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

Daniel S. Jones
NASA Dryden – Aerodynamics & Propulsion Branch (RA)

Presented during the

NASA Dryden Brown-Bag Session
June 5th, 2013

Approved for public release
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 PA-1 Launch, 06May10

Typical Orion Pad Abort sequence of events
**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.

**Key Features:**

- High performance turn-flow motor featuring 4 nozzles at an efficient 25 degrees cant
  - Total flow turn = 155 degrees
- Light weight high performance carbon fiber composite case
- High burn rate propellant in a high surface area grain configuration provides required abort performance
- Convergent manifold configuration stabilizes flow, balances thrust, and maximizes performance
- High performance pyrogen igniter

Approved for public release

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></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>
<tr>
<td>Description</td>
<td>Subscale test series:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• ~1/4-scale of the geometry</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• ~1/25-scale of the overall thrust</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>First full-scale test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test configuration</td>
<td>Horizontal</td>
<td>Vertical, upside-down</td>
<td></td>
</tr>
<tr>
<td>Nozzle configuration</td>
<td>• Two reverse flow nozzles</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 180 degrees apart</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Canted 25 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Four reverse flow nozzles</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 90 degrees apart</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Canted 25 degrees</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• 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></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><strong>Static fire test date</strong></td>
<td>31Oct07</td>
<td>31Jan08</td>
<td>14Jan09</td>
<td>09Apr08</td>
<td>31Mar09</td>
</tr>
<tr>
<td><strong>Number of valves</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Burn time</strong></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

Approved for public release
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>
<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 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.
• Special Thanks to my colleagues (Orion AFT Propulsion Subject Matter Experts):
  – Syri Brooks, NASA Dryden
  – Marvin Barnes, NASA Marshall
  – 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:
  – “Executive Summary of Propulsion on the Orion Abort Flight-Test Vehicles,”
    AIAA 2012-3891.
  – 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