

# 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

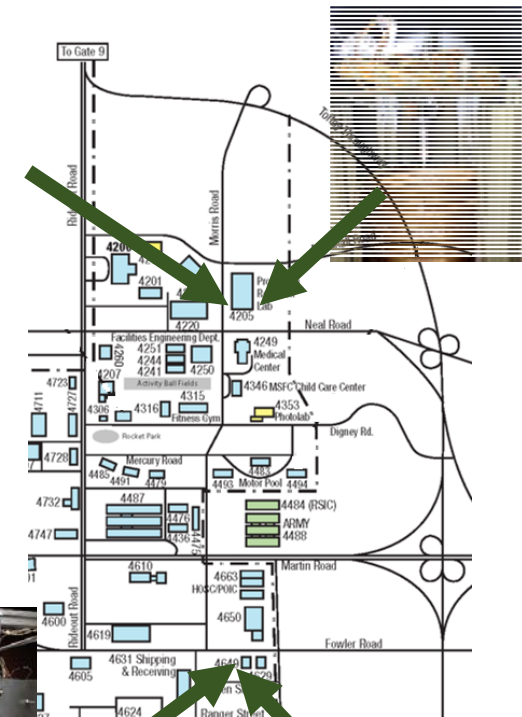
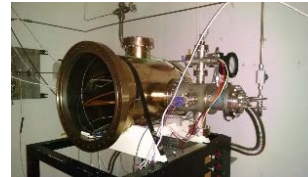


- MSFC has a strong history in large and small propulsion system development
  - Green propulsion systems form a logical component of the spacecraft propulsion development branch's work and future activities
  - MSFC has invested internal funding for facility modifications, hardware procurements, and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

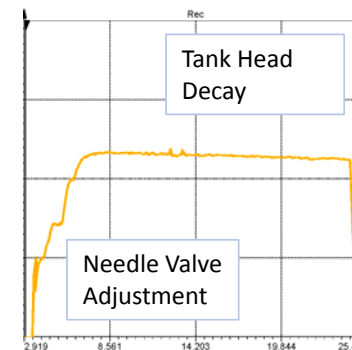
- FTO-1 and FTO-3 series RF pick-off flowmeters
      - FTO-1 range (0.12 to 1.2 mL/sec) for 1N to 5N class thrusters
      - FTO-3 range (1.5 to 15 mL/sec) for 22N class thrusters

- Kistler Force Sensors

- Type 9207 Low Level force sensor
      - -50 to 50N range for 0.1 to 22N class thrusters

- Stellar Technologies

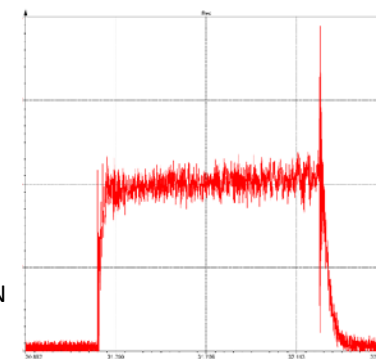
- ST-120 and FT-260 pressure transducers cavity and flush type
      - Various ranges from 15 psia to 10,000 psig



Water calibration conducted in 4205



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



# Recent Activities

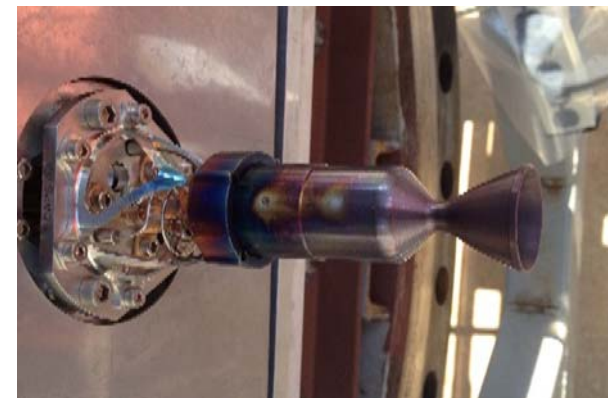


- Hot-Fire testing of a 22N LMP-103S Thruster
  - Testing Completed in April 2015
- Hot-Fire Testing of a 1N AF-M315E Thruster
  - Initial testing in July 2015, but continuing to conduct testing currently

# 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



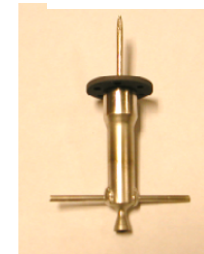
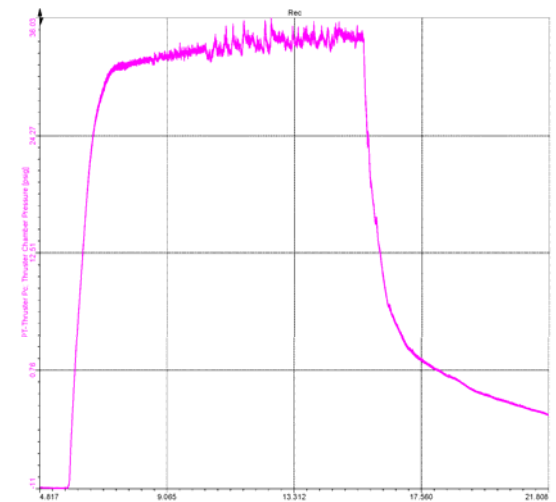
22N LMP-103S Thruster During Hot-Fire Testing



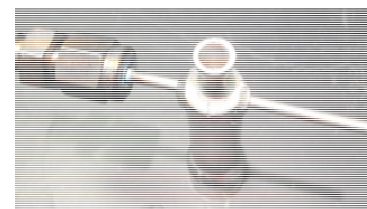
# 1N AF-M315E Hot-Fire Testing



- 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 ( $\sim 0.3$  mL/s)
  - Auto sequence controller not used – Tests conducted manually
  - Following ignition confirmation testing, feed system modified for current propellant conditioning system.



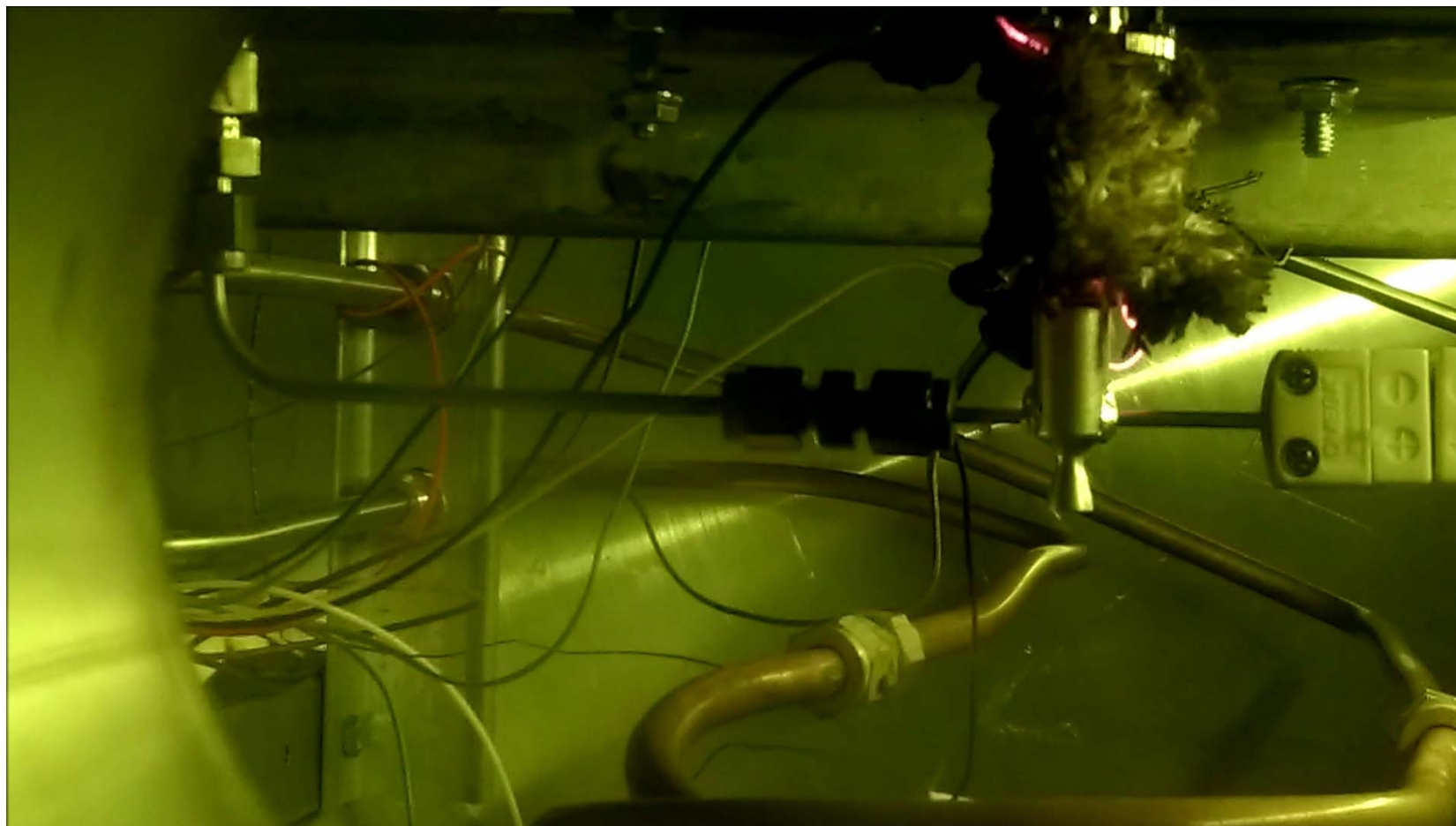
1N iridium thrusters  
(manufactured by PPI)



Description	Heater T [degC]	Tank P [psig]	On-Time [sec]	Off-Time [sec]	# pulses
Priming	425	95	$\sim 1$	As-needed	4
Single Pulses	$\sim 425$	95, 100, 120	$\sim 1$ , $\sim 5$ , $\sim 10$	As-needed	1



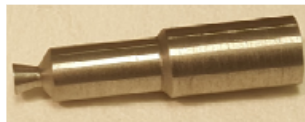
# 1N AF-M315E Hot-Fire Movie



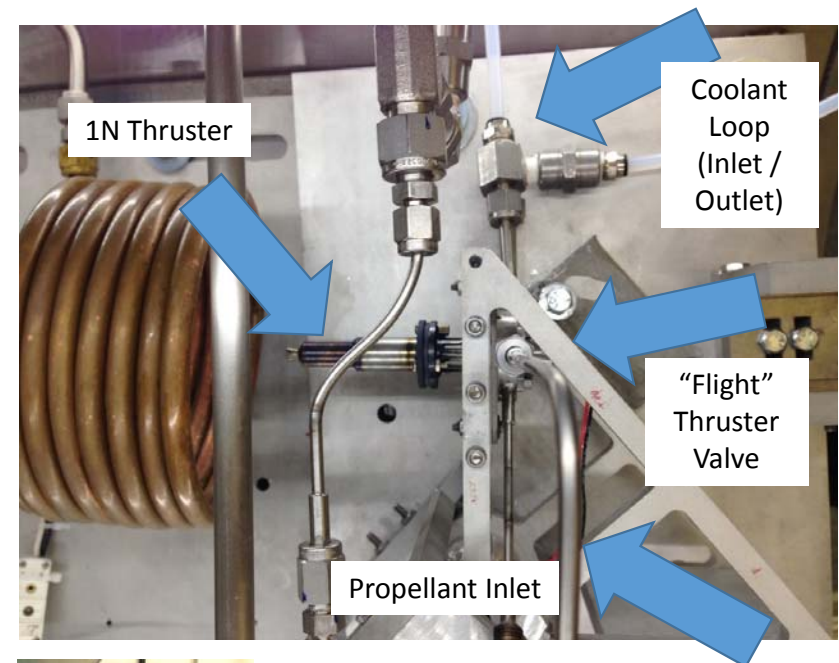
# 1N Cold AF-M315E Testing



- 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 TQM thruster (manufactured by MSFC)

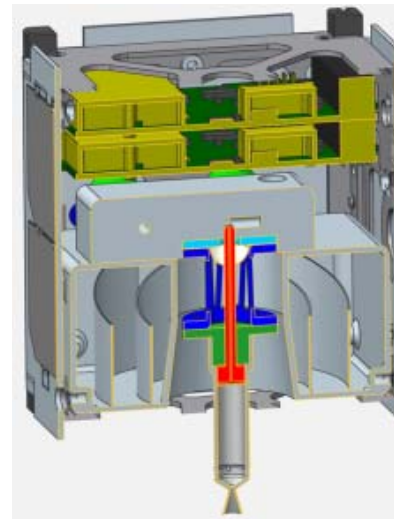


1N test stand (thruster not installed) looking toward thrust measurement stand and heater (in front of copper coil)

# Integrated Cube Sat System Testing



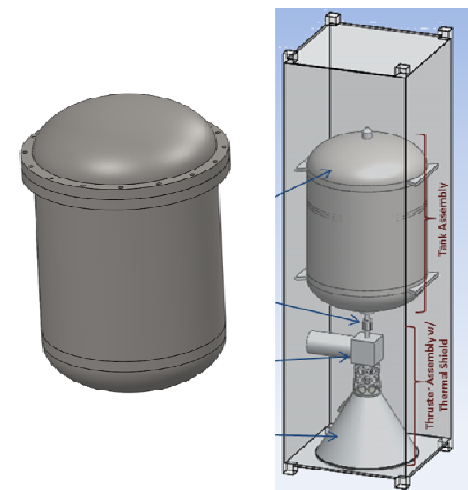
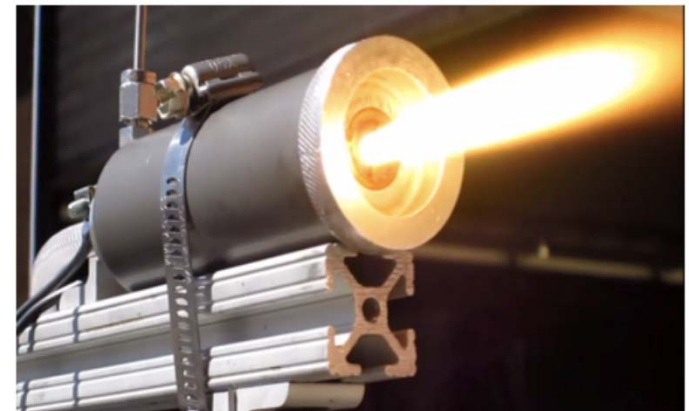
- Ultimate goal is to provide a usable cubesat propulsion module for a flight application
  - NASA designed SLM titanium propellant tanks
  - PPI designed 100 mN thruster
  - NASA designed/manufactured heat shield
  - NASA design/manufactured controller board
    - RS-422 controlled board for valve and 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



# NSTRF – Raman Spectroscopy



- 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)



ND:Yag laser during servicing in March 2016

# 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



