



Progress in Red Vs Green Propellants

AF-M315E Load Operations Results and Lessons Learned

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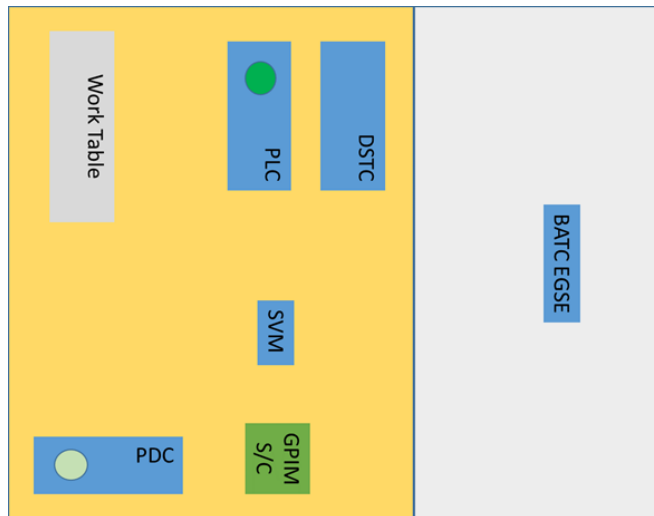
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Introduction

- Green Propellant Infusion Mission (GPIM) is a NASA Space Technology Mission Directorate funded effort to demonstrate Advanced Space Craft Energetic Non-Toxic (ASCENT, formerly known as AF-M315E) technology
- AFRL was co-investigator with Ball Aerospace & Technologies Corporation (BATC) to establish and demonstrate ASCENT load operations in support of flight demonstration
- 3 previous publications
 - Initial publication contrasted hydrazine versus ASCENT operations
 - Jacobs, J., Watson, L. and Labrador, J., RED VS. GREEN PROPELLANTS, An Operational Comparison of Hydrazine-based and AF-M315E-based Thruster Testing. 5th JANNAF Spacecraft Propulsion Subcommittee, December 2011, Huntsville, AL
 - Succeeding two publications specific to load operations approach and trial results
 - Jacobs, J.; Adkison, P.; Gabrang, G., Red vs. Green Propellants: Propellant Load Operations for AF-M315E Part I. 7th JANNAF Spacecraft Propulsion Subcommittee, June 2015, Nashville, TN
 - Jacobs, J., Adkison, P., Emory, D., Gabrang, G., Zuttarelli, A., Progress in Red vs. Green Propellants, Part II. 8th JANNAF Spacecraft Propulsion Subcommittee, December 2016, Phoenix, AZ

PGSE Synopsis

- PGSE layout unchanged from previous presentations
- Comprised of 4 components
 - Propellant Load Cart (PLC), 1
 - Dry Side Tank Cart (DSTC), 2
 - Service Valve Manifold (SVM), 3
 - Propellant Detank Cart (PDC), 4
 - Practice Tank, 5
- Practice configuration shown at right



- Operational configuration shown at left
- Line lengths were sufficient for re-arrangement
- All liquid and gas pathways that communicated with the GPIM Green Propellant Propulsion System (GPPS) were cleaned to IEST-STD-CC1246E Level 50 standard
 - All wetted lines and fittings comprised of compatible translucent polymer
 - All gas lines and fittings comprised of stainless steel

PGSE Synopsis

- Service Valve Manifold (SVM)
 - Interface between all PGSE components and the spacecraft
- Load configuration sampling panel used 2X 250 mL bottles rather single 1 L bottle shown
- Lessons learned:
 - Reuse (repeated cleaning) of PFA lines and fittings changes their shape, more difficult to assemble and meet leak requirements
 - Evacuation path from bottom to top of sample bottle makes decontamination flush more difficult
 - Sample panel was disposed of in solid waste stream after use



- Propellant Load Cart (PLC)
 - ASCENT transfer from shipping container to spacecraft and sampling panel via the SVM
- Line lengths were sufficient for re-arrangement
- Lessons learned:
 - Diaphragm pump was not used for flight load operations
 - Was integrated in event pressure difference insufficient to maintain flow to meet load objective in one shift
 - Tendency to introduce bubbling at start up
 - Required much practice to achieve load accuracy
 - Future configurations may require less procedural refinement if using syringe pump rather than diaphragm pump

PGSE Synopsis

- Dry Side Tank Cart (DSTC)
 - High pressure branch for Ghe leak check and GN2 load of Green Propellant Propulsion System (GPPS)
 - Vacuum branch for evacuation
- All stainless steel lines, no wetted propellant contact



- Propellant Detank Cart (PDC)
 - Evacuates ASCENT ullage from load lines
 - Reservoir loaded with approximately 25 gallons of deionized water
 - Ensures sufficient diluent to meet established standard to take the evacuated ASCENT from a UN Class 1.3C explosive to a Class 3 flammable

Documentation Readiness

- Approval of Missile System Prelaunch Safety Package (MSPSP) required ahead of operations
- Spacecraft (payload preparation) procedures are part of the MSPSP
 - All equipment and operations must be in compliance with Air Force Space Command Manual 91-710
 - Documentation must be on hand to demonstrate compliance
 - Requirements can be tailored and still meet intent to assure risk mitigation
- AFRL requested tailoring of marking requirements for PGSE
 - 17 marking requirements for PGSE
 - Put forward use of “dog tags” on all pressure load bearing components of PGSE
 - Would have impeded quick turn serviceability
 - Requested tailoring to allow for use of a Component Identification Number (CIN) that refers back to a build book with all required information

AFSPCMAN 91-710 Para No	Original Text	Revised Text
11.2.1.7.3. [a]	Individual lengths of fabricated assemblies of pipe and tubing in ground support pressure systems shall be identified with part number and/or contractor tracking number, pipe or tube size, schedule number or wall thickness, test pressure, and the date of the hydrostatic and/or pneumatic test.	Individual lengths of fabricated assemblies of pipe and tubing in ground support pressure systems shall be identified with a CIN that references to the following information located in the build book: part number and/or contractor tracking number, pipe or tube size, schedule number or wall thickness, test pressure, and the date of the hydrostatic and/or pneumatic test.
11.2.1.7.3. [b]	Identification data for piping and tubing in ground support pressure systems shall be affixed to fabricated assemblies by means of an attached stainless steel band or “dog tag” that has been stamped or electrochemically etched.	Identification data for piping and tubing in ground support pressure systems shall be permanently affixed to the item by means of a laser marking.

Documentation Readiness

- Check Lists (CL) and Standard Operating Procedures (SOP)
 - 5 CL and 9 SOP required for ASCENT PGSE operations developed
 - Subservient to 2 Ball Aerospace & Technology Corporation (BATC) overarching procedures
 - Accompanied by a PID configuration sheet for each operation
 - 3 SOP were contingency
 - Spill Response
 - Detank
 - Carboy Swap
- CL and SOP development continued from early demonstration
 - Demonstration covered basic load operations of PGSE, did not encompass other facility and spacecraft considerations
- Change logs kept to track evolution
 - Eased review/approval cycle

CL or SOP Designator	Purpose
CL 1-14-8595-0001	PGSE Leak Check
CL 1-14-8595-0004	PPE and Cleanroom Inspection
CL 1-14-8595-0005	PDC Setup-Shutdown
CL 1-14-8595-0006	Scale Calibration
CL 1-14-8595-0011	Spill Response
SOP 1-14-8595-GPIM-3001	ASCENT Shipping Container Install
SOP 1-14-8595-GPIM-3002	ASCENT Point of Use Sample
SOP 1-14-8595-GPIM-3003	GPPS Evacuation
SOP 1-14-8595-GPIM-3004	ASCENT propellant load
SOP 1-14-8595-GPIM-3005	GN2 Pressurant Load
SOP 1-14-8595-GPIM-3006	PGSE Decontamination
SOP 1-14-8595-GPIM-3007	Detank
SOP 1-14-8595-GPIM-3008	GPPS Leak Check
SOP 1-14-8595-GPIM-3009	Carboy Swap

PGSE Readiness

- PGSE original execution plan targeted September 2015 launch
- Time afforded by launch delays used for additional practice through 2017
 - Upon completion of practice trials, all PGSE had to be dismantled for cleaning
 - Time lapse from reassembly to launch exceeded required proof and calibration intervals
- AFSPCMAN 91-710 requires annual hydrostatic or pneumatic proof test
 - PGSE also required to be IEST-STD-CC1246E Level 50 standard clean
 - For PGSE internals, used pneumatic test to meet requirement without violating cleaning
 - For external lines (flexible hoses) used hydrostatic test
- AFSPCMAN 91-710 also requires all calibrated items to be within calibration interval
 - Calibrated items were put under Contingency Exception Equipment (CEE) status
 - Enables delay of calibration interval start date up to 18 months from actual calibrations
 - Interval begins upon first use
 - Necessary for PGSE since removal, calibration, cleaning and reinstall impractical
- Decontamination standard for return non-hazardous shipping of ASCENT wetted PGSE
 - Deionized water flush until readings of 10 ppm or less nitrate content
 - Basis from guidance provided in 49 CFR 171.8
 - Approximately 50 gallons of deionized water used in operations

Crew Readiness

- PGSE SOPs were activated by overarching BATC procedures
 - Load operations required both AFRL and BATC personnel

Position	Duties
TC	Responsible for conducting the test as outlined in the overarching test countdown and associated documents and for directing all activities.
LC	Responsible for conducting the test as outlined in the test countdown and associated documents for the PGSE and for directing all activities of the Red Crew.
OE	Responsible for supporting LC maintaining status of the PGSE and ensuring LC follows the test as outlined in the test countdown and associated documents for the PGSE.
TPO	Responsible for operating the PGSE test panels during propellant operations. Receives Instructions only from the LC and perform tasks only after being directed by the LC.
TSO	Responsible for operating the spacecraft test set during propellant operations to provide propulsion system status and operate any valves as directed. Receives Instructions only from the TC and perform tasks only after being directed by the TC.
RCL	Responsible for supervising activities of the Red Crew. Has available a current copy of the SOP while performing test activities; receive instructions from the LC and perform tasks only after being directed by the LC; and immediately notify the LC of problems encountered or uncertainties.
RC	Responsible for performing potentially hazardous operations and tasks during propellant operations.

- LC, TPO, RCL, & RC positions were AFRL staffed
 - Additionally, had analytical lab support position standing by as back up
- Several practice load trials executed leading up to actual load operations
 - Rehearsal with overarching BATC procedure also performed to ensure continuity during handoffs

Crew Readiness

- A minimum of generalized training was required for the AFRL load team since directly handling ASCENT
 - Training was accomplished at AFRL on recurring basis

Training	Purpose
Energetic Materials	Site specific training to ensure understanding of energetic material hazard and mitigation within the local environment
Hazardous Communications	Facility specific training to ensure understanding of energetic material hazard and mitigation within the work area
Facility Safety	Facility specific training to ensure all personnel know the particular facility safety control measures
Fire Extinguisher	Understand different types of fires and fire extinguishers
CPR & First Aid	Stabilize fellow personnel until professional help is obtained

- Documentation of training currency needed to perform hazardous operations
- As with proof and calibration, it is critical to track required training intervals to ensure they do not expire while in operations

ASCENT Readiness

- Particulate count and makeup was of specific concern due to lack of legacy data for ASCENT
 - Sensitivity driven by the small dimensions of the various flow control devices in the propulsion system
 - Assessment of particle size and distribution was made relative to the IEST-STD-CC1246E level 50 standard

IEST-STD-CC1246E standard, based upon 100 mL sample volume		
Particle Size Range (µm)	Level 50 Allowable Particles	Level 100 Allowable Particles
5-15	141	1519
15-25	17	186
25-50	6	67
50-100	1	9
100-250	0	1

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Date	8/29/2018	5/24/2019	5/24/2019
Sample	KSC Receipt	Point of Use #1	Point of Use #2
Particle Size Bins:	Particle Count:		
5-10	197	77	51
11-25	99	56	33
26-50	62	61	42
51-100	37	39	15
100-250	20	25	17

- Particulate count in the size bins greater than 10 microns were out of specification
 - Additional contingency filter options assessed
 - 10 micron filter in PLC and 3 micron filter in SVM
 - Numerous additional fittings required to integrate
 - Weren't pursued due to additional risk from FOD & ability to leak check

ASCENT Readiness

- Particulate count in the size bins greater than 10 microns were out of specification
 - Particulate make up assessed
 - Found to be comprised of a non-rigid cellulosic material that would break up upon light contact
 - Characteristics were not considered a risk to the system
- GPPS included 25 micron filter
 - Analysis performed per AIAA 92-3535
 - Results showed no danger of overwhelming the filter
- “Go” for load

Lessons Learned (1 of 2)

- Introduction of ASCENT to flight environment required additional effort early in program
 - Educated all involved of the credible risks associated with ASCENT
 - Supported assessment of PGSE design and approach for compliance with AFSPC 91-710 requirements
 - Defined in CL, SOP, and PID documentation
 - Ensured all required facilities had appropriate explosive site plans and facility capabilities to allow ASCENT operations
- Re-use of compatible translucent polymer components is not recommended since the material does slightly change in dimension with cleaning
 - If re-use is desired for the sample panel, flow path should accommodate both ease of sample draw and decontamination
- Maintaining PGSE readiness requires attention to proof and calibration currency over long periods of latency
 - Where calibration intervals cannot be extended, sufficient time should be planned for component removal and reintegration
 - Any removal and reintegration activity should be executed as near to component clean standards as possible
- Experience with initial PGSE architecture revealed areas for functional improvement
 - A spare for each gage in the system should be on hand
- Tailoring of AFSPCMAN 91-710 requirements to meet intent and support more efficient operations should be pursued
- Cross organizational teaming requires clear hierarchy, role definition and coordination
 - Rehearsal of procedures and handoffs from one to another critical for smooth execution
 - Team skill set should include direct experience with all components within the system

Lessons Learned (2 of 2)

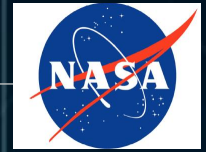
- Microfiltration of ASCENT may be required if the propellant is intended for use with systems having high sensitivity to particulates
 - PGSE should implement additional filtration capability
- Particulate analysis should include assessment of particulate properties
- Spacecraft propulsion system filter capacity analysis is necessary based upon particulate data
- Combination of particulate property and spacecraft propulsion system filter capacity necessary for load “go/no-go” decision

Summary and Conclusions

- GPIM objective of successful demonstration of ASCENT monopropellant (Advanced Space Craft Energetic Non Toxic, formerly known as AF-M315E) ground operations accomplished
 - Established acceptance, decontamination and waste stream methodology standards
- Lessons learned related to introduction of energetic material to the launch operation environment
 - PGSE design improvements recognized
 - ASCENT particulate assessment requires collateral data
 - Applicable to ground test and common energetic operations
- Success of initial ASCENT operation demonstration anticipated to reduce the efforts of follow on missions

Acknowledgements

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 - NASA Glenn Research Center
 - SpaceX
 - USAF 45th Space Wing
 - USAF Space and Missile Systems Center Space Test Program



Questions?