GREEN PROPULSION AUXILIARY POWER UNIT DEMONSTRATION AT MSFC

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ABSTRACT

In 2012, the National Aeronautics & Space Administration (NASA) Space Technology Mission Directorate (STMD) began the process of building an integrated technology roadmap, including both technology pull and technology push strategies. Technology Area 1 (TA-01)[1] for Launch Propulsion Systems is one of fourteen TAs that provide recommendations for the overall technology investment strategy and prioritization of NASA's space technology activities. Identified within TA-01 was the need for a green propulsion auxiliary power unit (APU) for hydraulic power by 2015. Engineers led by the author at the Marshall Space Flight Center (MSFC) have been evaluating green propellant alternatives and have begun the development of an APU test bed to demonstrate the feasibility of use. NASA has residual APU assets remaining from the retired Space Shuttle Program. Likewise, the F-16 Falcon fighter jet also uses an Emergency Power Unit (EPU) that has similar characteristics to the NASA hardware. Both EPU and APU components have been acquired for testing at MSFC. This paper will summarize the status of the testing efforts of green propellant from the Air Force Research Laboratory (AFRL) propellant AF-M315E based on hydroxyl ammonium nitrate (HAN) with these test assets.

INTRODUCTION

Starting in April 2010, the Office of Chief Technologist (OCT) began the Nanoenergetics Propulsion Project (NEPP) with MSFC managing the effort. The project was initiated to develop game-changing propellants for chemical rocket propulsion. With the development of nanomaterials, and in particular nanoenergetics, the potential existed to develop new propellants that previously could not be imagined. Nanoenergetics such as aluminum offer benefits in combustion systems such as lower ignition temperatures and increased reactivity.[2]

Starting in January 2011, the author was assigned to take over Project Manager responsibilities. Unfortunately, due to OCT budget priorities, the project was cancelled 8 months later at the end of Sept 2011. However, the Technology Assessment Group, made up of other NASA Centers, industry representatives, Department of Defense (DoD) agencies, and academia, recommended additional propellant combinations in the summer of 2011. Of the various propellants considered for nanoenergetics applications, the use of ammonium dinitramide (ADN) was a leading concept. Further meetings at MSFC were conducted with ATK, the Swedish Space Corporation, the Ecologically Advanced Propulsion System (ECAPS) group and the Swedish National Space Board (SNSB) to discuss use of ADN in the green propellant LMP-103S.

During the final months of NEPP, MSFC led discussions with Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL) regarding use of green propellants for future spacecraft opportunities. Further discussions also began with the OCT Small Satellite Office at the Ames Research Center (ARC). In Sept 2011, the Swedes invited MSFC, GSFC, and ARC to attend a week of events focused on their propellant. The group observed Prisma operations, the first satellite launched with LMP-103S propellant, from the ECAPS facility in Solna, Sweden where maneuvers were transmitted to the satellite real time to show capability. The team also visited the test facilities in Grindsjon and visited Eurenco to see ADN processing in Karlskoga.

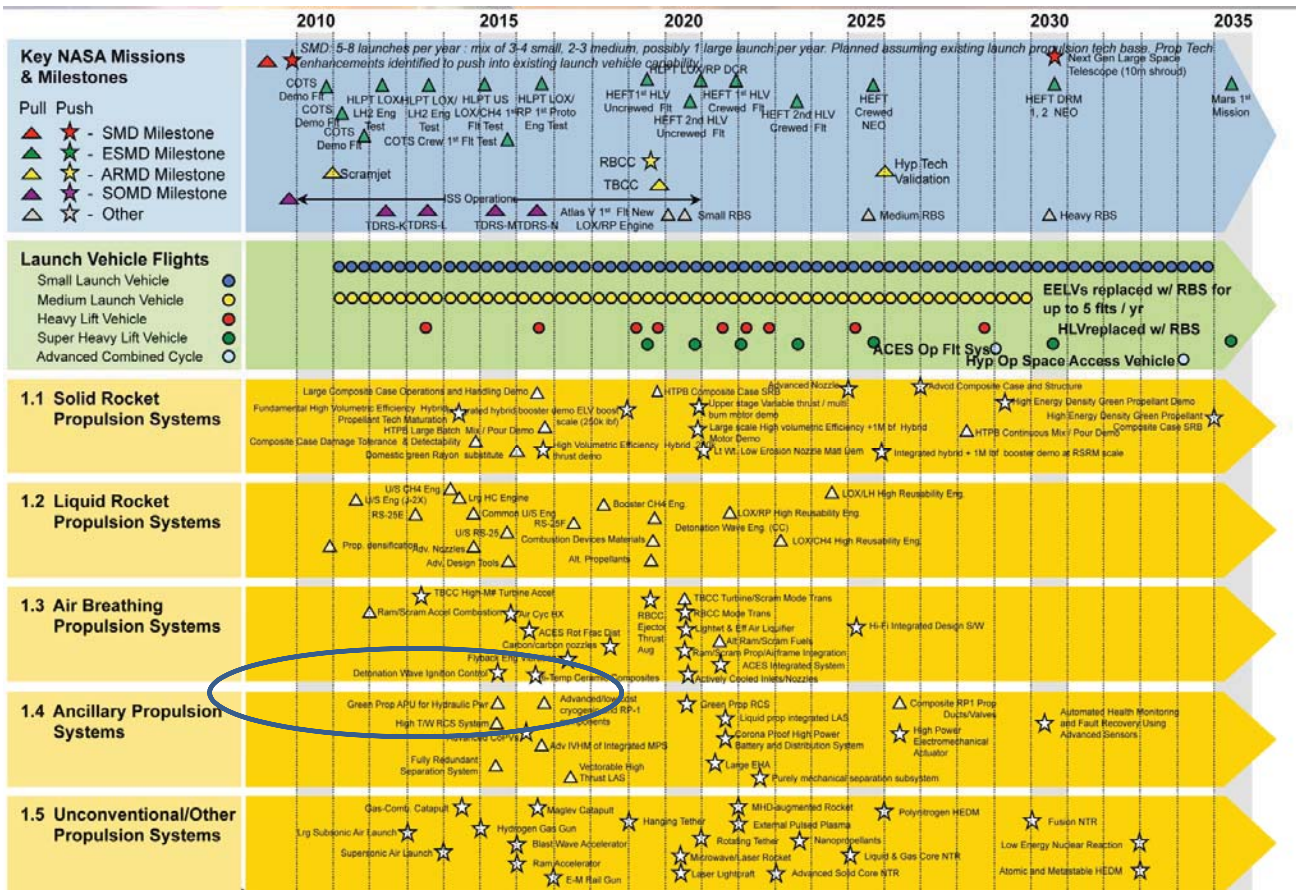

Figure 1. A summary schedule of NASA's Technology Roadmap for propulsion, highlighting a Green Propulsion APU for Hydraulic Power targeted for 2015.

In December 2011, the author was invited to present on green propulsion at the NASA Expendable Launch Vehicle Payload Safety Program Workshop at the Kennedy Space Center (KSC). This lead to a separate visit to KSC a month later to provide a Technical Interchange Meeting with range safety personnel with other NASA Centers attending the briefing. Coinciding with the timing of the visit in Jan 2012 was a community announcement from NASA OCT of a future solicitation coming from the Technology Demonstration Mission (TDM) Office focused on green applications.[3]

Figure 2. Visit to FOI Test Facility.

Green propellants offer a variety of improvements over existing propellants. The author has presented in this forum on testing of cryogenic, green propellants at MSFC using liquid oxygen/liquid methane in 2010[4] and 2012[5]. Recent attention has focused on the potential replacement of hydrazine. Improvements include having a storable liquid monopropellant, with good pulse performance and higher specific and density impulse. These green monopropellants are easier to handle and transport, and in some cases are compatible with commercial off-the-shelf components and hardware. The most attractive benefits are in the safety protocol improvements: lower shock sensitivity, lower toxicity, non-carcinogenic, and environmentally benign.

Various experts in the field have different ways of describing the attributes and advantages of green monopropellants. From this author's perspective (beyond the items noted above), there are three classifications. First, are there any environmental issues with the propellant production? How safe is it to produce and how repeatable is the process? Second, how well does it transport/off-load? This deals with the lower shock sensitivity and eliminating the need for SCAPE suits while handling. Third, and not typically discussed, what are the byproducts of combustion? While there are statements about how environmentally benign the exhaust may be compared to interaction with humans, a strong emphasis should be placed on the effects once in-orbit. For instance, there are highly sensitive optics used in space and soot from hydrazine systems can be detrimental. The author believes as the green monopropellants gain a foothold in applications that this feature will increase their usage even further.

TDM PROPOSAL

Once the TDM call came out in February 2012, various Centers and industry partners split off in different directions to pursue the opportunity. The solicitation had three major areas for consideration. First were the applications: spacecraft primary propulsion, spacecraft reaction control systems, launch vehicle roll control, and launch vehicle power generation. Second were the testing/flight environments: ground, aerial, suborbital, and orbital. Lastly, the call was capped at $50M USD but TDM was considering awards in the low-, medium-, and high-cost classifications, but never delineated the thresholds for cost categories.

Based upon the variety of discussions from multiple site visits, the author teamed as principal investigator (PI) with ATK and ECAPS to assess use of green propellants for auxiliary power units (APU). The proposal focused on a low-cost, ground-tested, launch vehicle power generation concept.

The work was divided into three phases: research and early risk reduction testing, gas generator (GG) testing, and culminating in an APU demonstration. During the time of the call, the NASA Space Launch System (SLS) Program was acquiring hardware from the retired Space Shuttle Program, including multiple GG and APU assets. Unfortunately, SLS was reluctant to provide many assets for research uses as the Program wanted to reserve the hardware for multiple flights and margin for spare equipment. Agreement was reached to acquire a single GG and a single APU. Given the limited amount of hardware, a suitable replacement was needed for Phase 1 testing.

In developing the proposal, the PI identified other DoD assets that could be used as surrogate hardware in support of this activity. Both the U-2 and F-16 airplanes use a form of hydrazine (H-70 or 30% diluted with water) for auxiliary power needs. There are a limited number of U-2 assets and given their United States national security implications, MSFC could not pursue that option. However, there have been over 4,400 F-16 fighter jets sold since inception to the DoD inventory. While demonstrating the green propellants in the H-70 environment will prove to be more difficult given the lower decomposition temperature, a successful demonstration to SLS could infuse potential future use.

ASSESSMENT OF OTHER POWER SOLUTIONS

While the Space Shuttle Program was active, the Agency used hydrazine-fueled APUs in two different applications. There were two APUs mounted in the tail section of each solid rocket motor to provide nozzle gimbaling during the first 2 minutes of ascent. There were also 3 APUs mounted in the shuttle orbiter to provide power for a variety of systems once on-orbit. While the SLS design does not include use of hydrazine fueled APUs for their crewed spacecraft (Orion), solid rocket motors are still baselined for 1st-stage propulsion of the vehicle stack. Based on discussions with SLS personnel, alternative approaches for APUs are a gas blowdown system, a lithium-ion battery, or a thermal battery-driven motor.

An external gas blowdown system may employ the use of a stored gas, most likely Helium, to drive the APU turbine. The primary disadvantage to this concept is the mass and volume required to store the compressed gas. A similar approach is to use gaseous Hydrogen tapped off of the main stage liquid propellant rocket engine. However, APU checkouts would be problematic without the rocket engine in operation. An additional system would be required to provide the gas for checkout purposes. In addition, future launch system elements may not have direct access to the liquid rocket engine and would require a disconnect for staging, adding to its complexity.

Lithium-ion batteries require many cells that must be matched, which drive the weight and the costs. The disadvantage of thermal batteries lies in operation or turnaround. For APU checkouts, an external power source is required and in the event of a launch abort or scrub, these batteries must be replaced. The use of a propellant alternative to hydrazine provides a green, high power density packaged power source that can be started multiple times with minimal effects on turnaround from the issues presented of the other concepts. In addition, this propellant could also be used for launch vehicle roll control, hereby limiting the overall system mass and lowering the complexity of the propulsion systems.

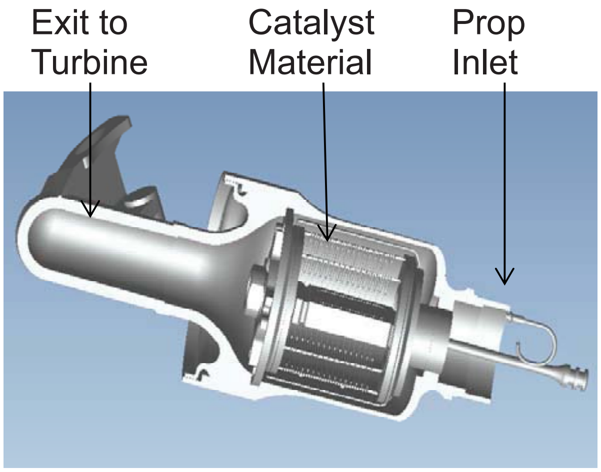

Figure 3. APU gas generator.

STATUS OF CURRENT WORK

The primary objective of the proposed TDM work was to demonstrate the use of LMP-103S to APU systems while minimizing changes to existing hardware. While it is true that the leading green propellants have their own proprietary blend of catalyst to maximize thruster performance, in many ways the opposite is needed for APU applications. Rocket engine components and systems are designed to withstand the higher temperatures experienced with maximizing combustion efficiency. However in the case of the existing Shuttle heritage APU and F-16 EPU, the downstream components were designed to hydrazine combustion products and lowered temperature effects compared to green propellant exhaust.

So in essence, can the community explore use of green propellants (either ADN or HAN based) with the existing Shell 405 catalyst material and the materials of construction for downstream components? Some existing work has shown that Shell 405 catalyst can combust with ADN and HAN-based propellants, but that the life of the catalyst becomes an issue. When looking at this issue through the lens of the thruster focus, a washout or retarding effects of catalyst poisoning would immediately send engineers retreating from this as a possible solution. This is in large part measured by the duty cycles of RCS thrusters, the on-time demand for pulsing, and the life expectancy of satellite missions for multiple years of operation. When looking at this issue from the standpoint of a limited-life focus, perhaps even single use application for APU/EPUs, the use of green propellant with existing hydrazine catalysts seems on the surface very promising. Of course, the devil lies within the details.

Assessment of this activity determined that the highest risk was the current decomposition temperature of green propellants (double if not higher than hydrazine). Risk reduction options were to a) dilute the propellant, since water is an ingredient for most green propellants, b) reduce the residence time that the propellant is in contact with the catalyst, or c) dilute the exhaust post-decomposition. Having not been selected for the TDM award, current focus has shifted to dilution of propellant to reduce future test activities by eliminating design modifications to the existing hardware available.

After OCT evaluated the proposals received for the TDM solicitation of FY2012, the Agency selected in August 2012 a single award for the Green Propulsion Infusion Mission (GPIM), focused on demonstrating satellite operations with the AFRL-developed green propellant, AF-M315E. Given these results, the author has continued to pursue Center investment funding to advance this concept, albeit at a slower pace than originally proposed. During FY13, Center funds were made available to acquire two F-16 emergency power units (EPU) from the Davis Monthan Air Force Base (AFB) in Tucson, AZ. Aircraft at that base are typically scavenged for parts and/or eventually scrapped.

During FY13, residual Shuttle assets at KSC that were not transferred to SLS were being disposed of from the inventory. For less than $15k USD, the author has received the two EPUs, an APU checkout unit, two APU controllers, and associated checkout cabling. All total, all hardware received totals $2.9M USD but only transport costs were the outlay. Retaining these assets allows MSFC to consider pursuing additional

APU testing assuming the near-term demonstrations are achieved.

Figure 4. Removing an EPU from a retired F-16 at Davis-Monthan AFB.

As FY14 started, the author developed partnership arrangements with KSC and the Dryden Flight Research Center (DFRC) for consideration of Center Investment Funds (CIF). In reaching out to KSC, there was interest in demonstrating leak detection capability as the GPIM mission is scheduled to fly in FY15 from their launch facilities. The teaming would allow for KSC to demonstrate leak detection on MSFC-tested EPUs prior to use in service for the GPIM mission. With their proximity to the United States Air Force Edwards AFB, DFRC would be able to coordinate use of an F-16 from Edwards to demonstrate ground testing of the green propellant EPU. Given the GPIM use of HAN propellant, the author contacted AFRL for support and in turn received reactivity and minipino testing to identify ignition delay and pressure rise prior to propellant being sent to MSFC.

At present, MSFC is building up the test capability at our Component Development Area (CDA). The CDA provides component, hydrostatic, leak, proof, burst, electrical function, and system level testing. The facility has two outdoor explosion-proof test cells with low- and high-speed data acquisition systems with inert gaseous distribution systems for support purging and pressurization. Initial testing at MSFC is planned with a single EPU gas generator, eventually testing the EPU as a system. Assuming successful testing with the KSC provided leak detection sensors, the green propellant EPU will be shipped to DFRC for installation into an F-16 aircraft. The ground test will demonstrate that the landing gear can be deployed and that the aero control surfaces are properly exercised.

Figure 5. Component Development Area (CDA) at MSFC.

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