# Propulsion and Cryogenics Advanced Development (PCAD) Project Propulsion Technologies for the Lunar Lander

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**The Propulsion and Cryogenics Advanced Development (PCAD) Project in the Exploration Technology Development Program is developing technologies as risk mitigation for Orion and the Lunar Lander. An integrated main and reaction control propulsion system has been identified as a candidate for the Lunar Lander Ascent Module. The propellants used in this integrated system are Liquid Oxygen (LOX) /Liquid Methane (LCH4) propellants. A deep throttle pump fed Liquid Oxygen (LOX) /Liquid Hydrogen (LH2) engine system has been identified for the Lunar Lander Descent Vehicle. The propellant combination and architecture of these propulsion systems are novel and would require risk reduction prior to detailed design and development. The PCAD Project addresses the technology requirements to obtain relevant and necessary test data to further the technology maturity of propulsion hardware utilizing these propellants. This plan and achievements to date will be presented.**

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**Presentation to the Space Technology & Applications International Forum**

*February 12, 2008*

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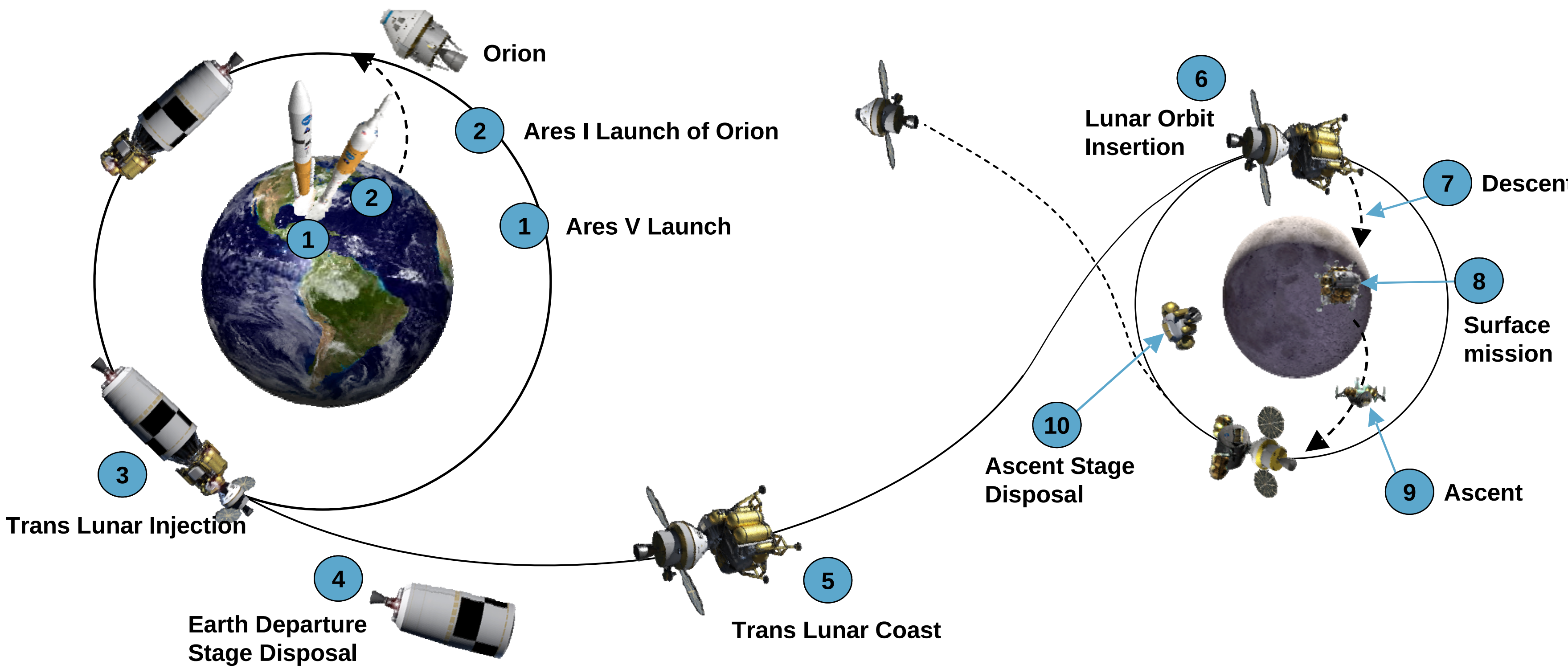
# *PCAD*
# Architectural Benefit




Exploration mission is more ambitious than the Apollo mission

- More people to the surface
- Longer duration stays

# Architectural Benefit

### Descent Propulsion

- LOx/LH2 is **enabling** to meet lunar lander **weight budget**.
- **Hypergols** would make the lunar lander **too heavy** to be supported by Ares V

### Ascent Propulsion

- **Both** NTO/MMH and **LOx/$CH_4$** under consideration
- Initial Lunar Design Analysis Cycle-1 (LDAC-1) design assumed NTO/MMH integrated Reaction Control System (RCS)/Main Propulsion System (MPS)
- **After completion of LDAC-1, Ascent Propulsion System re-designed using LOx/$CH_4$**
- LOx/$CH_4$ Ascent Module design completed by Lunar Architecture Team-II (LAT-II) team lead by Eric Hurlbert

Source: Tom Brown - Lander Propulsion Overview and Technology Requirements Discussion - Constellation Technology Conference – November 2007

# LO2-LCH4 Option for Altair Ascent Stage

Benefits (from Cx Prop Study Findings):

- **Improved Performance:**
  - For a minimal ascent stage the savings are 400- 800 lbms (from Cx Prop Study Findings)
    - This **mass benefit** translates into a **sizable reduction** in IMLEO (>25,000 lbm based on ESAS LSAM configuration)
    - Lower gross weights translate to **lower launch costs**, increased margins, or decreased program risk for closure (need to quantify)
- **Cost:** Lowest total estimated LCC alternative option to hypers (+$411M total through 2030)
  - Higher recurring cost based on higher dry mass (worst case analysis)
  - Cost benefit of **higher performance** will reduce LCC (not included in analysis)
- **Schedule:** Estimated 74 mo. (6.2 year) development schedule compares favorably with 71 mo. estimated for hypers
- **Reliability:** Mature system reliability equivalent to that of hypers (0.999982 vs 0.999984)
  - Initial lower reliability (0.80 vs 0.95) to be improved through ongoing test program

# *PCAD*
# Lunar Lander Technology Needs

- **LOx/$LH_2$ Deep Throttling Pump Feed Engine(s)**
- **LOx/$CH_4$ Pressure Feed Main Engine**
- **LOx/$CH_4$ RCS Thrusters**
- Cryogenic Propellant Storage and management
  - LOx/$LH_2$
  - LOx/$CH_4$
- Cryo Mass Gauging
  - LOx, $LH_2$, $LCH_4$
- Low Heat Transfer Tank Mountings, and interfaces
- **Variable area valve and actuation technology**

Source: Tom Brown - Lander Propulsion Overview and Technology Requirements Discussion - Constellation Technology Conference – November 2007

# *PCAD*
# Lunar Lander Technology Needs

- **$LOx/LH_2$ Descent Propulsion**
  - **1 – 4 engines**
  - **28 – 30 klbf optimal stage thrust**
  - **35 – 40 klbs optimal stage thrust (engine out configurations)**
  - **Throttle range (3.3 to 1) – (8 to 1)**
  - **LOx/LH2 Main Engine (Expander Cycle)**
    - **9,000 lbf – 28,000 lbf**
    - **448 sec Isp (maximize @ 100% RPL)**
    - **2 – 4 starts per mission**
  - $LOx/LH_2$ Storage & Fluid Management
    - 14 – 28 days LEO
    - 3 days Transit
    - 2 days LLO
- **$LOx/CH_4$ Ascent Propulsion**
  - **LOX/CH4 Main Engine (Pressure Feed)**
    - **4500 lbf – 6500 lbf**
    - **355 sec Isp**
    - **1 – 3 starts per mission**
  - **LOx/CH4 RCS Thrusters**
    - **100 lbf**
    - **80 ms pulse length (40 ms growth risk)**
    - **300 + sec Isp**
  - $LOx/CH_4$ Storage & Fluid Management
    - 14 – 28 days LEO
    - 3 days Transit
    - 2 days LLO
    - 210 days Lunar surface

Source: Tom Brown - Lander Propulsion Overview and Technology Requirements Discussion - Constellation Technology Conference – November 2007

# Propulsion Technical Risk Areas

- **Reaction Control Technology**
  - Reliable ignition
  - Performance
  - Repeatable pulse width
- **Ascent Main Engine**
  - Reliable ignition
  - Performance
  - Fast start
- **Descent Main Engine**
  - Stable throttling
  - Performance
  - Reliable ignition

# *PCAD*
# Project Structure

**Propulsion and Cryogenics Advanced Development**
Conduct risk reduction activities to demonstrate that green/non-toxic propellants can be a feasible option for Constellation propulsion systems.

### 1.0 Project Management

**Objective**: Manage the overall development of propulsion technologies to increase technology readiness levels and reduce risk.

### 2.0 Reaction Control System Propulsion

**Objective**: Reduce the risk of liquid oxygen / liquid methane ignition and **demonstrate and validate performance** levels for reaction control engines for use on the Lunar Lander descent and ascent stages

### 3.0 Main Engines

**Objective**: **Demonstrate and validate performance** levels for a Lunar Lander liquid oxygen / liquid methane ascent engine and a deep throttling liquid oxygen / liquid hydrogen descent engine

### 4.0 Orion Propulsion

**Objective**: Demonstrate the **key enabling technologies** needed for the design of a thruster for oxygen-based non-toxic in-space Orion crew module (CM) propulsion

### 5.0 Mars Propulsion

Tentative

*FY12 Start*

**Objective:** Demonstrate engine performance levels for engines on the Mars Lander descent and ascent stages

### 7.0 Education and Outreach

**Objective:** PCAD Project will cooperate with appropriate personnel in any education and outreach activities as requested.

# *PCAD*
# WBS 2.1 – RCS Technologies

***WBS 2.1.1 Exciter Technology (GRC)***

- Advanced exciter technology development to **reduce weight and volume** from current SOA. Both capacitive discharge and inductive designs will be examined

***WBS 2.1.2 Spark Plug Durability (GRC)***

- Determine the **mechanism of ceramic insulator failure** in an igniter system. Provide material solutions to overcome insulator failure

***WBS 2.1.3 Wide Operating Range Ignition (GRC)***

- Identify igniter **life-limiting phenomena** and address wear mechanisms associated with igniter operations. Characterize the repeatability of the ignition pulses over the duration of the test
- Demonstrate **50,000 ignition pulses** using LOx/$LCH_4$

***WBS 2.1.4 High Area Vacuum Test (WSTF 401)***

- The design and testing of high area ratio (150+) workhorse engine to obtain **nozzle performance and kinetics data** with LOx/$LCH_4$ in vacuum conditions.

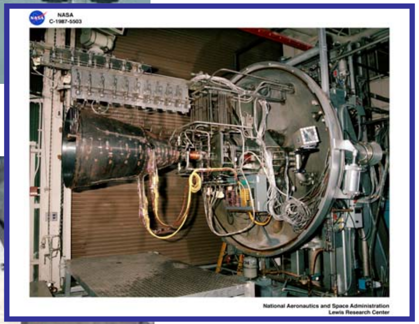
***WBS 2.1.5 100-lbf Sea Level Testing (GRC)***

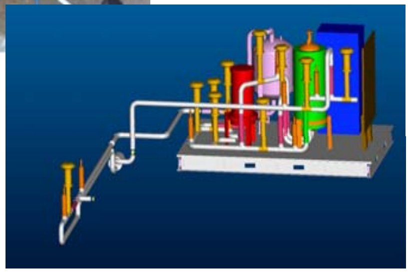
- Build a system to provide **propellant conditioning** for liquid oxygen (LOx) and liquid methane ($LCH_4$) to test 25-100 lbf rocket engines
- **Tight controls on pressure and temperature** to provide a wide range of operating set points not available at other facilities

***WBS 2.1.6 100-lbf Vacuum Testing (GRC)***

- Hot-fire testing will be conducted at **vacuum** conditions to determine the **ignition and performance** characteristics for a 100-lbf thruster.
- Use propellant conditioning system from sea level testing



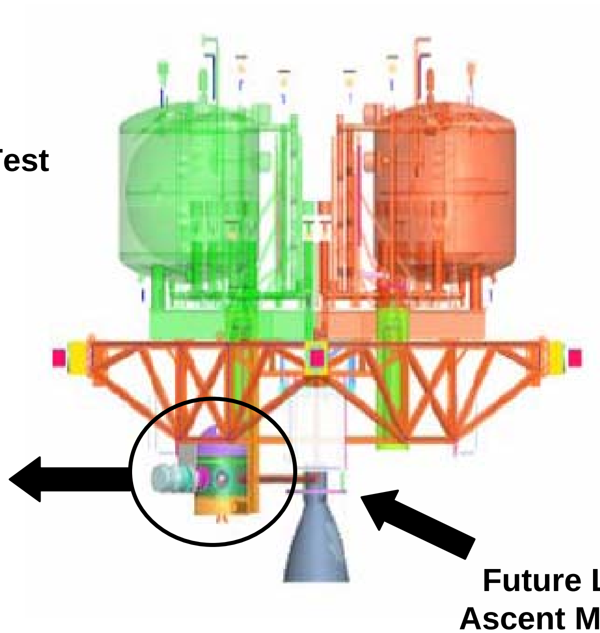


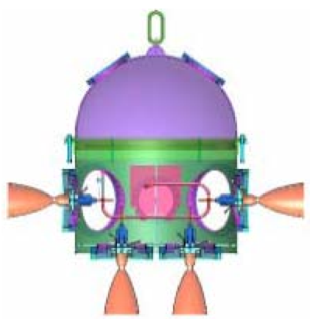
# *PCAD*

# WBS 2.2 – Integrated Testing

- **Integrate four 100-lbf RCS** into the WSTF (Auxiliary Propulsion System Test Bed) APSTB test bed.
  - Perform integrated engine and feed system testing at altitude.
- Configure **APSTB with a main engine simulator**
  - Test with multiple RCS engines to determine impacts from main engine operation

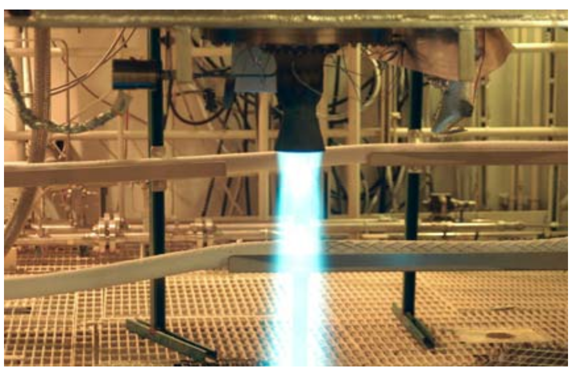
**WSTF Auxiliary Propulsion System Test Bed – TS 401**





**RCS engines in Bell Jar vacuum enclosure.**

**Future LOx/LCH$_4$ Ascent Main Engine Position**



**870-lbf engine test on APSTB at WSTF 401**

**RS18 Engine**

# Accomplishments – LOx/$LCH_4$ Ignition

***Key Accomplishment:***

- Over **150** vacuum ignition tests with Aerojet spark torch igniter in GRC RCL21
- Over **1400** vacuum pulse cycles on in-house RCE class spark torch igniter in GRC RCL21
- Over **750** tests vacuum testing with main engine class spark torch igniter in GRC RCL21
- Aerojet –Vacuum testing of spark torch igniter for 100-lbf RCE thruster
- Northrop Grumman –Vacuum testing of spark torch igniter for 100-lbf RCE thruster
- ATK - Sea level testing spark torch igniter for 7500-lbf thrust main engine
- KTE - Sea level testing spark torch and catalytic igniter for 7500-lbf thrust main engine.  Testing also at Purdue University.

**RCE Class Igniter Vacuum Testing – GRC RCL21**

**Main Engine Class Igniter Vacuum Testing – GRC RCL 21**


***Significance:***

- Testing has demonstrated that oxygen – methane ignition systems can operate over a wide range of pressure, temperature, and mixture ratio conditions.
- System / sub-system tests are keys to identifying technical challenges for vehicle application

# Accomplishments - RCS Thruster

***Key Accomplishment/Deliverable/Milestone:***

- GRC successfully completed **156** ignition runs with a modified Aerojet Corporation Igniter.
- Completed Aerojet 870-lbf LOx/LCH4 thruster testing in WSTF Auxiliary Propulsion System Test Bed (APSTB) (April 2007)
- Completed Northrop Grumman 100-lbf thruster Test Series 3 and 4 with workhorse hardware. (May 2007)
- Completed Aerojet 100-lbf thruster Option 1 with pre-prototype engine.
  - ***Fastest known demonstrated pulse*** *width for a cryogenic thruster. The engine has produced a 40 msec EPW (Electrical pulse width 40 msec on 120 msec off-25% Duty Cycle).* (June 2007)

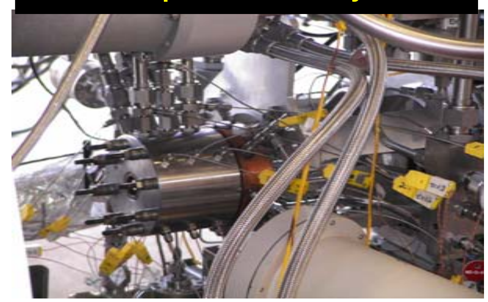
***Significance:***

- Testing has demonstrated that reaction control engines with non-toxic propellants can be ignited over a range of conditions and can meet key performance parameters.

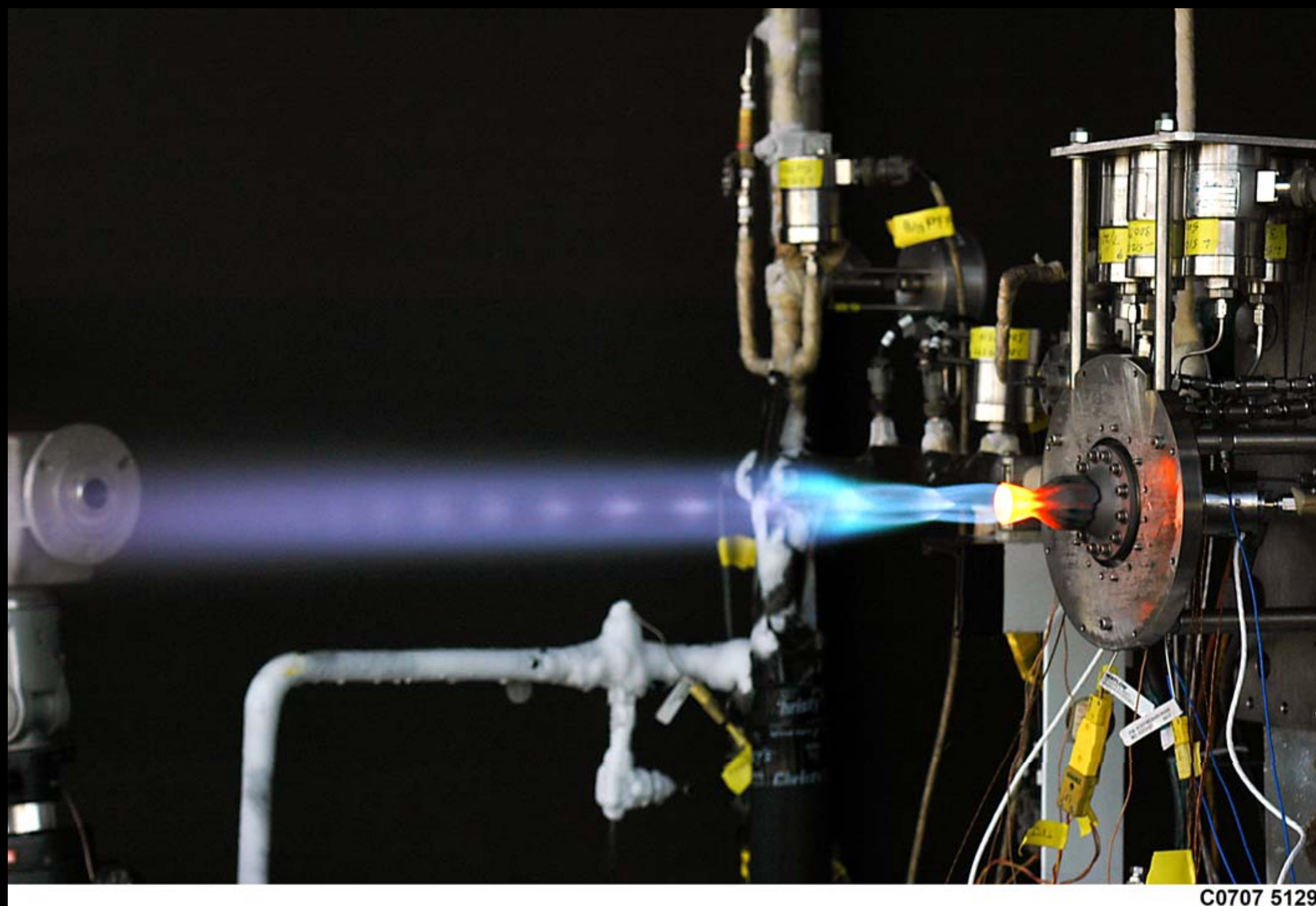
**Aerojet 870-lbf LOx/LCH$_4$ thrusters with film cooled nozzle**


**Dual 870-lbf LOx/LCH$_4$ thrusters with ablative nozzles in WSTF APSTB**

**NGST 100-lbf LOx/LCH$_4$ workhorse hardware at Capistrano Facility**



# 100 lbf Pulse Width Test



# WBS 3.1 – Ascent Main Engine

***WBS 3.1.1 Ascent Main Engine Contracts (MSFC/GRC)***

- Contract with industry for next-generation of a **workhorse engine** for engine performance demonstrations.
  - Injector combustion efficiency **(target ~98%)** and chamber heat transfer

***WBS 3.1.2 In-house Combustion Performance (MSFC)***

- Evaluate injector concepts with potential of **enhancing C*** (combustion) efficiency.
  - Characterize C* and heat transfer for either regenerative or ablative combustion chambers in existing 6”-diameter water cooled hardware and ablative chamber

***WBS 3.1.3 Main Engine Vacuum Performance (WSTF/MSFC)***

- Test workhorse engine hardware in **vacuum** conditions at WSTF 401 to Characterize **specific impulse (Isp) and nozzle performance**.

***WBS 3.1.4 Igniter Vacuum Characterization (MSFC)***

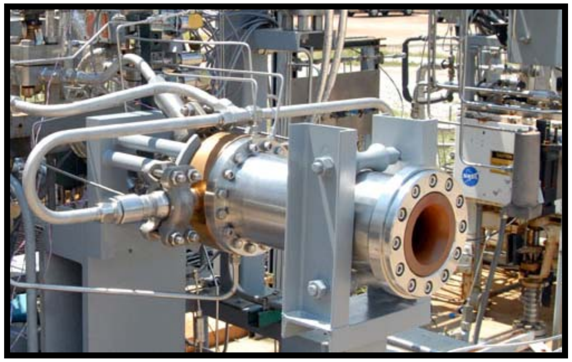
- Characterize **torch igniter** with in-space relevant environment (vacuum, low temperature) through hot-fire tests and CFD simulation
- Demonstrate and characterize **microwave igniter** in vacuum conditions

***WBS 3.1.5 Dual Diverse Igniters (GRC)***

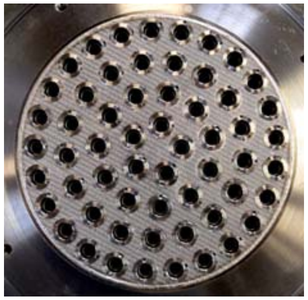
Evaluate common components between **main and redundant** ignition system

***WBS 3.1.6 High Temperature Materials (MSFC)***

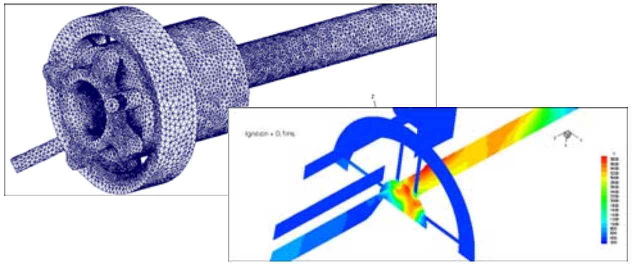
Characterize fabrication process for **high temperature** (possibly ≥4700oF) thrust chambers.



**MSFC 6”-diameter combustion chamber**



**MSFC 6”- Coaxial Injector**



**GRC igniter CFD simulations**

# Accomplishments - Ascent Main Engine

### *Key Accomplishment:*

- Continued work on two contracts for development of prototype engines along with in-house injector designs at NASA MSFC.
  - KT Engineering (Ablative chamber)
  - ATK GASL (Regenerative-cooled chamber)
- Design reviews completed for ATK 7500-lbf design (January 2007) and 3500-lbf design (June 2007)
- Completed ATK segmented engine testing at XCOR (March 2007)
- Completed 6” LOx/LCH4 Swirl Coax in-house injector testing at NASA MSFC (May 2007)
- Completed ATK workhorse engine testing at XCOR (July 2007)
- KTE workhorse engine testing at MSFC discontinued with contract performance period (Sept 2007)
- Issued RFP for follow-on contract addressing revised Altair requirements

### *Significance:*

- Test results provide initial performance measures and igniter results for LOx/LCH4 main engines.
- Test results did not meet required combustion efficiency
- Additional workhorse class testing required

**ATK/XCOR workhorse engine testing at XCOR, Mojave, CA**

**KTE LOx/Methane workhorse main engine installed at MSFC TS500**

**6” Injector Hot-fire Test (Ablative Chamber), MSFC TS115**

# WBS 3.2 – Descent Main Engines

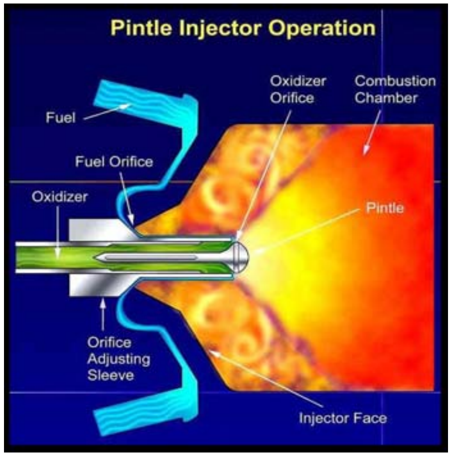
- ***Demo 1.6 - Insulated/Revised area injector (PWR)***
  - Base RL10A-4 injector with **insulated inter-propellant plate** and backplate with a revised LOx flow area
- ***Demo 1.7 Two stage injector (PWR)***
  - **Second LOx manifold** added to base RL10A-4 injector
  - Required for high thrust/deep throttle applications
  - System level test required to determine ultimate operability and effectiveness
- **Pintle Variable Area Injector Technology**
  - Fabricating injector

***Hot-fire test of deep throttling CECE engine in PWR E6 – West Palm Beach***

# Accomplishments - Descent Main Engine

## *Key Accomplishment*

- Successful Preliminary Design Review of NGST Pintle Injector Test Bed was completed ( November 2006)
- NGST Pintle test bed injector critical design review (March 2007)
- Completed PWR CECE Demo 1.5. Conducted **4 hot fire tests**, with total run time of approximately **2100 seconds**. (April 2007)
- Completed Preliminary Design Review PWR CECE Demo 1.6 (January 2008)



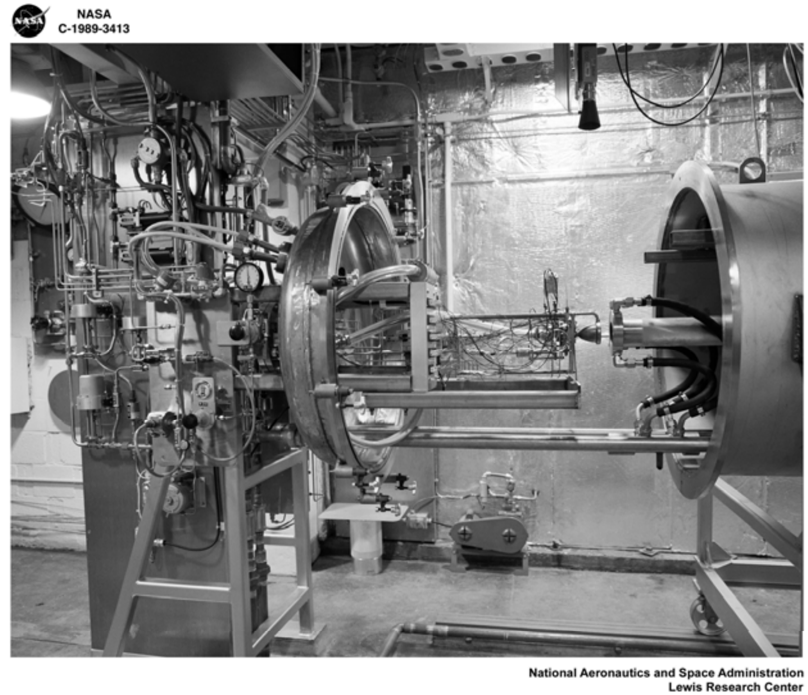

*Northrop Grumman Variable Area Pintle Injector*

## *Significance:*

- Testing demonstrated stable operation to 20% (5:1) throttle point and throttling operability to 9.5% (11:1).

# *PCAD*
# WBS 4.1 – Orion CM 25-lbf Gas-Gas Thruster

- **Dual regenerative cooled thruster** with gaseous oxygen and gaseous methane as the propellants
- **Self-contained ignition** system that does not require interfaces with the vehicle's electrical system
- Technology will lead to a non-toxic propulsion system that is **simple and reliable**
- Technology is transferable to Lunar Lander as option for improved vehicle control.
- Contract with PWR to obtain and modify 25-lbf thruster
    - Previously evaluated as a GOx/$GH_2$ ISS candidate thruster
- Test hardware at sea level and vacuum conditions.
    - Obtain thrust and heat transfer date to quantify engine performance and ignition reliability




25lbf Rocketdyne GOx/GH2 ISS candidate thruster installed at GRC RCL11 in 1989

**Key Accomplishment:**

- PDR completed

# Summary

- Exploration mission is more ambitious than the Apollo mission
  - More people to the surface
  - Longer duration stays

- New technologies are required to meet more difficult missions
  - High performance LOX/LH2 deep throttle descent engines
  - High performance LOX/LCH4 ascent main and RCS engines

- The PCAD Project is on the path to provide those technologies
  - Reliable ignition
  - High efficiency engines
  - Reliable pulse RCS
  - Fast start
  - Stable deep throttling