Executive Summary of Propulsion on the Orion Abort Flight-Test Vehicles

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Outline

- Introduction
- Launch Abort System (LAS) Abort Motor (AM)
- LAS Attitude Control Motor (ACM)
- LAS Jettison Motor (JM)
- Crew Module (CM) Reaction Control System (RCS)
- Abort Test Booster (ATB) SR118
- Conclusion
Introduction
Constellation, Orion, and the AFT Program

• Constellation Program – Background
  – Continue U.S. human transport capability to the International Space Station (ISS), after the retirement of the Space Shuttle
  – Return humans to the Moon, and eventually take them to Mars
  – Included development of the Ares I rocket, Ares V rocket, Orion Crew Exploration Vehicle (CEV), and Altair lunar lander.

• Orion CEV – Background
  – The Ares I architecture includes the Orion CEV.
  – Consists of: the Launch Abort System (LAS), Crew Module (CM), Service Module (SM), and Spacecraft Adapter (SA).
  – Focus: LAS capability.

• Orion Abort Flight Test (AFT) program
  – Purpose: Conduct a series of flight tests in several launch abort scenarios to certify Orion LAS capability.
  – Responsibility: The NASA Orion Flight Test Office (FTO), located at NASA JSC.
LAS Motors, and the Orion AFT Flight Manifest

- LAS includes several subsystems, three of which are solid rocket motors: the Attitude Control Motor (ACM), the Jettison Motor (JM), and the Abort Motor (AM)
- Conducted a significant review of Apollo architecture, including the Launch Escape System (LES)
- Review of the Apollo Flight Test Program facilitated the initial creation of the Orion AFT Flight Manifest
  - Pad Abort (PA) and Ascent Abort (AA) flight tests were planned at the White Sands Missile Range (WSMR), NM

<table>
<thead>
<tr>
<th>Flight Test (in chronological order)</th>
<th>Test Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA-1</td>
<td>Abort from launch pad</td>
</tr>
<tr>
<td>AA-1</td>
<td>Maximum dynamic pressure abort</td>
</tr>
<tr>
<td>PA-2</td>
<td>Abort from launch pad with flight-like abort trajectory</td>
</tr>
<tr>
<td>AA-2</td>
<td>Transonic abort</td>
</tr>
<tr>
<td>AA-3</td>
<td>Off-nominal maximum dynamic pressure abort</td>
</tr>
<tr>
<td>AA-4</td>
<td>High altitude abort</td>
</tr>
</tbody>
</table>
Introduction
PA-1, and Planned Future Flight Test Vehicles

- The Orion FTO successfully completed PA-1
- AA-1 was to include a CM cold gas Reaction Control System (RCS)
- All AA flights were to include an Abort Test Booster (ATB), with an SR118 motor
LAS AM Overview, PA-1
Purpose, Design, and Development

- **Purpose:** Provide the thrust force necessary to propel the LAV safely away from a failed booster.
  - Thrust is balanced between the desire to escape quickly, and the human tolerance for acceleration.
- **Developed by:** Alliant Techsystems, Inc. (ATK) in Utah.

High performance turn-flow motor featuring 4 nozzles at an efficient 25 degrees cant
- Total flow turn = 155 degrees

Convergent manifold configuration stabilizes flow, balances thrust, and maximizes performance

High weight high performance carbon fiber composite case

High burn rate propellant in a high surface area grain configuration provides required abort performance

High performance pyrogen igniter

LAS AM manifold during hydroproof testing at ATK
• Subscale Tests (SST) and a full scale Static Test (ST) were completed.

<table>
<thead>
<tr>
<th></th>
<th>SST-1</th>
<th>SST-2</th>
<th>ST-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Fire Test Date</td>
<td>26Jun07</td>
<td>10Aug07</td>
<td>20Nov08</td>
</tr>
</tbody>
</table>
| Description              | Subscale test series:  
                           | • ~1/4-scale of the geometry  
                           | • ~1/25-scale of the overall thrust  
                           | First full-scale test |
| Test configuration       | Horizontal | Vertical, upside-down |
| Nozzle configuration     | • Two reverse flow nozzles  
                           | • 180 degrees apart  
                           | • Canted 25 degrees  
                           | • Four reverse flow nozzles  
                           | • 90 degrees apart  
                           | • Canted 25 degrees |

• PA-1 LAS AM Performance:
  – Nominal maximum thrust: ~500,000 lbf
  – Action time: ~7 seconds
• Purpose: Provide pitch and yaw control to optimize the LAV abort trajectory.
  – Boost phase: Utilized for LAV directional control during ascent vehicle separation, and stabilizes the LAV during LAS AM operation.
  – Sustain phase: Utilized to pitch-over and reorient the LAV into a “CM heat-shield forward” attitude, and stabilize the LAV in preparation for LAS jettison.
• Developed by: Alliant Techsystems, Inc. (ATK) in Elkton, Maryland.

Lithium-ion battery assembly, with 28-volt and 140-volt batteries, each with a redundant backup

Gas generator assembly, with D6AC steel case and closure, and aluminum skirts

Controller assembly, including single-fault-tolerant controller circuits with an arbiter

Eight proportionally controlled pintle valve assemblies
LAS ACM Overview, PA-1
Static Fire Testing and Performance

- Several subscale High Thrust (HT) tests were completed
  - Primary focus: To develop the valve assembly

<table>
<thead>
<tr>
<th>Static fire test date</th>
<th>HT-4</th>
<th>HT-5</th>
<th>HT-6</th>
<th>HT-7</th>
<th>HT-8A</th>
</tr>
</thead>
<tbody>
<tr>
<td>31Oct07</td>
<td>31Jan08</td>
<td>14Jan09</td>
<td>09Apr08</td>
<td>31Mar09</td>
<td></td>
</tr>
<tr>
<td>Number of valves</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Burn time</td>
<td>~9 sec</td>
<td>~27 sec</td>
<td>~27 sec</td>
<td>~8 sec</td>
<td>~13 sec</td>
</tr>
</tbody>
</table>

- Two full scale Demonstration Motor (DM) static fire tests were completed
  - DM-1: 15Dec09
  - DM-2: 17Mar10 (shown)

- LAS ACM Performance:
  - Maximum thrust: 7,000 lbf
  - Action time: 35 seconds
LAS JM Overview, PA-1
Purpose, Design, and Development

- **Purpose**: Provide the thrust force required to jettison the LAS from the Orion CM, in both the abort and nominal flight scenarios.
  - Abort scenario: Utilized after the AM and ACM have performed their functions.
  - Nominal scenario: Utilized with fully loaded AM and ACM propellant.
- **Developed by**: Aerojet in Sacramento, California.

Gas generator assembly, including a high performing propellant grain design, with a pyrogen igniter

Case, aft closure, and shroud assembly, all made with 6AL-4V titanium

Nozzle assembly, 4 each:
- 17-4 stainless steel housing
- Canted 35 degrees
- 3 nozzles with a large throat, and 1 nozzle with a small throat
- Scarfed to OML of LAS

(shown with nozzle covers)

Aft closure assembly (not shown)

Shroud assembly: clamshell configuration with structural ribs
**Las JM Overview, PA-1**  
**Static Fire Testing and Performance**

- Subscale Ballistic Test Evaluation System (BATES) tests were successful

<table>
<thead>
<tr>
<th>Static Fire Test Date</th>
<th>BATES-1</th>
<th>BATES-2</th>
<th>BATES-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Date</td>
<td>02Oct07</td>
<td>09Oct07</td>
<td>17Oct07</td>
</tr>
<tr>
<td>Top-Level Description</td>
<td>Igniter assembly test in free volume simulator</td>
<td>Axial nozzle assembly test</td>
<td>Canted and scarfed nozzle assembly test</td>
</tr>
</tbody>
</table>
| Test Configuration Details | • Full-scale igniter  
• Open BATES chamber  
• No nozzle | • Sub-scale igniter  
• BATES chamber with ~1/4 flight mass propellant  
• Single nozzle, axial, with flight-like throat | • Sub-scale igniter  
• BATES chamber with ~1/4 flight mass propellant  
• Single nozzle, canted and scarfed, with flight-like throat |

- Two full scale DM static fire tests were completed
  - DM-1: 27Mar08
  - DM-2: 17Jul08 (shown)

- PA-1 LAS JM performance:
  - Nominal maximum thrust: Over 40,000 lbf
  - Action time: ~2 seconds
Purpose: To induce a roll torque to determine the response of the CM main chutes, and to position the CM properly for landing. Also used to provide rate damping, as needed.

Developed by: NASA Glenn Research Center (GRC), in Cleveland Ohio.
CM RCS Overview, AA-1
Purpose, Design, and Development (continued)

- CM RCS was to be utilized throughout five phases of the AA-1 flight test:

<table>
<thead>
<tr>
<th>Phase</th>
<th>RCS function</th>
<th>Time, s</th>
<th>Altitude, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rate damping after drogue chute deployment</td>
<td>0 - 1</td>
<td>34,750 - 34,550</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 - 70</td>
<td>34,550 - 16,675</td>
</tr>
<tr>
<td>2</td>
<td>Rate Damping</td>
<td>177 - 178</td>
<td>9,200 - 9,130</td>
</tr>
<tr>
<td>3</td>
<td>Induced Roll Torque (Development test objective)</td>
<td>184 - 196</td>
<td>9,000 - 8,680</td>
</tr>
<tr>
<td></td>
<td></td>
<td>196 - 202</td>
<td>8,675 - 8,520</td>
</tr>
<tr>
<td>4</td>
<td>Rate Damping</td>
<td>202 - 205</td>
<td>8,500 - 8,430</td>
</tr>
<tr>
<td>5</td>
<td>Roll Control Algorithm</td>
<td>221 - 223</td>
<td>8,000 - 7,960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>223 - 268</td>
<td>7,945 - 6,700</td>
</tr>
</tbody>
</table>

- GRC design team completed PDR, and procured most of the flight hardware

RCS developmental testbed

RCS developmental testbed, PRA
ATB SR118 Overview, all AA Flights
Purpose, Design, and Development

- **Purpose:** To provide the required thrust force to simulate an ascent of the Orion spacecraft on the Ares I CLV, and deliver the LAV to the appropriate test conditions for an abort.
- **ATB Developed by:** Orbital Sciences Corporation, in Chandler Arizona.
- **SR118 Developed by:** ATK in Utah.
  - Development initiated in 1978 (aka Peacekeeper, first stage)
  - Peacekeeper deactivated in 2002

**ATB Architecture**
- Aeroshell structure, to simulate OML of Ares I CLV upper stage
- SR118 is encased within the ATB aeroshell

**SR118 Architecture**
- Dimensions:
  - 27.8 feet long
  - 7.7 feet case diameter
- Conventional propellant
- Pre-impregnated epoxy resin composite case
- Partially submerged nozzle, with TVC
- Pyrogen igniter in the forward dome

Photo of the SR118 during rotation
• SR118 testing has been extensive, and successful
  – Completed over 35 static fire tests
  – Over 50 flights, with no propulsion failures
• Orbital experience with SR118:
  – Three successful Minotaur IV flights, in support of DARPA, SMC, and Space Test Programs under a USAF SMC RSLP contract, all in 2010.
• Performance: Nominal average thrust ~500,000 lbf
Conclusion

• The architecture of any human-rated launch vehicle and spacecraft will always require the greatest level of safety.

• PA-1 required the use of three propulsive subsystems: the AM, ACM, and JM.
  – All three successfully demonstrated their required functions during the PA-1 flight.

• Subsequent Orion FTVs were also being developed that required the use of two additional propulsive subsystems: the CM RCS, and the ATB SR118.

• Since 2004, hundreds of people across the country have been devoted to increasing flight safety, with the development and testing of the Orion LAS.
  – Includes numerous government and private sector organizations.
Orion PA-1 Video

http://www.youtube.com/watch?v=wzIcDDJyTRI

Courtesy: Space City Films