></td>
<td>Real time code</td>
<td>- Simulation</td>
</tr>
<tr>
<td>1-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10.3 Aerodynamics</strong></td>
<td>Aero databases;</td>
<td>- Wind tunnels: (Hyper/sub/trans/sonic)</td>
</tr>
<tr>
<td>1-5</td>
<td></td>
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</tr>
<tr>
<td><strong>10.3.1 Aeroelasticity</strong></td>
<td>Thermo-chemical noneq CFD codes; Coupled CFD/Finite Element Analysis</td>
<td>- Ballistic range. Quiet tunnels</td>
</tr>
<tr>
<td>for flexibles</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>10.3.2 Aero + Propulsion</strong></td>
<td>Real-Gas Aero +</td>
<td>- Wind tunnel with .</td>
</tr>
<tr>
<td>1-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(retro and reaction control system)</td>
<td>Propulsion CFD; combined propulsion Ground effects</td>
<td></td>
</tr>
</tbody>
</table>

* Red colored text: critical issue under threat e.g., potential termination, demolition/ closure / mothballing
**Blue colored text: special issue or no capability
*** Metrics: 1. (code to code or model to model fly-offs), 2. (comparison to ground test) 3. pre/post flight test comparisons, 4. (bi-annual peer review) and 5. Proficiency of existing corps as established from flight test and NRC evaluation of education programs for the next generation of explorers, and 6. Capability to replicate previous “landmark” decisions
### Capabilities (cont.)

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Model/codes</th>
<th>Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Facilities</strong>*</td>
<td><strong>Metrics</strong>*</td>
<td></td>
</tr>
<tr>
<td>10.4 Aerothermodynamics</td>
<td>Real-gas/non equ. CFD: Coupled convective and radiative heating; Ionized flow, transition to turbulence models; turbulence models; afterbody heating; rarefied flow/transitional codes</td>
<td>Wind tunnels, Shock Tubes, Shock Tunnels, Ballistic range, Rarefied flow tunnels, Quiet tunnels</td>
</tr>
<tr>
<td>10.5 Human Rated Thermal Protection Systems (TPS)</td>
<td>Materials specifications; flow/materials coupling (convection/radiation/unsteady); scalability (e.g. gaps bonds; seals, e.g.)</td>
<td>Arc Jets, Combined (conv. +radiation + unsteady flow), Materials, TPS pilot plants with manufactureability, Full scale TPS manufacture, environments (shake, vac, bake, etc)</td>
</tr>
</tbody>
</table>

*Note: All facilities and metrics are specific to NASA's Advanced Planning & Integration Office.*
<table>
<thead>
<tr>
<th>Knowledge Facilities*</th>
<th>Model/codes</th>
<th>Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10.6 Engineering Flight</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5 Sensors</td>
<td>Press, Temp, heat</td>
<td>- Arc jets</td>
</tr>
<tr>
<td>(rad/convect); TPS recession sensors; accelerometers; gyros strain; flutter sensors, flush air data system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **10.7 Terminal descent/land** |
| 1-5 Engineering models based on physics-based codes and extensive tests for combined effects incl. dynamics with correct gravity effects, etc.; Real time hazard recog-, inition, terminal GN & C |
| - Large wind tunnel (NFAC) - Large Prop. Test (White Sands) - GRC (Plum Brook)/AEDC - Helicopter / balloon air drop/ sounding rockets - China Lake (Rocket sled) - lidar and radar - Large Environmental Test facility (shake, bake, etc.) |

Facility (ARC)
### Capabilities (concluded)

<table>
<thead>
<tr>
<th>Knowledge Metrics***</th>
<th>Model/codes</th>
<th>Ground Facilities/data source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10.8 Engineering Model of AEDL Planetary Environment</strong></td>
<td>Real time updatable models based on robotic missions: rock distribution - Odyssey (atm/rocks)</td>
<td>1-5</td>
</tr>
<tr>
<td><strong>10.8.1 Atmospheric predictions</strong> (structure {Press, Temp.}, turbulence, winds) and surface properties (dust, mesoscale wind models; toxicity, strength, slopes, terrain, hazards) global circulation models; global dust transport models</td>
<td>Atmospheric predictions models; 30 cm imagery; - TBD future atm. orbiter.</td>
<td></td>
</tr>
<tr>
<td><strong>10.8.2 Pico/nano satellites and probes</strong></td>
<td>Pico/nano satellite - None additional for to provide just-in-time update information and atmospheric pico/nano sats./probes probes to update models</td>
<td></td>
</tr>
<tr>
<td><strong>10.9 Astronaut AEDL performance at Mars g-profiles, etc.</strong> Human-machine-robotic interface</td>
<td>Human perf. engineering - China Lake Type rocket sled (with tailored g-profiles) - High performance aircraft - ARC Vertical Motion - ARC Bed rest facility - ARC Future Flight Central - ARC Vestibular Research</td>
<td>1-5</td>
</tr>
</tbody>
</table>

**Facility**

- Simulator
• Listing of critical capabilities (knowledge, procedures, training, facilities) and metrics for validating that they are mission ready

• Examples of critical capabilities and validation metrics: ground test and simulations

• Flight testing to prove capabilities are mission ready

• Issues and recommendations
## Wind Tunnels: Apollo era vs. 2005

### Government (NASA and military)

<table>
<thead>
<tr>
<th>Year</th>
<th>Transonic</th>
<th>Supersonic</th>
<th>Hypersonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>24</td>
<td>31</td>
<td>40</td>
</tr>
<tr>
<td>2005</td>
<td>10</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

Large subsonic tunnels ARC 40’x80’ & 30’x60’ at LaRC 1965 vs 40x80x120 (NFAC) 2005 (may be needed for parachute tests)

### Commercial

<table>
<thead>
<tr>
<th>Year</th>
<th>Transonic</th>
<th>Supersonic</th>
<th>Hypersonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>10</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>2005</td>
<td>7</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>

Quiet tunnels - new capability developed in the 1980/1990’s

* Does not include propulsion, arc-jet, or ballistic range facilities

Hypersonic Aero/ Aerothermodynamics
Wind Tunnel Testing

Aerodynamic and Aerothermodynamic phenomena produced in wind tunnel tests

Results of Hypersonic Wind Tunnel Testing:

- Aerodynamic forces and moments
- Control surface effectiveness
- Surface pressure distributions
- Laminar and turbulent convective heating distributions
- Boundary-layer and shear-layer transition correlations
- Reaction control system (RCS) jet effectiveness and interactions
- Mach number, Reynolds number, shock-density ratio (real-gas simulation) effects
- Configuration parametric effects
- CFD validation/verification data
Recent Hypersonic W.T. tests

Attached ballute aeroelasticity

Wake shear layer payload impingement

Heat-shield cavity boundary-layer transition

Trailing ballute heating and flow-field

Unsteady Flow
Ballistic Range: Any Test Gas

- Aerodynamic forces and moments in free flight, no sting effects and true real gas effects
- Afterbody flow simulations without sting effects
- Laminar and turbulent convective heating distributions
- Transition to turbulent flow in real gas, on real surfaces in a quiet environment
- Mach number, Reynolds number, shock-density ratio true real gas
- CFD validation/verification data

- **Disadvantage: Small scale models**
Every US entry vehicle flown at Mars has used the basic Viking shape, but we do not fully understand its aerodynamic performance. Lack of understanding is disturbing.

- Lack of adequate engineering flight data clouds this issue

The Shuttle Orbiter pitching moment was mis-predicted despite thousands of hours of wind tunnel testing and early CFD. With today’s CFD and wind tunnel testing can we predict aerodynamic performance for a new shape?

Grand Aerodynamics Challenge: Choose a likely new shape (based on systems engineering) for a human rigid and flexible Mars aeroshells.

- With no cross-talk, multiple groups (NASA, academia and industry) predict aerodynamics with emphasis on pitching moment, trim angle of attack and dynamics of the flexible, deformable aeroshell for air and Mars atmosphere.
- Measure aerodynamics in wind tunnels and ballistic ranges.
- Conduct balloon/rocket hyper/super/trans/subsonic flight test with a properly instrumented, scaled flight vehicle.
- Grade teams against pre-determined numerical score

Properly instrument MSL for 2011 flight. Review Viking aero data base. Examine post-flight data. Grade same teams against pre-determined numerical score.

Successful efforts on the two prior bullets could make a significant start to validate that our capability is ready for human-critical project development.
### Apollo peak stagnation point heating

<table>
<thead>
<tr>
<th>Vel, km/sec</th>
<th>$q_c$, W/cm²</th>
<th>$q_r$, W/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.7</td>
<td>39</td>
<td>0.0</td>
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<tr>
<td>11.2</td>
<td>185</td>
<td>336</td>
</tr>
<tr>
<td>12.5</td>
<td>241</td>
<td>1283</td>
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</tbody>
</table>

Radiative heating is an issue for large, blunt bodies at higher velocities for Mars and Earth entry as is the need to develop coupled radiative/convective codes.
Shock Layer Radiation

Transition to Turbulence

Coupling between radiation/TPS/fluids

Non-continuum flows and aeroelastic effects for low $\beta$

Gaps are addressed via:
- Mission-specific uncertainty analysis to rank importance
- Ground testing tailored to reduce key uncertainties
- Model development based on test results
- Model validation with flight instrumentation
Shock Tube Radiation Physics for Huygens Titan Entry

Results of Shock Tube Testing

- Provides nominal 1-Dimensional flow with actual rarefied flow gas kinetics, chemical reactions and radiative properties that occur for flight system at given free stream conditions.

- Electric Arc Shock Tube (EAST) can simulate Mars, Earth, Outer Planet and Titan atmospheric gases over all velocity ranges of interest.

- Provides rate constants for basic gas processes and properties needed for real-gas CFD codes.
Ablative Thermal Protection System

Energy management through material consumption

Given: Vehicle environment
Max. bondline temperature
R & D provides:
- Materials Specification
- Materials response models
- Scalability
- Manufacturability.

Gaps
- Apollo ablator no longer available
- Extremely small No. of researchers available
Ballute Thermal Protection System using Tailorable, Advanced Blanket Insulation (TABI)
Arc Jet and Test article
## Arc Jet Simulation: Missions

“In the 1960’s hundreds of arc jets were operational - this is the remainder” J. Hartman (ARC)

<table>
<thead>
<tr>
<th>Mission</th>
<th>SOMD (Shuttle)</th>
<th>Capsule LEO/Lunar Return</th>
<th>Mars (Viking, Pathfinder, MER)</th>
<th>Mars (Human and cargo)</th>
<th>Venus (Pioneer Venus)</th>
<th>Gas Giants (Galileo, Jupiter Multi-Probe)</th>
<th>Human Mars Return</th>
</tr>
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<tbody>
<tr>
<td>Gov. Facility</td>
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<td>Heat rate, W/cm²</td>
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<td>20 – 80 (convective)</td>
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<tr>
<td>20 – 350 (convective / combined)</td>
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<tr>
<td>25 – 150 (convective)</td>
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<td>Up to approx. 400 for Triconic* (combined)</td>
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<td>6,000 – 12,000 (combined)</td>
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<tr>
<td>35,000 – 50,000 (combined)</td>
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<tr>
<td>800 – 2,000 (combined)</td>
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<tr>
<td>Pressure, atm</td>
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<tr>
<td>0.02 – 0.05</td>
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<tr>
<td>0.02 – 0.5</td>
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<td>0.05 – 0.25</td>
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<td>0.05 – 0.25</td>
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<td>4 – 10</td>
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<td>5 – 10</td>
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<tr>
<td>0.5 - 1</td>
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</tr>
<tr>
<td>ARC</td>
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<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
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<tr>
<td>JSC</td>
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<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
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<tr>
<td>AEDC</td>
<td></td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
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<tr>
<td>CIRA</td>
<td></td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
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<td>D</td>
</tr>
</tbody>
</table>

- Capable of full range with existing facilities
- Capable of partial range with existing facilities
- Gap identified: Capability not available
- Potential exists but not demonstrated

*For Triconic. Much larger for Blunt Ellipseld

Combined = radiative + convective. This is a gap for human missions at both Mars and Earth Return
Rigorous Landing Test Program Will be Required and Includes tests such as:
- Landing dynamics
- Control system validation
- Pilot training
- Payload egress and deployments
- Emergency procedures
- Simulated ascent vehicle launches

The gantry built for testing the Apollo lander (Langley’s IDRF) is the ONLY existing facility capable of testing future human landers (lunar or Mars).

Little modification or upgrading required to test these systems
- Up to 60,000 kg landers currently envisioned in the reference missions.
- 60,000 kg in 1/6 gravity \( \rightarrow \) 22,000 lbs
- IDRF could handle up to 60,000 lb
- Customization for vehicle and test specific needs will be required
Quick Facts
- Length: ~ 400 ft
- Width: ~ 280 ft (at bottom), (100 ft top)
- Height: ~ 240 ft

Originally built for:
- 30,000 pound lander, 28 ft/sec (limited by the bridge)
- Bridge upgrade to 60,000 lb ($250k) stopped when facility was closed.
- Each A frame is rated to 100,000 pound load.

Currently “Closed”
- Primarily means no maintenance being done
- $200,000 averaged yearly maintenance cost

Slated for Demolition
- NASA LaRC’s Structures and Materials branch has determined that the facility should be demolished.
- It is a National Historic Landmark
  - In Sept 04 NASA submitted public notice of demolition intention
  - Public hearings being held to approve the demolition plan
- Raytheon has been discussing take-over plans

THIS IS A MUST-HAVE FACILITY FOR HUMAN SURFACE MISSIONS!

Point of Contact:
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ph: (757) 864-4147
fax: (757) 864-8547
LaRC Full-Scale Impact Dynamics Research Facility
• Listing of critical capabilities (knowledge, procedures, training, facilities) and metrics for validating that they are mission ready

• Examples of critical capabilities and validation metrics: ground test and simulations

• **Flight testing to prove capabilities are mission ready**

• Issues and recommendations
## Flight Tests 2008 - 2015

<table>
<thead>
<tr>
<th>Class flights</th>
<th>Validates</th>
<th>No.</th>
</tr>
</thead>
</table>
| Earth, suborbital ballon, ballon + rocket, sounding rocket and piggyback out-of-orbit | - Aerodynamics  
- Toward human rated TPS  
- Engineering Sensors  
- Flexible aeroelasticity/control | Eight |
| Earth, Shuttle/Station | - Test Human AEDL Perf. | 3-4 |
| Mars, Instrumented MSL | - Engineering Sensors / G,N&C  
- Transition to Turbulence (Mars)  
- Viking aerodynamics | One |
<p>| Mars, Robotic scale flights to prove aero. capture when possible/Affordable - still being discussed | - Aerocapture System | One |
| Earth, instrumented CEV | - GN &amp; C, aero/aerothermal human rated TPS for Earth orbital entry and engineering inst. | Two |</p>
<table>
<thead>
<tr>
<th>Class</th>
<th>Validates</th>
<th>No. flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth, Instrumented Aero. Capture From Lunar return</td>
<td>Aerocapture into Earth orbit for Mars return to orbiting quarantine station</td>
<td>Two</td>
</tr>
<tr>
<td>Mars, Small scale (human configuration) A/C + EDL</td>
<td>Aerocapture System EDL System</td>
<td>Two</td>
</tr>
<tr>
<td>Earth, full scale</td>
<td>DL, Super/trans/subsonic and touchdown systems</td>
<td>Five-Seven</td>
</tr>
<tr>
<td>Mars, Instrumented Astrobiology Lab</td>
<td>EDL</td>
<td>One</td>
</tr>
<tr>
<td>Moon, CEV Spiral 2 accomplished</td>
<td>DL</td>
<td>All</td>
</tr>
</tbody>
</table>
Example of Properly Instrumented Flight Experiment
Aeroassist Flight Experiment (AFE): Vehicle Environment, TPS, GN&C, etc.

Forebody instrumentation

Base region instrumentation

- BPHE Tiles
- RAME
- Camera
- Pressure tap

- Wall Catalysis
- ATPM
- Total radiometer
- High resolution spectrometer
- Heatshield performance
- Pressure distribution
- Air data system
- Thermocouple
- WCE pressure
- WCE thermocouple

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## Flight Tests 2020 - 2036

<table>
<thead>
<tr>
<th>Class</th>
<th>Validates</th>
<th>No. flights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeat tests TBD</td>
<td>Acceptable</td>
<td>TBD</td>
</tr>
<tr>
<td>(planned failure and train mission implementers)</td>
<td>mission risk</td>
<td></td>
</tr>
<tr>
<td>Mars, Full scale (cargo configuration)</td>
<td>EDL for Mars 1st</td>
<td>One</td>
</tr>
<tr>
<td></td>
<td>Crewed Landing</td>
<td></td>
</tr>
<tr>
<td>First Human Landings</td>
<td>Staggered by 2 years</td>
<td>Two</td>
</tr>
<tr>
<td></td>
<td>or on same opportunity</td>
<td></td>
</tr>
</tbody>
</table>
Team 7: Human Planetary Landing Systems Section 10.0 Roadmap

Key Assumptions:
- 2006 MRO Surface site Characterization
- Begin orbiter-based Mars Atmosphere Recon.
- Baseline Mars DRM under CM
- Pin point landing at Mars (MSL)
- 2014 Human Lunar Missions

Capability Roadmap 7: HLPS

10.1 Systems Engr
- Select tools
- Validate/upgrade tools
- Validate with CEV results
- Sub scale Earth flight tests/CEV
- Select tools
- Validate/upgrade tools
- Validate with CEV results
- Sub scale Earth flight tests/CEV
- Select tools
- Validate/upgrade tools
- Validate with CEV results
- Sub scale Earth flight tests/CEV

10.2 GN & C
- Select Algorithms
- Hyper-Terminal
- Fly-offs
- Validate/Earth/ground tests
- Hyper-Terminal
- Validate/Earth/ground tests
- Hyper-Terminal
- Validate/Earth/ground tests

10.3 Aerodynamics
- Select Codes
- Validate codes - new gnd. test
- Sub scale Earth flight tests/CEV
- Validate codes - new gnd. test
- Sub scale Earth flight tests/CEV
- Validate codes - new gnd. test
- Sub scale Earth flight tests/CEV

10.4 Aerothermodynamics: Identical flow as for Aerodynamics

10.5 TPS
- Rebuild personnel base
- Identify Facilities
- Sub scale Earth flight test and CEV Lunar
- Flexible TPS for human Mars
- Identify Facilities
- Sub scale Earth flight test and CEV Lunar
- Flexible TPS for human Mars
- Identify Facilities
- Sub scale Earth flight test and CEV Lunar
- Flexible TPS for human Mars

10.6 Eng. Flight Sensors
- Build Personnel
- AEDL Instrumentation Suite completed
- AEDL Instrumentation
- Earth subscale & (MSL)
- AEDL Instrumentation
- Earth subscale & (MSL)
- AEDL Instrumentation
- Earth subscale & (MSL)

10.7 Terminal Descent
- Define Options
- Sys. Eng. fly offs/work
- Define Options
- Sys. Eng. fly offs/work
- Define Options
- Sys. Eng. fly offs/work

10.8 Eng. Models of Mars for Human AEDL --->
- First model & assessment of high
- First model & assessment of high
- First model & assessment of high

10.9 Astronaut EDL perform.
- Define Test/train Approach
- Complete testing with shuttle/station
- Complete testing with shuttle/station
- Define Test/train Approach
- Complete testing with shuttle/station
- Complete testing with shuttle/station

Major Event / Accomplishment / Milestone
- Ready to Use
- Decommission TBD facilities
- Decommission TBD facilities

2005 2010 2015
• Listing of critical capabilities (knowledge, procedures, training, facilities) and metrics for validating that they are mission ready

• Examples of critical capabilities and validation metrics: ground test and simulations

• Flight testing to prove capabilities are mission ready

• Issues and recommendations
Issues

- Knowledge capture/training across generations of implementers (technologists project/program personnel, leadership, managers, crew {medical, pilot, science: geology, biology, etc.})

- Sustaining/developing facilities, technologies and tools across three decades

- Independent review, analysis and assessment capability

- Early Technical Interchange Meetings (TIMs) and facility review required to ensure that facilities are not closed prematurely and that new facility capabilities are clearly understood during the NASA transformation, e.g. Aerodynamics and Aerothermodynamics CFD validations
Recommendations

• Review/adopt the best practices/lessons/program funding approaches learned from the Apollo, Viking, Shuttle, ISS and current Mars program as initiated after Mars ‘98

- Example: in the 60’s, 70’s and 80’s NASA separately (and adequately) funded facilities, technology programs, flight projects and salaries for core competencies. Flight program/projects only paid facility “occupancy” fees. Technologists were not beholden to projects for funding. Independent, expert opinions were critical for project reviews. New enabling technologies were adopted.

• In the late 80’s/early 90’s an ad-hoc “Aeroassist Working Group” was formulated by Langley, Ames, JSC and MCFC, later joined by JPL. Industry/Academia have played roles from time-to-time. In the one-NASA spirit, leadership rotates from center to center. This group has been successful in securing funding for its activity.

-This group should be re-invigorated and expanded to include all aspects of AEDL for both human and robotic missions. Its charter should be to facilitate multi-generational knowledge, tools and facilities necessary for agency missions for the next 3-4 generations. It must include early involvement by academia (next generations) and industry (system builders).

• This expert group should be tasked to conduct TIMs and facilities reviews to understand/advocate for facilities needed by the HPLS for the next 3 decades
Facility Details
Langley Aerothermodynamics Laboratory Flight Simulation Range and Test Techniques

measurement Techniques
Aerodynamic Forces/Moments
Aeroheating via Phosphor Thermography
Surface Pressure
Flow Structure via Schlieren Photography
Surface Streamlines via Oil Flow

31-Inch Mach 10 Air Tunnel
\( \gamma_{eff} = 1.38, \frac{p_2}{p_\infty} = 5.9 \)

20-Inch Mach 6 Air Tunnel
\( \gamma_{eff} = 1.10, \frac{p_2}{p_\infty} = 5.3 \)

20-Inch CF4 High Mach Aerodynamics Simulator
\( \gamma_{eff} = 1.13, \frac{p_2}{p_\infty} = 12 \)
Apollo development (1962-1965)

- Estimated 6200+ hours (155 x 40-hour work-weeks or 3 work-years) of wind tunnel testing conducted on Apollo entry and escape configurations.
- Test plan called for use of at least 33 facilities: 22 transonic, supersonic, or hypersonic wind tunnels, 8 high-enthalpy shock tubes or arc jets and 3 free-flight ballistic ranges.

• Space Shuttle (1969 through 1984)

- Shuttle development required over 100,000 hours of wind tunnel testing (2500 x 40-hour work-weeks or 48 work-years) in more than 60 wind tunnels.
- Shuttle was far more complex than Apollo capsule: winged vehicle with external fuel tanks and boosters vs. simple capsule.
• Robotic exploration programs are more risk tolerant than human-rated programs
• Robotic entry systems are simple geometries with no control surfaces
• Every human-rated entry system has been wind-tunnel tested across the speed range
• Many of these tunnels have already vanished
• Remaining tunnels are threatened with closure
Sub / Tran / Supersonic Wind Tunnel Uses

- Configuration development
- Validation of numerical techniques
- Multi-body interactions (launch stack)
- Reaction Control System (RCS)
  \textbf{interactions with flow field}
- Dynamic stability (forced oscillation)
Boeing/AFOSR Mach-6 Quiet Tunnel

- Mach 6 in 9.5-in.-dia. nozzle at $10/shot
- Operates from $Re=1E5/ft.$ to $6E6/ft.$
- Quiet flow to about $0.5E6/ft.$, plans to $3E6/ft.$
- Usually clean air, could run $CO_2$

Hot wires (have been calibrated in $CO_2$), Hot films
Temp. paints, laser differential interferometer, controlled perturbers for stability experiments

All Clean Stainless Steel from Second-Throat Section Upstream
Unique Low-Noise Flow due to Laminar Nozzle-Wall Boundary Layer
(Slow) Gate Valve

17.5-in. Driver Tube, 122.5-ft. long

Bleed-Slot Suction Plumbed Both Through Fast Valve to Tank and to Diffuser

Max. 300 pslg (21.7 bar, abs.) and 392F (200C). One 10-s. run per hour. About $10/run operating cost.
Eight openings for windows (blue), presently one 7x14-inch window and one pair of 5-in.-dia. windows. Auto. traverse in vertical centerplane for wires and pitot probes. Green marks nominal low-noise uniform flow.

300 psig stagn. = 6.17E6/ft, 150 psig = 3.08E6/ft. Designed to be quiet to exit at 150 psig stagnation.
GRC Plumbrook Quick Facts

• Overall Functions:
  – Sustains high vacuum
  – Simulates solar radiation (400-kW arc lamp / 4-MW quartz heat lamp array)
  – Produces cold environments via cryogenic cold wall (-320 °F)
  – Provides a high degree of vibration isolation for sensitive optical tests

• Test Chamber
  – 100-ft diameter by 120-ft.-tall test area
  – Chamber penetrations for power, data acquisition, and high-pressure liquids and gases
WSTF Overview

- Constructed in 1962-64 to support project Apollo
- Component of JSC Houston
- Occupies 28 square miles - SW Corner of WSMR

Aerial View Looking North
Unique WSTF Capabilities

- Simulated altitude testing of full-scale integrated hypergolic propulsion systems
- Agency facility for hypervelocity impact testing, including accommodations for hazardous targets
- Capability for all materials testing defined by NASA Standard 6001 (NHB 8060.1C)
- Design and hazards analysis of oxygen and hydrogen systems
- Large-scale explosion testing of hypergolic, cryogenic, and solid propellants
- Component testing in high temp/high flow gaseous oxygen and hydrogen
Full-scale Shuttle OMS pod installation at vacuum test cell TS-403
Cassini - Saturn orbit insertion engine glows during 3 hr. 20 min. continuous firing
The Vestibular Research Facility (VRF) located at NASA Ames Research Center houses approximately 2,000 square feet of laboratory space and 1,000 square feet of office space. The VRF provides a centrifuge and two types of linear sleds for ground-based studies of vestibular function. Support laboratories and office areas complete the facility. Both flight and ground-related science questions may be addressed using either humans or animals as subjects.

The 30-f Linear Sled of the Vestibular Research Facility can be used to examine otolith-ocular-perceptual responses humans (the reinterpretation of otolith signals driving both perception and gazer stabilization reflexes is a major component of human adaptation to altered gravity). It consists of a carriage mounted on an ultra smooth horizontal 10-m granite slab. The carriage is supported by low-pressure air bearings that float ~2.5 microns above the granite surface to provide a silent, frictionless linear motion. Artifacts due to mechanical vibration and auditory noise are therefore eliminated. The sled is human-rated and instrumented to deliver visual stimuli in conjunction with the linear-acceleration vestibular stimulus while recording eye movements, arm m
The 20-G Centrifuge located at NASA Ames Research Center can be used to evaluate the effects of altered gravity, and G-load transients, and rotational acceleration on humans (in addition to examining G-effects per se, this device can be used to evaluate candidate AG regimes that astronauts may also be exposed to). A cab mounted at the end of the 6.8m-diameter rotating arm contains a modified jet-fighter ejection seat. The centrifuge is human-rated and instrumented to deliver a variety of visual stimuli at a range of possible static g levels (usually up to 3g; capable up to 20g) while recording eye movements, limb movements, and perceptual responses.
The Vertical Motion Simulator (VMS), which is located in the Flight and Guidance Simulation Laboratory (SimLab) at NASA Ames Research Center, is renowned for its efficient production of high-fidelity, fixed and moving base, real-time, piloted flight simulations of aerospace vehicles. Engineers can customize the system to simulate any aerospace vehicle, whether existing or in the design stage. Existing vehicles that have been simulated include a blimp, helicopters, fighter jets, and the Space Shuttle Orbiter. One aircraft being designed that may be simulated at the VMS is a next-generation transport capable of flying in near-earth orbit. Simulations occur with high fidelity; that is, the simulator reproduces flight characteristics with a high degree of accuracy. This entails delivering realistic cues to the astronaut/pilot in real time.