



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

**Daniel S. Jones and Syri J. Koelfgen**

*NASA Dryden Flight Research Center, Edwards, California, 93523*

**Marvin W. Barnes, Rachel J. McCauley, and Terry M. Wall**

*NASA Marshall Space Flight Center, Huntsville, Alabama, 35812*

**Brian D. Reed**

*NASA Glenn Research Center, Cleveland, Ohio, 44135*

*and*

**C. Miguel Duncan**

*TASC Rocket Systems Launch Program, Kirtland AFB, New Mexico, 87117*



# 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

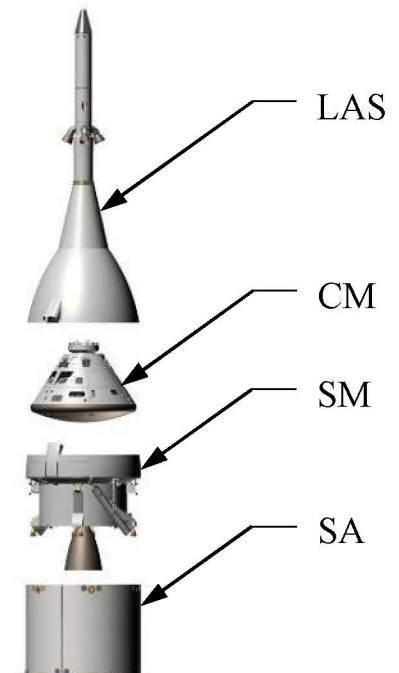


# Introduction

## 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.



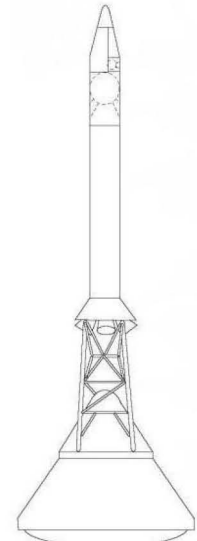


# Introduction

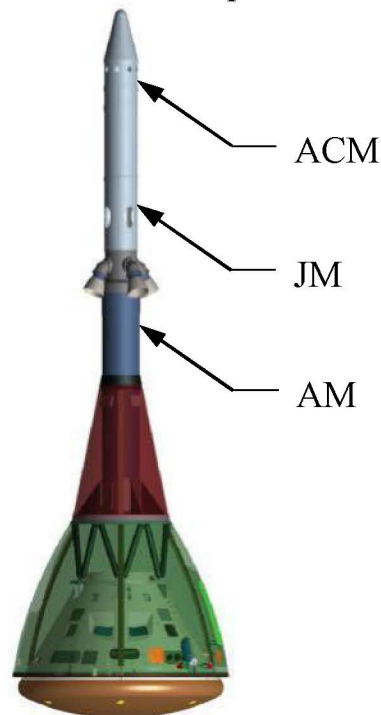
## LAS Motors, and the Orion AFT Flight Manifest



- 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



Apollo,  
with LES



Orion, with LAS

Flight Test (in chronological order)	Test Description
PA-1	Abort from launch pad
AA-1	Maximum dynamic pressure abort
PA-2	Abort from launch pad with flight-like abort trajectory
AA-2	Transonic abort
AA-3	Off-nominal maximum dynamic pressure abort
AA-4	High altitude abort

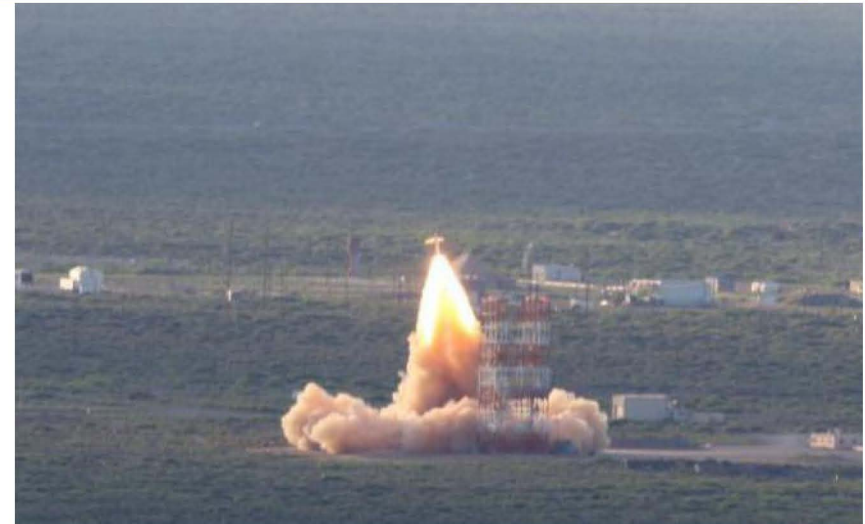


# Introduction

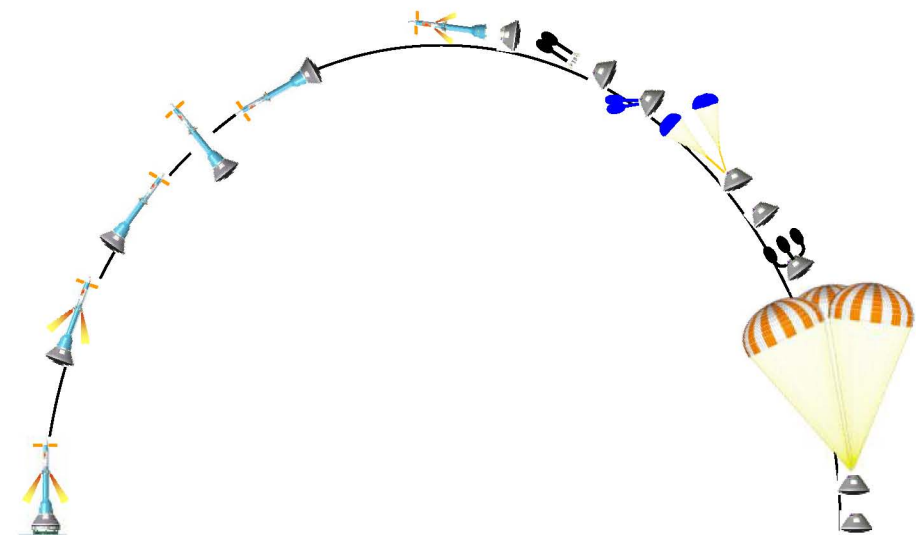
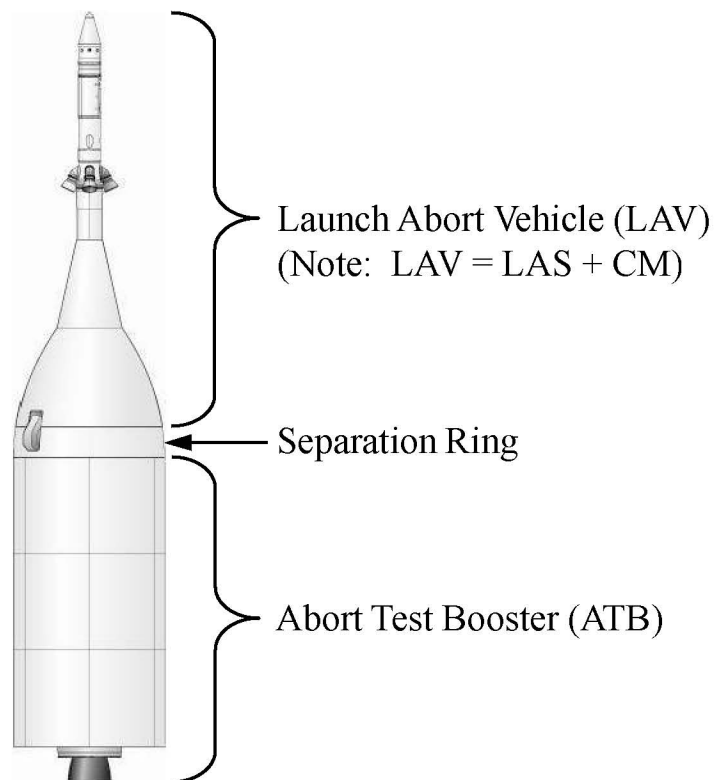
## PA-1, and Planned Future Flight Test Vehicles



- 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



PA-1 Launch, 06May10



Typical Pad Abort sequence of events





# LAS AM Overview, PA-1

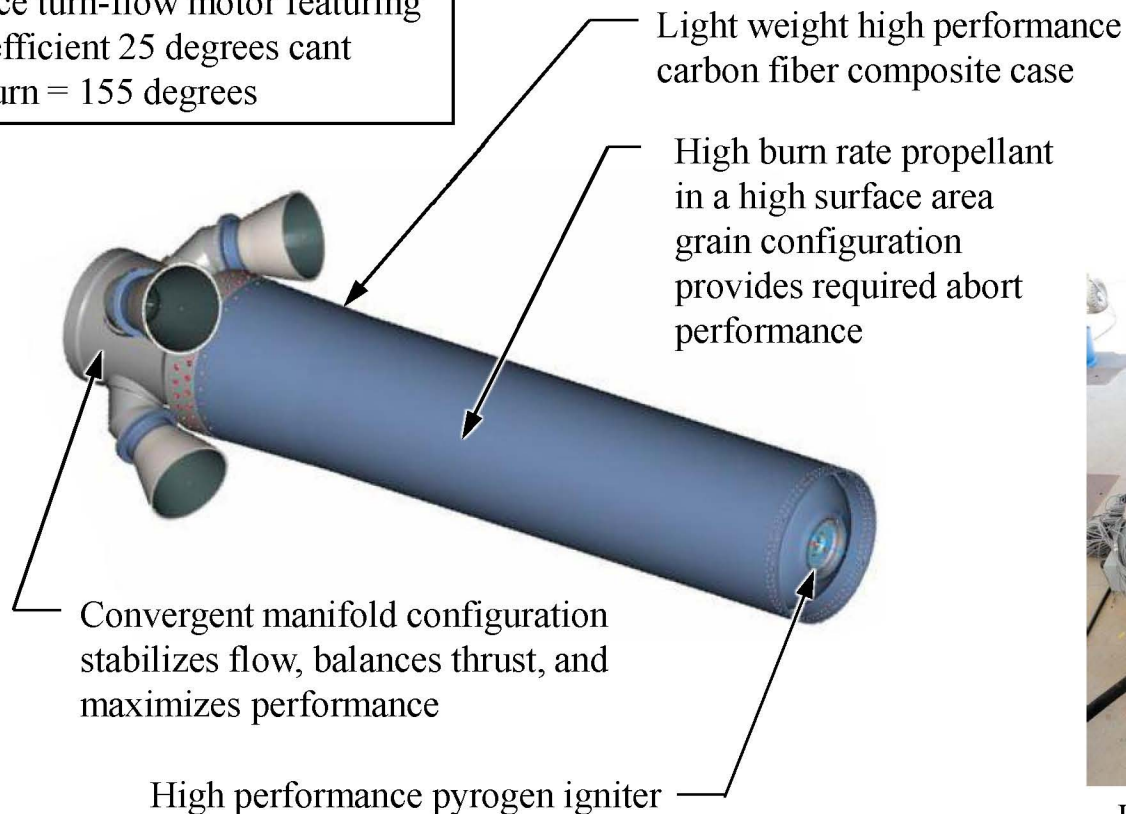
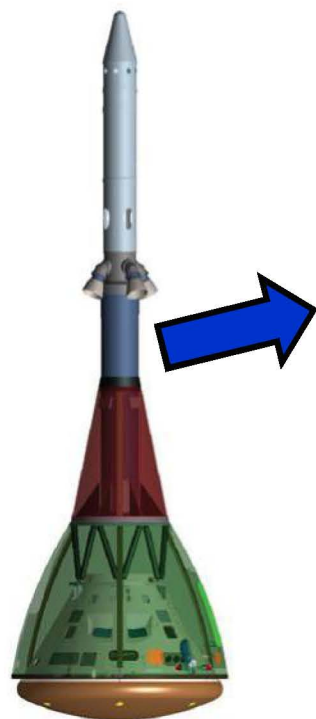
## Purpose, Design, and Development



- 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



LAS AM manifold during hydroproof testing at ATK



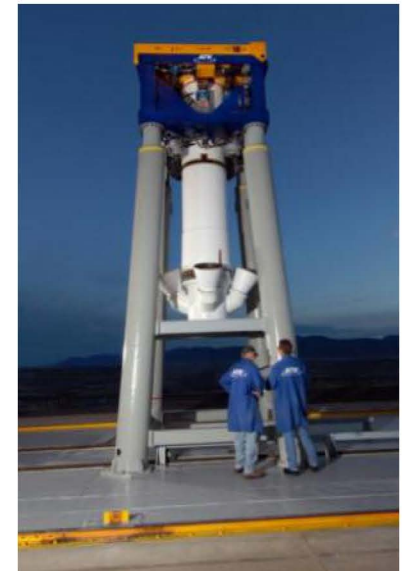
# LAS AM Overview, PA-1

## Static Fire Testing and Performance



- Subscale Tests (SST) and a full scale Static Test (ST) were completed

	SST-1	SST-2	ST-1
Static Fire Test Date	26Jun07	10Aug07	20Nov08
Description	Subscale test series: <ul style="list-style-type: none"><li>• ~1/4-scale of the geometry</li><li>• ~1/25-scale of the overall thrust</li></ul>		First full-scale test
Test configuration	Horizontal		Vertical, upside-down
Nozzle configuration	<ul style="list-style-type: none"><li>• Two reverse flow nozzles</li><li>• 180 degrees apart</li><li>• Canted 25 degrees</li></ul>		<ul style="list-style-type: none"><li>• Four reverse flow nozzles</li><li>• 90 degrees apart</li><li>• Canted 25 degrees</li></ul>



- PA-1 LAS AM Performance:
  - Nominal maximum thrust: ~500,000 lbf
  - Action time: ~7 seconds



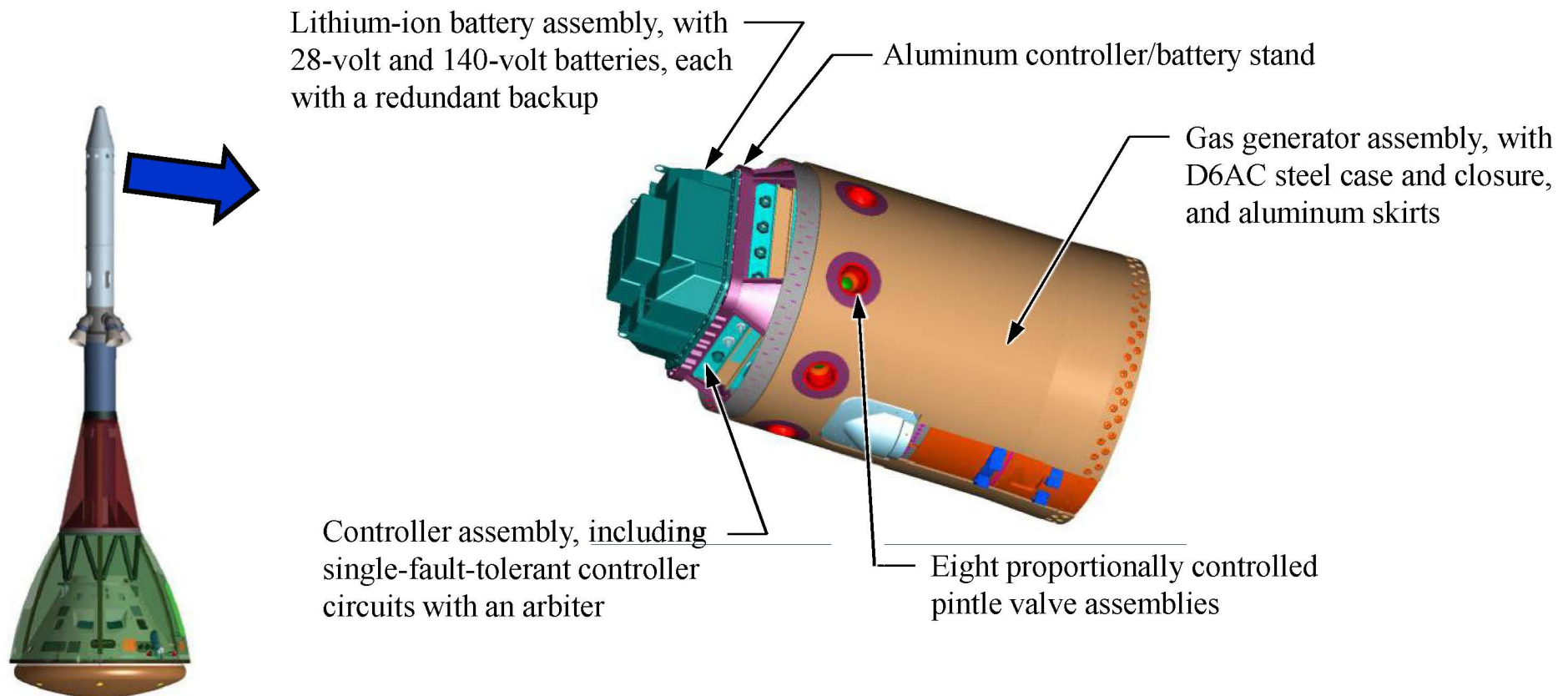


# LAS ACM Overview, PA-1

## 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.







# 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

	HT-4	HT-5	HT-6	HT-7	HT-8A
Static fire test date	31Oct07	31Jan08	14Jan09	09Apr08	31Mar09
Number of valves	1	1	1	2	1
Burn time	~9 sec	~27 sec	~27 sec	~8 sec	~13 sec

- 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



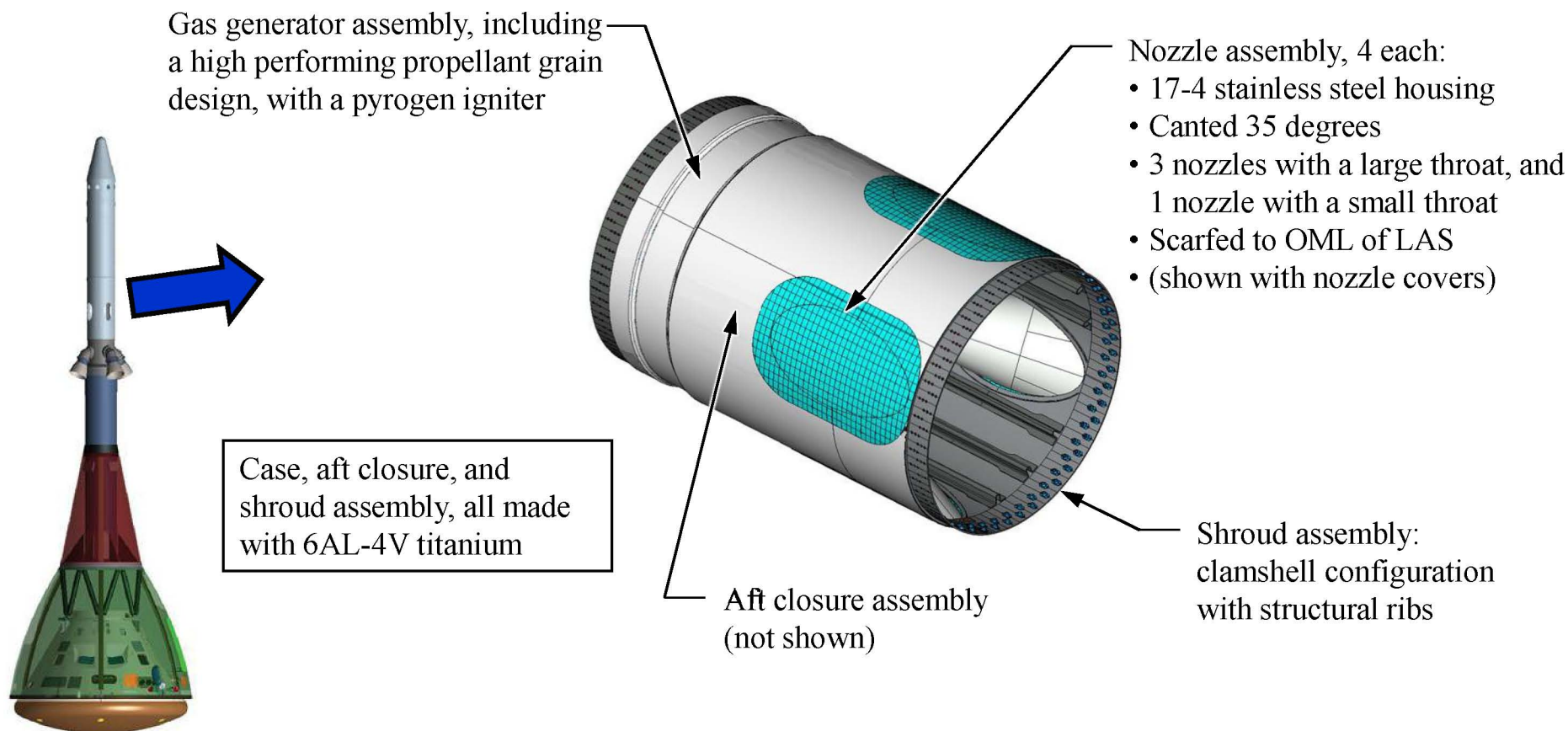


# LAS JM Overview, PA-1

## 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.





# LAS JM Overview, PA-1

## Static Fire Testing and Performance



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

	BATES-1	BATES-2	BATES-3
Static Fire Test Date	02Oct07	09Oct07	17Oct07
Top-Level Description	Igniter assembly test in free volume simulator	Axial nozzle assembly test	Canted and scarfed nozzle assembly test
Test Configuration Details	<ul style="list-style-type: none"><li>Full-scale igniter</li><li>Open BATES chamber</li><li>No nozzle</li></ul>	<ul style="list-style-type: none"><li>Sub-scale igniter</li><li>BATES chamber with ~1/4 flight mass propellant</li><li>Single nozzle, axial, with flight-like throat</li></ul>	<ul style="list-style-type: none"><li>Sub-scale igniter</li><li>BATES chamber with ~1/4 flight mass propellant</li><li>Single nozzle, canted and scarfed, with flight-like throat</li></ul>

- 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





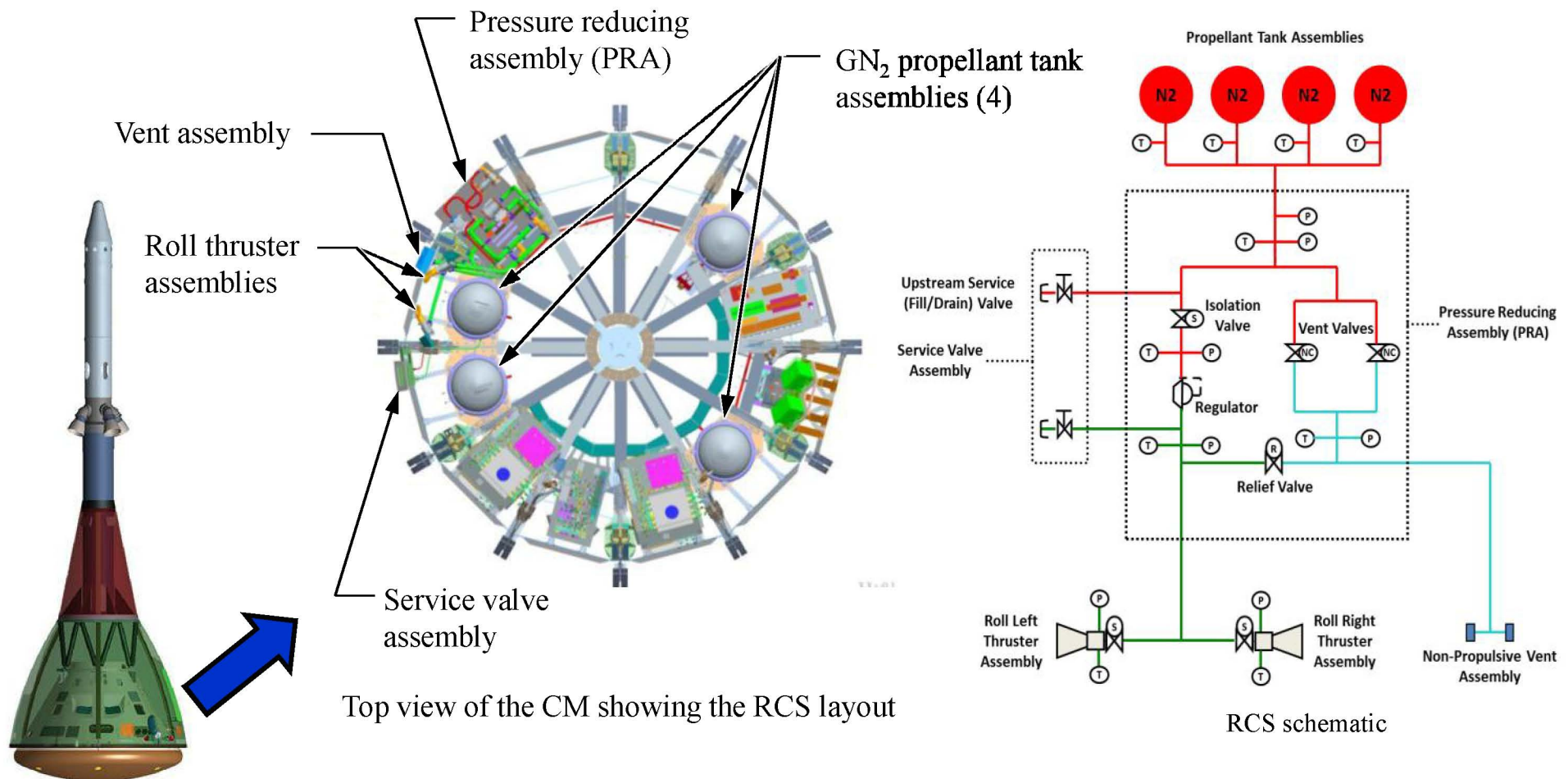


# CM RCS Overview, AA-1

## Purpose, Design, and Development



- 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.



Top view of the CM showing the RCS layout

RCS schematic





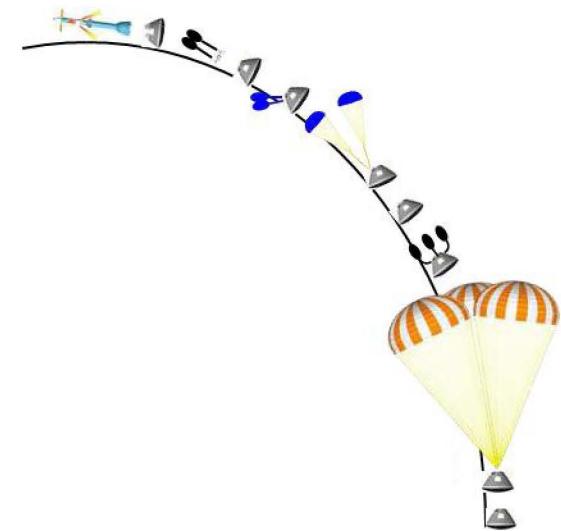
# CM RCS Overview, AA-1

## Purpose, Design, and Development (continued)



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

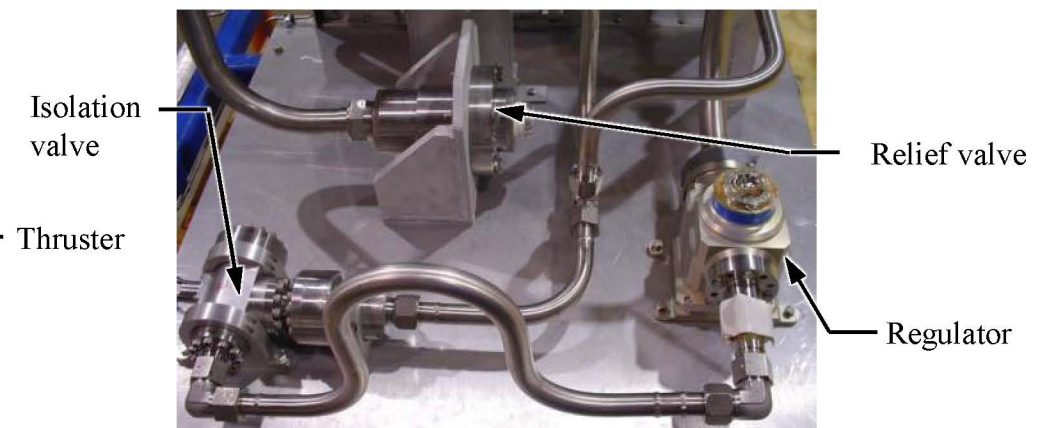
Phase	RCS function	Time, s	Altitude, ft
1	Rate damping after drogue chute deployment	0 – 1	34,750 - 34,550
		2 – 70	34,550 - 16,675
2	Rate Damping	177 – 178	9,200 - 9,130
3	Induced Roll Torque (Development test objective)	184 – 196	9,000 - 8,680
		196 – 202	8,675 - 8,520
4	Rate Damping	202 – 205	8,500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



- 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

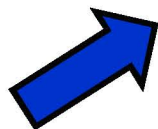
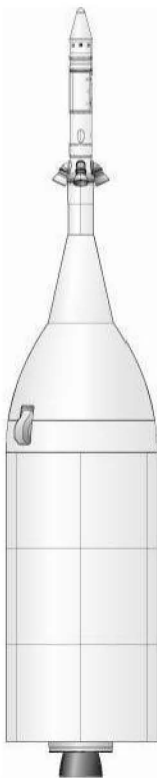


Photo of the SR118 during rotation





# ATB SR118 Overview, all AA Flights

## Static Fire Testing and Performance



- 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 Taurus flights, in support of DARPA and the USAF SMC RSLP, in 1994, 1998, and 2000.
  - 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.



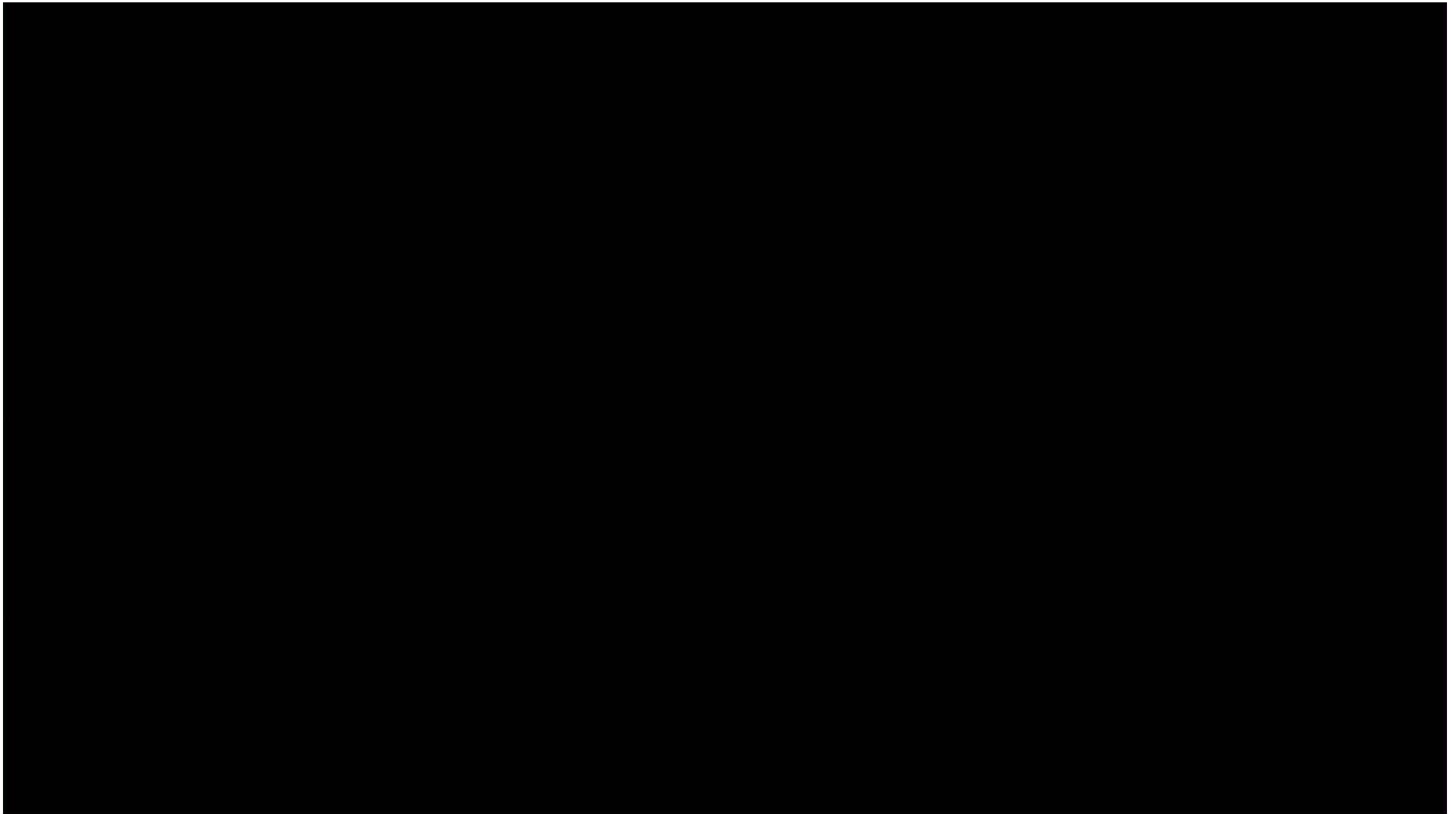




## Orion PA-1 Video

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

---



Courtesy: Space City Films