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/LH₂ deep throttle descent engines
  – High performance LOX/LCH₄ 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

Unison compact-style igniter developed for AME and RCE engines
Augmented Spark Impinging (ASI) Igniter developed by MSFC
Microwave Igniter tested at MSFC
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 lb₉-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 CH₄ to 224 °R LOX & CH₄)
• 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
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


