Green Monopropellant Status at Marshall Space Flight Center

NASA Marshall Space Flight Center
C.G. Burnside, C.W. Pierce, and K.W. Pedersen

Huntsville, Alabama 35812

DISTRIBUTION A: Approved for public release; distribution is unlimited.

DESTRUCTION NOTICE: For classified documents, follow the procedures in DoD 5200.22-M, National Industrial Security Program Manual, Chapter 5, Section 7. For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.
Background

- Goals of MSFC in Green Propulsion Development
- Facilities dedicated to the efforts
- Recent Activities
  - 22N LMP-103S Testing
  - 1N AF-M315E Testing
- MSFC Internally Funded Activities
  - 1N Temperature Conditioned AF-M315E Testing
  - 100 mN Integrated Cubesat Propulsion Module Design/Testing
- Collaborative Efforts
  - Cooperative Agreement Notices (CAN)
    - Utah State University
    - AMA
    - ASTS
- Future Activities (FY16-FY17)
  - Announcement of Collaborative Opportunity (ACO)
    - 5N AF-M315E Hot-Fire Testing (with Busek)
    - 445N LMP-103S Hot-Fire Testing (with Orbital ATK)
  - CAN – MIT
    - Dual mode chemical/electrospray propulsion system
  - NSTRF (NASA Space Technology Research Fellowship)
    - Raman Spectroscopy of green monopropellant catalyst beds
MSFC Testing Goals

• MSFC has a strong history in large and small propulsion system development
  • Green propulsion systems form a logical component of the spacecraft propulsion development branch’s work and future activities
  • MSFC has invested internal funding for facility modifications, hardware procurements, and test hardware/propellants

• MSFC is striving to help industry, government, and academia advance the TRL on several activities
  • Pushing up to 440N thrust class
    • Allows complete replacement of hydrazine propulsion systems for many spacecraft sizes
  • Pushing down to 0.1N thrust class
    • Less challenging than pushing upwards, but still has challenges in performance data generation
    • Allows 6U or smaller cubesat propulsion system (delta-V and attitude control)
  • Develop and maintain relationships with other groups that need specific propulsion expertise
    • MSFC propulsion has knowledge base in many areas (materials, structures, thermal, etc.) that are critical for understanding thruster performance and propellant properties
  • Understanding the capabilities of other groups to ensure we are not needlessly duplicating efforts
    • Maximizes the investment capabilities
  • Identify collaborative areas
    • Ground testing of commercial hardware
    • In-space flight opportunities of green propulsion technologies
Testing Sites

• Hot-fire and other test activities squeezed into two (2) existing facilities
  • 1N and less in 4205:104
    • Facility is rated for 1 lbm TNT equivalent
    • Vacuum pump system
    • 15-20 torr altitude at steady-state (approximate)
  • 1N to 440N in 4656
    • Vacuum pump and 2-stage gaseous nitrogen ejector system
    • Less than 22 torr steady-state at 22N (average of 14-16 torr)

• Two (2) type 2 indoor magazines for green propellant storage (up to 50 lbm each holding capacity)
  • On-site currently 10kg AF-M315E and 11 kg LMP-103S

• Disposal of residual propellants/hardware with Redstone OBOD (Open Burn/Open Detonation)
  • MSFC is very interested in helping others with procedures/processes for disposal.
Data and Instrumentation Capabilities

- **High Quality Data Acquisition and Control Systems**
  - Dewetron DAQ System
    - 16 channel, 24-bit ADC (delta-sigma), 204.8 kS/s/channel
    - 24 channel, 24-bit ADC (delta-sigma), 12 S/s/channel TC input
  - National Instruments PXIe System
    - 16 channel, 24-bit ADC, 102.4 kS/s/channel strain gauge input
    - 32 channel, 24-bit ADC, 90 S/s/channel TC input
    - 96 channel, 10 MHz maximum rate, Digital I/O

- **High Accuracy Instrumentation**
  - Flow Technologies, Incorporated (Turbine Flowmeters)
    - FTO-1 and FTO-3 series RF pick-off flowmeters
      - FTO-1 range (0.12 to 1.2 mL/sec) for 1N to 5N class thrusters
      - FTO-3 range (1.5 to 15 mL/sec) for 22N class thrusters
  - Kistler Force Sensors
    - Type 9207 Low Level force sensor
      - -50 to 50N range for 0.1 to 22N class thrusters
  - Stellar Technologies
    - ST-120 and FT-260 pressure transducers cavity and flush type
      - Various ranges from 15 psia to 10,000 psig

Water calibration conducted in 4205

Hot-Fire Force Data from 22N thruster testing in April 2015
Recent Activities

- Hot-Fire testing of a 22N LMP-103S Thruster
  - Testing Completed in April 2015
- Hot-Fire Testing of a 1N AF-M315E Thruster
  - Initial testing in July 2015, but continuing to conduct testing currently
22N LMP-103S Hot-Fire

• Hot-fire testing completed in April 2015
• First demonstration of LMP-103S at MSFC
  • Largest LMP-103S green prop tested at the time by NASA
  • MSFC’s purchase of the 22N thruster allowed ECAPS to refine the design and produce a flight weight thruster for use by GSFC on a flight mission
• Final paper is undergoing final review
  • Process started for submission as a JANNAF journal article
1N AF-M315E Hot-Fire Testing

• 1N Hot-Fire Testing successful started July – August 2015
  • Initial testing was minimally instrumented. Focus on hot-fire confirmation.
    • No flowmeter or thrust data (instrumentation not installed)
      • Turbine flow meters are susceptible to over spin damage and thrust structure not ready for installation
  • Non-flight valve used
    • Pressure drops are not correctly set yet, but the estimated flowrate for 1N are as expected (~.3 mL/s)
  • Auto sequence controller not used – Tests conducted manually
  • Following ignition confirmation testing, feed system modified for current propellant conditioning system.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Priming</td>
<td>425</td>
<td>95</td>
<td>~.1</td>
<td>As-needed</td>
<td>4</td>
</tr>
<tr>
<td>Single Pulses</td>
<td>~425</td>
<td>95, 100, 120</td>
<td>~1, ~5, ~10</td>
<td>As-needed</td>
<td>1</td>
</tr>
</tbody>
</table>

1N iridium thrusters (manufactured by PPI)
1N AF-M315E Hot-Fire Movie
1N Cold AF-M315E Testing

- Continuation of initial 1N testing
  - Testing occurred on April 29, 2016
  - Modification of feed system for propellant conditioning
    - Cold (5 degC) to Hot (50 degC) propellant conditioning up to the thruster manifold for continuous operation (no run-time limit)
- Fully instrumented (flowrate and thrust measurements)
- Thrust/Flowrate measurements indicate good performance
- Third test suffered a failure of the thrust chamber
  - Investigation is focusing on two likely causes, but no definitive conclusion to date on the cause of the failure

1N TZM thruster (manufactured by MSFC)
Integrated Cube Sat System Testing

- Ultimate goal is to provide a usable cubesat propulsion module for a flight application
  - NASA designed SLM titanium propellant tanks
  - PPI designed 100 mN thruster
  - NASA designed/manufactured heat shield
  - NASA design/manufactured controller board
    - RS-422 controlled board for valve and heater controls
    - NASA designed/manufactured flight thruster valve
- Following hot-fire demonstration testing, system will integrate with a commercial piston tank for low cost tank testing
- A dual mode (chemical and electrical) propulsion system is scheduled for FY17
Cooperative Agreement Notices (CAN’s)

- Useful mechanism for collaborative work with outside entities (commercial/academia)
  - Low cost with equal cost/manpower sharing between NASA and partner
- MSFC green propulsion development is working three activities
  - Utah State University
    - Hybrid rocket engine technology development
    - Novel ignition of plastic grains (future NASA flight on suborbital rocket is in work)
  - Analytical Mechanics Associates, Inc
    - Low cost titanium propellant tank manufacturing techniques for cubesats and small spacecraft
  - Artic Slope Technical Services Inc.
    - Low power electrical ignition of green propellants
Future Activities

• 5N Busek Hot-Fire Testing
• 445N Orbital ATK hot-fire testing
• 100 mN acceptance testing
• MIT – CAN for Dual Mode Green Propulsion Systems
  • Final approval expected spring 2016
  • Anticipated work starting summer 2016
  • Completion of work in winter 2016/spring 2017
MSFC is hosting two NASA Space Technology Research Fellowships (NSTRF)

- Jared Willits (Purdue) is working on Raman Spectroscopy of green monopropellants
- Second of originally a two year effort in summer 2016, but has been extended two additional years

Experimental investigation of intermediate species in catalytic processes

- Vary the catalyst stack height in available wafer thicknesses to change ‘exhaust species’ seen with Raman spectroscopy

Facility is using the MSFC Nd:Yag 2 J pulsed laser (at 1064 nm)

- Serviced in March 2016 to align beam and swap flash lamps
- Dedicated feed system for AF-M315E, but very interested in other propellants as well
- Currently using catalyst from Plasma Processes, Inc.
  - Other catalyst are welcome

The feed system and laser are easy to operate and can support testing as needed.

Needed items:

- Spectra for various possible intermediate species
- Jared has collected many different spectra, but some of these intermediate species may not have spectra available (or have not been found by us yet)
Summary

• MSFC has been and continues to use internal funding to work on green propulsion technologies

• Continues to reach out to other NASA centers, government agencies, academic centers, and commercial partners to foster collaboration and to combine resources as much as possible
  • Working hard to break down the barriers to working together across the NASA centers has been a goal for management

• Activities are wide ranging and concurrent
  • Completed hot-fire testing of 1N, 5N, and 22N thrusters using both green propellants
  • Continuing with 5N and starting work in 100 mN, 445N thrusters using both propellants
  • Investigating alternative propellants for cubesat applications and additional components than thrusters
  • Testing of high Isp green propellant thrusters in electro-spray applications