Propulsion Overview of the Orion Pad Abort 1 (PA-1) Flight-Test Vehicle

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Outline

• Introduction

• Launch Abort System (LAS) Abort Motor (AM)

• LAS Attitude Control Motor (ACM)

• LAS Jettison Motor (JM)

• 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 (in 2011)
  – Return humans to the Moon, and eventually utilize for future human missions to Mars
  – Program was cancelled in 2010

• Space Launch System (SLS) Program – Background
  – Transport humans beyond low-Earth orbit, and take them further into our solar system than ever before
  – Provide a transport capability to the ISS, as a backup for commercially developed launch vehicles

• Orion Multi-Purpose Crew Vehicle (MPCV) – Background
  – The Constellation Ares I architecture included the Orion Crew Exploration Vehicle (CEV) (now the Orion MPCV)
  – The new SLS architecture includes the Orion MPCV
  – Consists of: the Launch Abort System (LAS), Crew Module (CM), Service Module (SM), and Spacecraft Adapter (SA)

• 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 Orion Flight Test Office (FTO), at NASA JSC
  – The Orion flight-test vehicle integration and operations effort was led by the NASA Dryden Flight Research Center
Introduction
Orion LAS Motors, and a Review of the Apollo LES

- The 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 the Apollo architecture, including the Apollo Launch Escape System (LES)
- Review of the Apollo Flight Test Program facilitated the initial creation of the Orion AFT Flight Manifest

Apollo 11, during launch
Apollo CM & LES

Orion Launch Abort Vehicle (LAV)
Orion PA-1 Launch, 06May10

Approved for public release
LAS AM Overview, for 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 performance pyrogen igniter
- Light weight high performance carbon fiber composite case
- High burn rate propellant in a high surface area grain configuration provides required abort performance

LAS AM manifold during hydroproof testing at ATK
LAS AM Overview
Static Fire Testing and Performance

- Subscale Tests (SST) and one full scale Static Test (ST) were completed prior to PA-1

<table>
<thead>
<tr>
<th>Static Fire Test Date</th>
<th>SST-1</th>
<th>SST-2</th>
<th>ST-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>26Jun07</td>
<td>10Aug07</td>
<td>20Nov08</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Subscale test series:</th>
<th>First full-scale test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• ~1/4-scale of the geometry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• ~1/25-scale of the overall thrust</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test configuration</th>
<th>Horizontal</th>
<th>Vertical, upside-down</th>
</tr>
</thead>
</table>

| Nozzle configuration | • Two reverse flow nozzles | • Four reverse flow nozzles |
|                     | • 180 degrees apart | • 90 degrees apart |
|                     | • Canted 25 degrees | • Canted 25 degrees |

- PA-1 LAS AM Performance:
  - Nominal maximum thrust: ~500,000 lbf
  - Action time: ~7 seconds
LAS ACM Overview, for PA-1
Purpose, Design, and Development

• 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
Aluminum controller/battery stand
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

Approved for public release
• Several subscale High Thrust (HT) tests were completed
  – Primary focus: To develop the valve assembly

<table>
<thead>
<tr>
<th>Test Date</th>
<th>HT-4</th>
<th>HT-5</th>
<th>HT-6</th>
<th>HT-7</th>
<th>HT-8A</th>
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<tbody>
<tr>
<td>Oct 07</td>
<td>31Oct07</td>
<td>31Jan08</td>
<td>14Jan09</td>
<td>09Apr08</td>
<td>31Mar09</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 prior to PA-1
  – DM-1: 15Dec09
  – DM-2: 17Mar10 (shown)

• PA-1 LAS ACM Performance:
  – Maximum thrust: 7,000 lbf
  – Action time: 35 seconds
LAS JM Overview, for 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

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)

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

Aft closure assembly (not shown)

Shroud assembly: clamshell configuration with structural ribs

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LAS JM Overview
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></td>
<td>02Oct07</td>
<td>09Oct07</td>
<td>17Oct07</td>
</tr>
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</table>

- Top-Level Description
  - Igniter assembly test in free volume simulator
  - Axial nozzle assembly test
  - Canted and scarfed nozzle assembly test

- 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 prior to PA-1
  - DM-1: 27Mar08
  - DM-2: 17Jul08 (shown)

- PA-1 LAS JM Performance:
  - Nominal maximum thrust: Over 40,000 lbf
  - Action time: ~2 seconds
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.

• 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.

• Future flight testing (beyond PA-1) will ensure LAS capability on the SLS/Orion MPCV.
Acknowledgments & References

• Special Thanks to my colleagues (Orion AFT Propulsion Subject Matter Experts):
  – Syri Brooks, NASA Dryden
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  – Rachel McCauley, NASA Marshall
  – Terry Wall, NASA Marshall
  – Brian Reed, NASA Glenn
  – C. Miguel Duncan, TASC RSLP

• For more detailed information, please refer to the following publication:
  – Additional documents have been published, and are available upon request.
Orion PA-1 Video
http://www.youtube.com/watch?v=wzIcDDJyTRI

 Courtesy: Space City Films