Survey of Constellation-Era LOX/Methane Development Activities and Future Development Needs

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Constellation Program

• NASA formed the Constellation Program in 2005 to achieve the objectives of maintaining American presence in low-Earth orbit, returning to the moon for purposes of establishing an outpost, and laying the foundation to explore Mars and beyond in the first half of the 21st century

• The Exploration Technology Development Program (ETDP) was formulated to address the technology needs to address Constellation architecture decisions

• The Propellants and Cryogenic Advanced Development (PCAD) project was tasked with risk mitigation of specific propulsion related technologies to support ETDP
Propellants and Advanced Cryogenics Development (PCAD)

- Propulsion systems were identified as critical technologies owing to the high “gear-ratio” of lunar & Mars landers
  - Cryogenic propellants offer performance advantage over storables (NTO/MMH)
    - Mass savings translate to greater payload capacity
  - In-situ production of propellant an attractive feature; methane and oxygen identified as possible Martian in-situ propellants
- New technologies were required to meet more difficult missions
  - High performance LOX/LH$_2$ deep throttle descent engines
  - High performance LOX/LCH$_4$ ascent main and reaction control system (RCS) engines
- The PCAD project sought to provide those technologies through
  - Reliable ignition & pulse RCS
  - Fast start
  - High efficiency engines
  - Stable deep throttling
Methane Ignition Risk Reduction

- Methane was historically seen as difficult to ignite compared to other cryogens
  - It has a longer ignition delay and higher ignition energy requirement as compared to other cryogenic fuels traditionally used in propulsion (e.g. hydrogen)
- Methane ignition was seen as a primary risk reduction area
  - Identify minimum ignition energy required
  - Identify life-limiting phenomena in igniter
  - Demonstrate reliable ignition over range of conditions and pulse cycles
- PCAD accomplished several goals with ignition risk reduction
  - 30,000+ pulses of methane spark igniter
  - Ignition studies with multiple igniter types
  - Ignition margin in RCE tests
  - RCE ignition over range of propellant temperatures

Augmented Spark Impinging (ASI) Igniter developed by MSFC

Unison compact-style igniter developed for AME and RCE engines

Microwave Igniter tested at MSFC

100-lb Aerojet RCE with Unison compact exciter installed at GRC

Ascent Main Engine class igniter during vacuum test at GRC

WASK spark-torch igniter during pulse durability testing at GRC
Reaction Control Engine Development

- Focused on 100-1000-lbf class engines
- Top 3 risks areas were
  - Reliable ignition
  - Vacuum performance
  - Repeatable pulse width
- For 100-lb RCE, goals were
  - MIB of 4 lb$_f$-s
  - Vacuum $I_{sp}$ of >317 s
  - 80 ms electric pulse widths (EPW)
  - 25,000 valve cycles
  - Operation over range of temperature inlet conditions
    (160 °R LOX/170 °R CH$_4$ to 224 °R LOX & CH$_4$)
- Two 100-lb engine concepts were developed and tested
Ascent & Descent Engine Development

• Three key risk identified for Methane Ascent Engines
  – Reliable ignition
  – Fast start (90% thrust in 0.5 s)
  – Performance (Vac. $I_{sp} > 355$ s)

• Analysis efforts to compare sea-level test data to altitude conditions

• Engine tests were aimed at achieving 355 s Vac. $I_{sp}$
  – AME (5500-lbf) tests were within 2% of $I_{sp}$ target

• Descent engine testing focused on 10:1 throttle with LOX/LH2
Integrated Propulsion System Testbed (IPSTB)

- Auxiliary Propulsion Systems Test Bed (APSTB) was precursor to IPSTB
  - APSTB was used to support PCAD RS-18, AME, RCE testing at WSTF-TS401
  - Modified to support concurrent testing of RS-18, AME and RCE thrusters
  - Originally designed for the Space Shuttle systems development, the rig was significantly oversized for PCAD needs

- IPSTB was designed to study, characterize, and model the integrated operation of LOX/LCH$_4$ components in an end to end propulsion system
  - Designed with smaller propellant tanks and with the flexibility to change component locations or vary feedline lengths
Summary of PCAD Accomplishments

- PCAD successfully provided risk reduction activities with respect to LOX/LCH4 engine technology
  - Demonstrated reliable ignition of LOX/LCH4 over a range of propellant conditions
  - Demonstrated 30,000+ ignition pulses of methane igniter hardware
  - Demonstrated RCE can be developed to pre-prototype level to meet mission requirements
- Additionally, PCAD also demonstrated stable throttling down to 10:1 power for a LOX/LH$_2$ descent scale main engine
- PCAD was heading towards integrated test bed modeling and test efforts
- An extensive set of literature is available to detail the numerous PCAD efforts
Activities Since PCAD (2011+)

• Additive Manufacturing Demonstration (AMD) Engine at MSFC (2012 –Current)
• Morpheus Testing (2011-current)
  – Test-bed article for exploring lander system technologies
    • Tethered flights at JSC
    • Free flights at KSC with ALHAT system
    • Vacuum tests in GRC B-2
Activities Since PCAD (2011+)

Additive Manufactured (AM) Thruster Hardware – Hot-fire Testing @ MSFC

Funding: Lander Technologies/CATALYST, LCUSP (Low Cost Upper Stage Propulsion)

- Uncooled Refractory Chamber
- Inconel LCH$_4$ cooled Chamber
- GRCop-84 LCH$_4$ cooled Chamber
- Inconel Swirl Coaxial Main Injectors
- Inconel Impinging Gas Generator Injector
- META4 (Methane Engine Thrust Assy for 4K lb$_f$) - swirl coaxial injector (LOX/CH$_4$) + 3D printed GRCop-84 chamber full regen cooling
- Fuel (CH$_4$) turbopump
- Vacuum testing MSFC ASI igniter & spark exciters at GRC

Printed GRCop-84 and printed Inconel Swirl Coax Injector & Chamber

META4 hot-fire testing at MSFC

GG-Injector Water Flow Testing

META4 Chamber

Fuel Turbopump at MSFC

Refractory Chamber

ASI Igniter testing at GRC ACS
Future Needs and Technology Gap Assessment

ISECG Looked at Future Needs

- Develop a throttle-able regenerative-cooled engines
  - pump-fed and/or pressure-fed engines
  - throttling (5:1 – 10:1), 360-365 sec, 30 – 100 kN range.
- Develop 100 to 220-N RCS thrusters and integrated cryogenic feed systems
- Develop long duration reliable cryogenic refrigeration systems (several hundred watts at ~90 K) for ISRU.
- Develop composite cryogenic tanks with focus on gap for spherical geometry
- Develop high performance pressurization systems that improve storage density and reduce mass
- Conduct extended duration thermal vacuum testing of integrated system
- Fly a zero-g cryogenic liquid acquisition experiment in space
- Fly a test vehicle in space as a technology infusion mission to demonstrate integrated LOx/Methane propulsion systems

Need to address gap of no in-space LOx/Methane flight experience.
References


