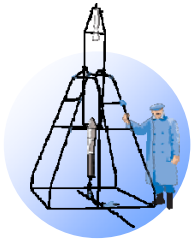
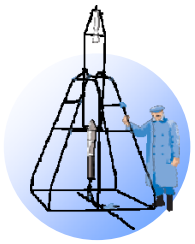


GFLD

Green Propellant Loading Demonstration at U.S. Range

Henry W. Mulkey, Joseph T. Miller, and Caitlin E. Bacha
NASA Goddard Space Flight Center, Greenbelt, MD 20771

52nd AIAA/SAE/ASEE Joint Propulsion Conference
25 - 27 July 2016, Salt Lake City, Utah



Overview

Structured as a pathfinder activity for LMP-103S propellant U.S. Range approval

- Scope:
  - Accept LMP-103S propellant on U.S. Range, Wallops Flight Facility (WFF)
  - Storage of LMP-103S propellant
  - Handle the propellant during a simulated flight vehicle propellant loading
  - Define initial requirements for facility, ground support equipment, and protective equipment

- Benefits:
  - First LMP-103S handling / loading at U.S. Range
  - NASA Goddard Propulsion personnel managed all aspects of the operation
  - Gained first-hand knowledge of LMP-103S handling through loading operations
  - Self Contained Atmospheric Protective Ensemble (SCAPE) not required
  - Direct comparison to N_2H_4 loading from recent hydrazine-based missions
    - Global Precipitation Measurement (GPM)
    - Magnetospheric Multiscale (MMS)

Collaboration

SNSB ⟷ **NASA**

•Implementing Arrangement (IA) between SNSB and NASA for cooperation in the testing and analysis of Green Propulsion Technologies
•SNSB has been a key funding source for the development of HPGP Technologies

GSFC

•NASA IA Point of Contact
•Procedure Development
•Implementation/ Handling
•Management
•Safety
•Logistics

ECAPS

•HPGP IP Owner
•Provide LMP-103S
•Provide Fuel Cart
•Procedure Support
•Handling Support/Training

Green Propellant Loading Demonstration

Pathfinder activity for U.S. Range approval for LMP-103S propellant to assist missions desiring the performance increase associated with green propellants

WFF

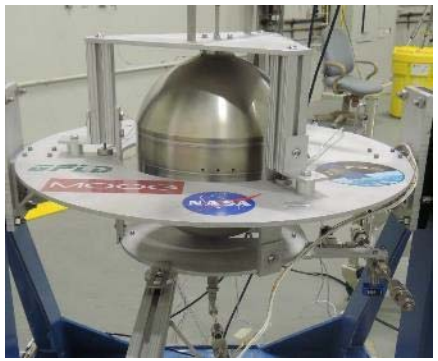
•Range Safety Analysis
•Receive LMP-103S Propellant
•Store LMP-103S Propellant
•Loading Demonstration Facilities

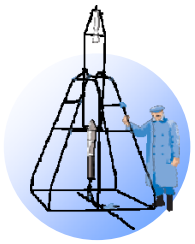

LMP-103S Shipping Container

ECAPS Fuel Cart

Moog Inc.

•Loan of Flight Development Tank and Latch Valve to GSFC
•Interest in Green Propulsion Technology


Moog Inc. Tank in GPLD Dolly Fixture



GPLD – 2014 – 2015 Timeline

2014

August

September

October

November

December

2015

January

Initial Discussions with Moog Inc. regarding Tank Loan – JPC 2014

Moog Inc. Tank maturation and design requirements initiated

GPLD - IRAD Selected to Proceed

MMS Launch Operations

GSFC – Moog Inc. Bailment Agreement commenced

MMS Water Load Demos

MMS Functional Testing

MMS Propellant Loading

Moog Inc. Ti diaphragm air reversal

MMS Launch

February

March

April

May

June

July

GSFC – Moog Inc. Bailment Agreement Signed and Finalized

FDT Ti Tank Design Finalized

FDT Ti Tank Diaphragm Manufactured

GPLD - IRAD Mid-Year

FDT Ti Tank Domes Manufactured

GSFC – WFF GOWG # 1

FDT Tank 3D printed for Dolly fabrication

GSFC Resources/ Procurements Originated

GSFC – WFF GOWG # 2

FDT Turnover Dolly Design and Fabrication Starts

LMP-103S Propellant shipped to WFF

FDT Ti Tank Welding and Final Assembly

August

September

October

November

December

DAQ-in-a-Box build started

GSFC – Moog Inc. Bailment Agreement Amended for Loan of Latch Valve

GSFC – WFF GOWG # 3

Moog Inc. FDT Tank ATP

GSFC –ECAPS Procedure Table Top

GSFC – WFF GOWG # 4

FDT Turnover Dolly Complete

Procedures supplied to WFF

Moog Inc. FDT Tank received at GSFC

GSFC – Procedure Table Top

DAQ-in-a-Box build complete

GPLD Water Load and Decon Practice # 1

GSFC – WFF GOWG # 5

Moog Inc. Tank Burst

GSFC – Procedure Table Top

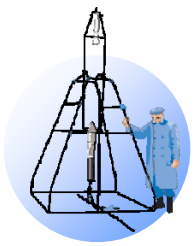
ECAPS FC arrives at WFF

GPLD Water Load and Decon Practice #2 WFF Safety Participation

GSFC – WFF GPLD TRR

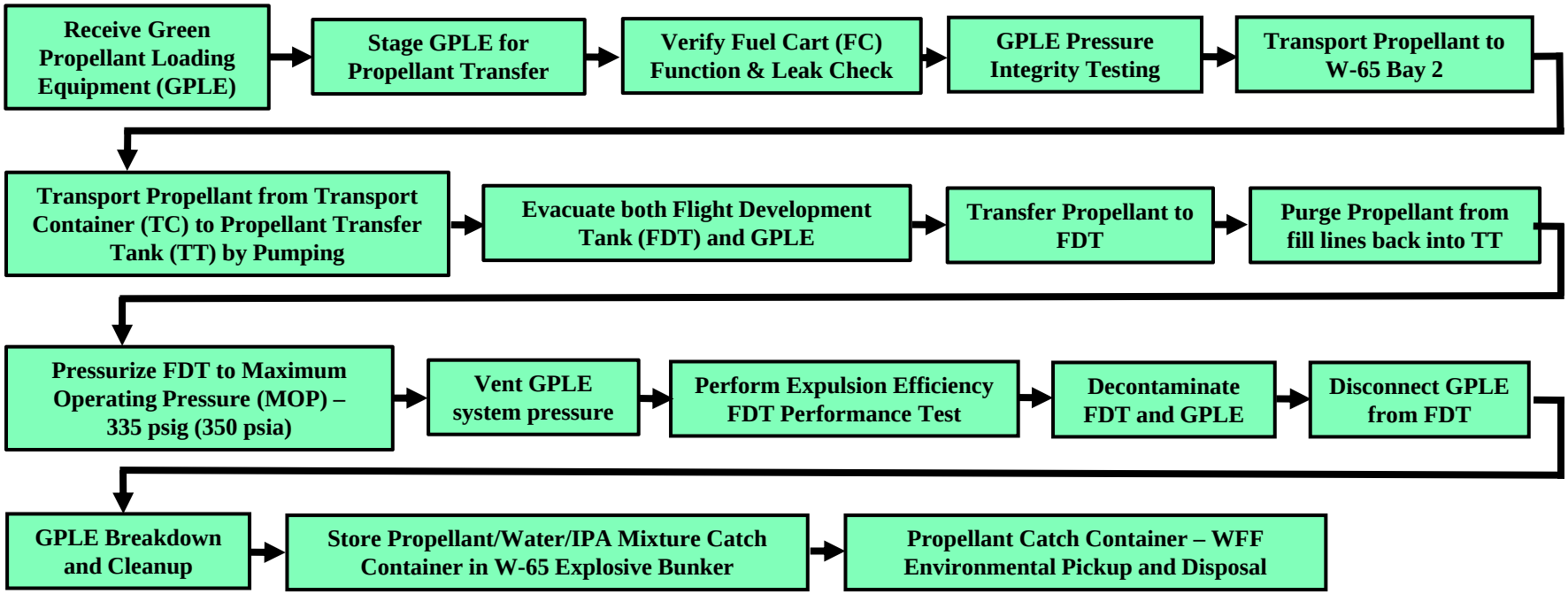
GPLD OPERATION

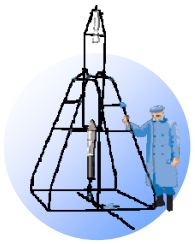
GPLD Procedures and WFF Safety Documents Approval



Operation Plan

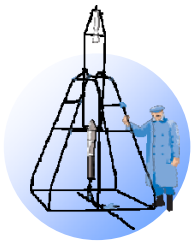
- Intended to emulate flight vehicle propellant loading operation
  - Similar to GPM and MMS performed by NASA Propulsion personnel
- Structured after the Prototype Research Instrument and Space Mission technology Advancement (PRISMA) spacecraft non-hazardous LMP-103S propellant loading operation
  - PRISMA launched 2010 utilizing High Performance Green Propulsion (HPGP) system





Operations Required Personnel

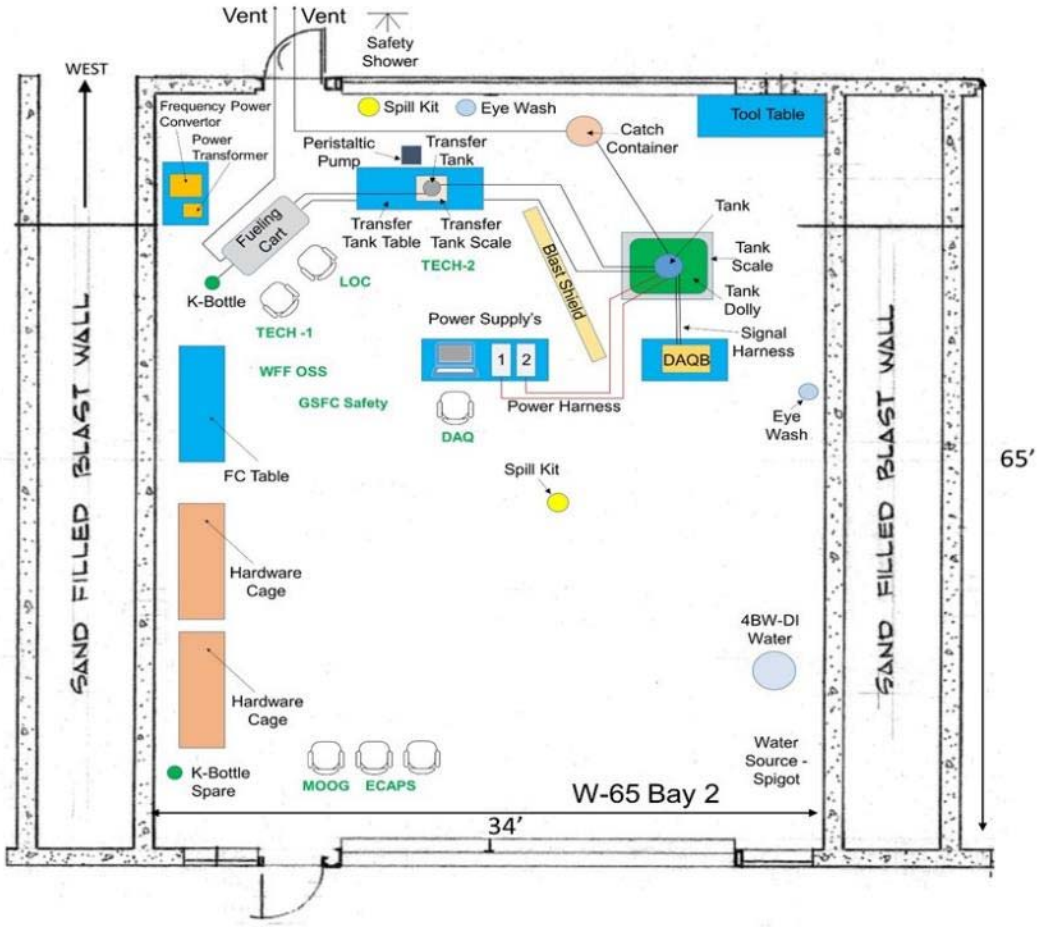
Organization	Critical / Essential Personnel	Operation	Job Responsibility
NASA-GSFC	GPLD Operations Coordinator (LOC)	Nominal Critical Pressurization	Lead Propulsion Engineer running the procedure and directing the overall operation.
	Instrumentation Operator (DAQ)	Nominal Pressurization	Propulsion Engineer primarily responsible for monitoring and recording through LabVIEW FDT temperatures, pressures and load cell output on the DIAB. Also in charge of Latching Isolation Valve (EPV-1) actuation
	Fueling Cart (FC) Operator (TECH-1)	Nominal Pressurization	Propulsion Technician primarily responsible for operating the FC.
	Transfer Tank / Peristaltic Pump Operator (TECH-2)	Nominal Critical Pressurization	Propulsion Technician primarily responsible for operating the TTA and FDT valves, and peristaltic pump operator for propellant transfer. Also, on stand-by to fill in and help out as necessary if required
	GSFC Safety Representative (Safety)	Nominal Pressurization	Monitors the operation to ensure safety of the personnel and the hardware.
NASA -WFF	WFF Safety (OSS)	Nominal Critical Pressurization	NASA WFF safety specialist who will monitor the GPLD operation to ensure the safety of the facility.
ECAPS	ECAPS Personnel	Nominal	LMP-103S Handling and Fueling Specialist
	ECAPS Personnel	Nominal	
Moog Inc.	Moog Inc. FDT subject matter expert	Nominal	Moog Inc. personnel Flight Development Tank (FDT) expert



Handling Facility

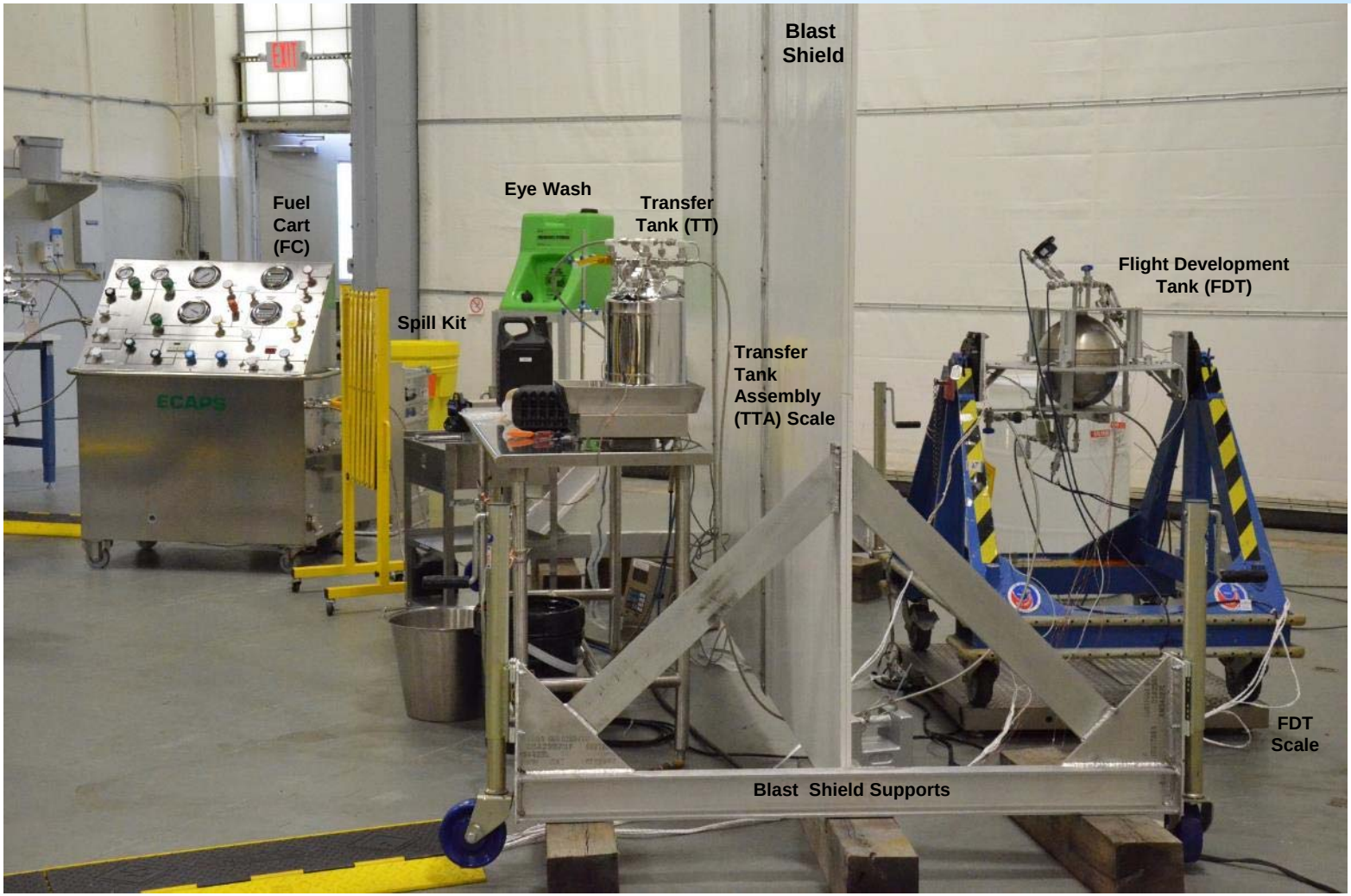
- Processing Facility W-65 Bay 2
  - 34’ x 65’ x 21’ (10 x 19 x 6.4 m)
  - Volume - 46,410 ft^3 (1314.2 m^3)
- Explosive Class 1.1 and 1.3 rating
- Non-Critical personnel stationed in Bay 3
- Safety shower and eye-wash Station
- Propellant storage bunker
- No scrubbers or air exchangers

WFF W-65 Facility



W-65 Bay 2 Facility GPLD Proposed Layout

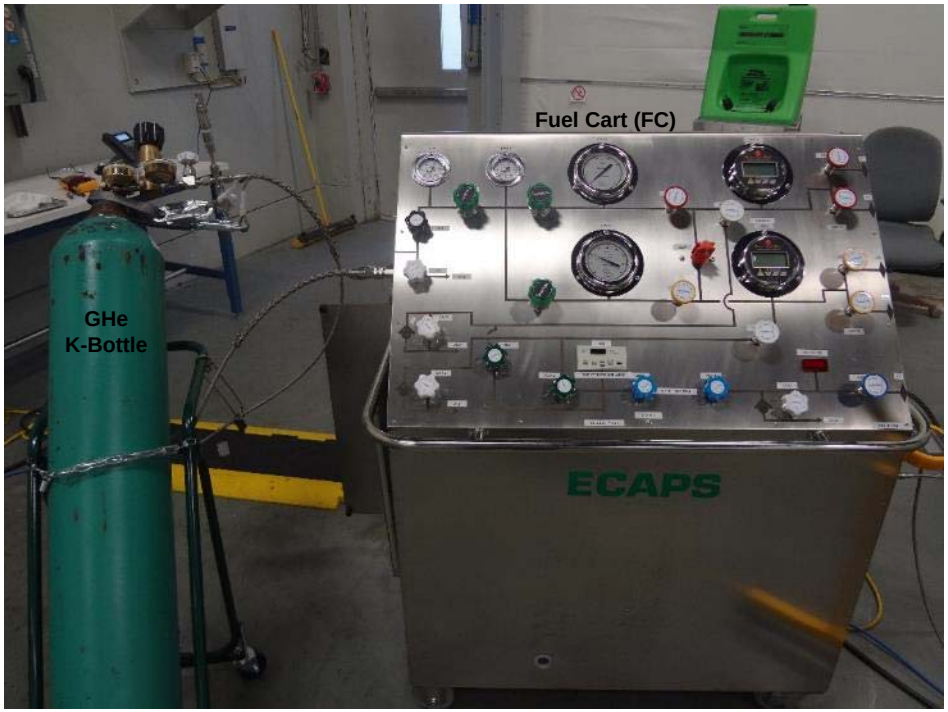
GPLD Facility – GPLE Layout



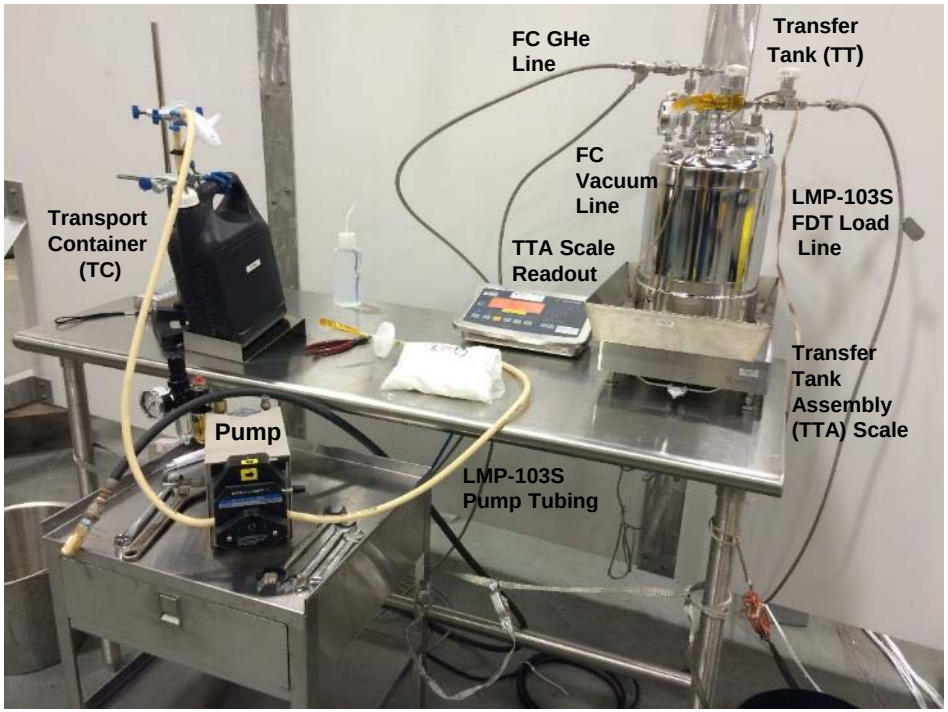
Green Propellant Loading Equipment (GPLE) Staged Overview - WFF W - 65 Bay 2 Facility

GPLD Facility – GPLE Layout

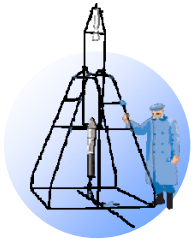
- The Fuel Cart (FC) was utilized for pressurization, vacuum and controlling the LMP-103S propellant flow into the Moog Inc. Flight Development Tank (FDT)
- LMP-103S propellant was pumped from the Transport Container (TC) into the Transfer Tank (TT)



ECAPS Fuel Cart

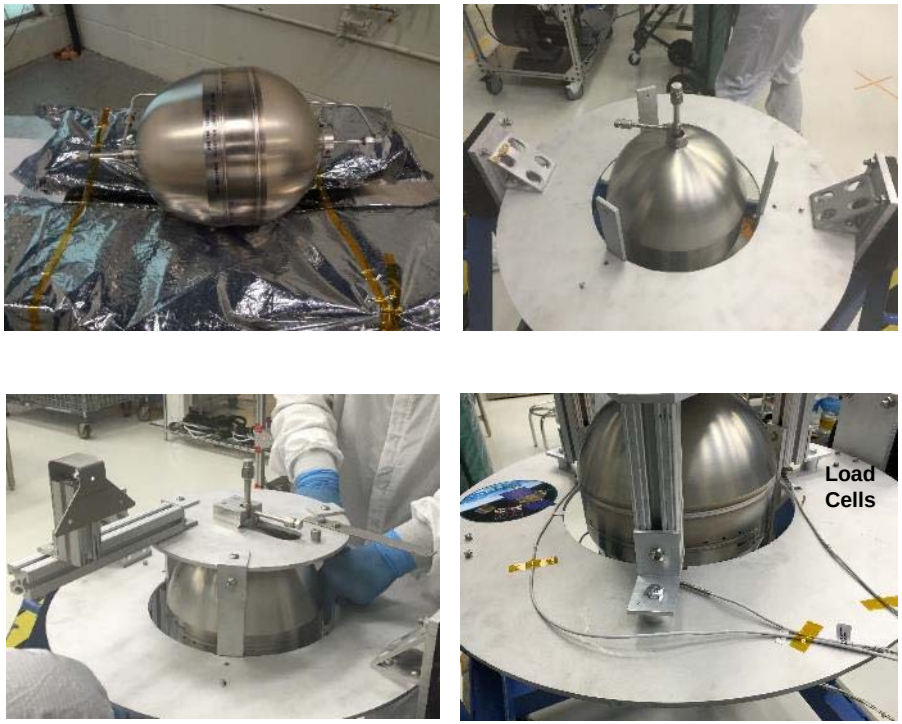


GPLD - Transfer Tank Processing Area

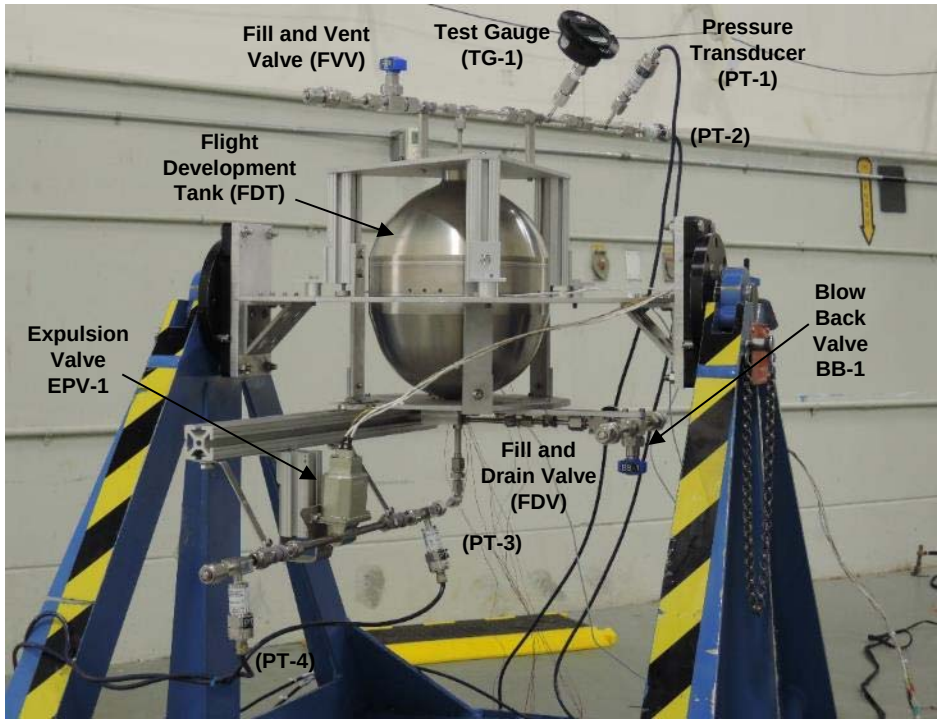


FDT Tank and Dolly Mounting

- MOOG Inc. FDT Titanium Rolling Diaphragm
- Re-purposed Get Away Special (GAS) dolly
- Custom tank mounting fixture with load cells mounted at 120º spacing
- 3-D printed surrogate tank to fabricate dolly



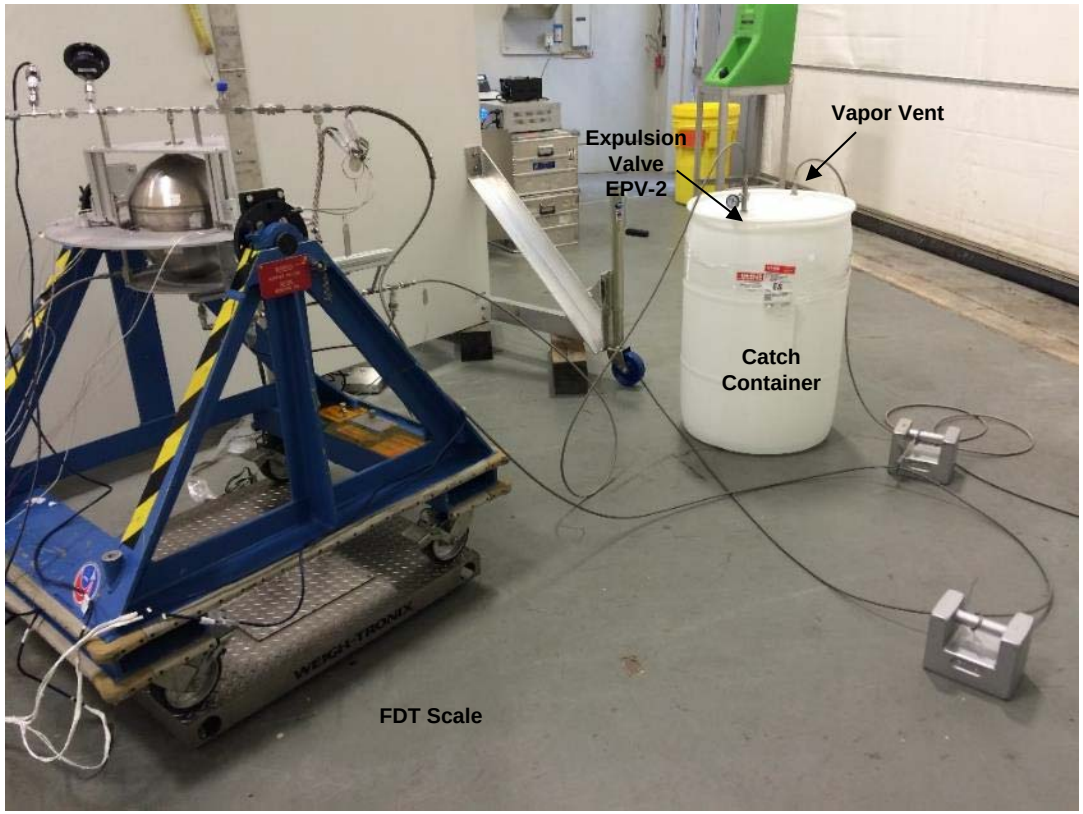
FDT Dolly Installation



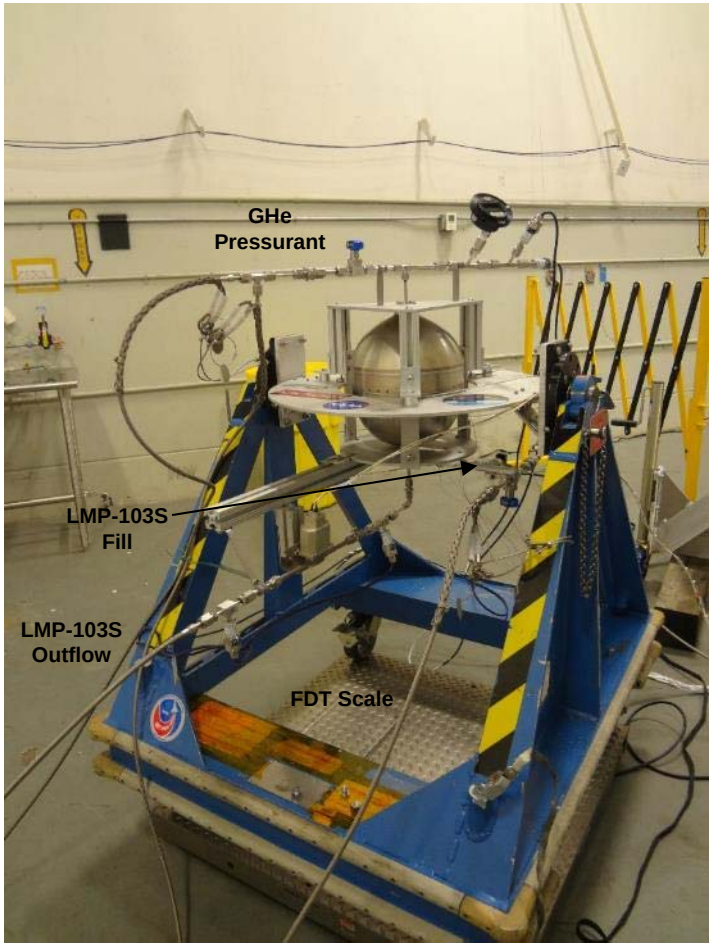
GPLD FDT Dolly Installation

Facility – GPLE Layout

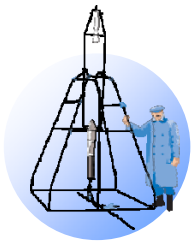
- LMP-103S propellant expelled into Catch Container by opening Expulsion Valve (EPV-1) Latch Valve
- Vapor vented to outside of W-65 Bay 2 facility



GPLD FDT Expulsion and Catch Container

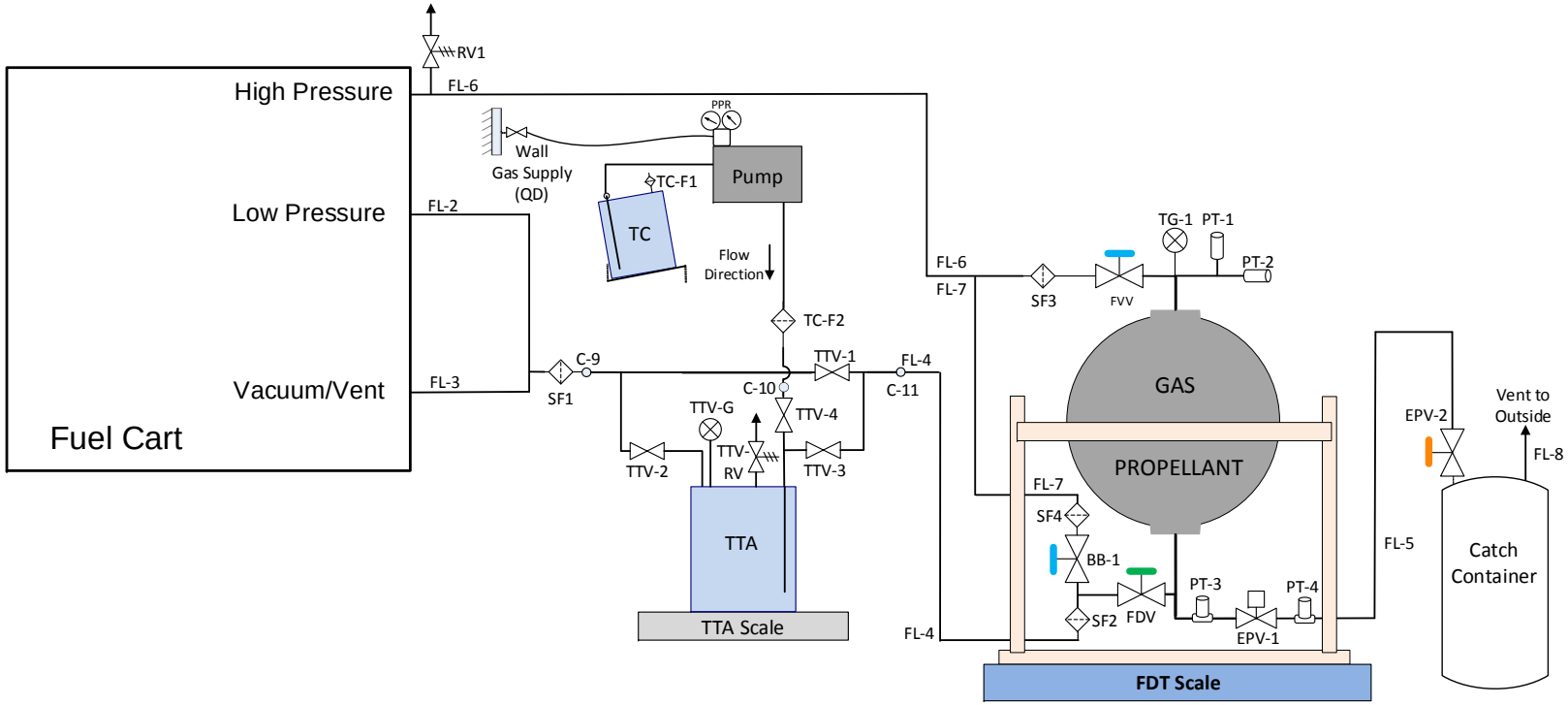


GPLD FDT Final Configuration

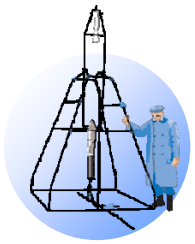


Transfer Tank Loading

- Post Pressure and Vacuum Integrity Testing
- Transfer Tank (TT) filled with GHe during Low Pressure Integrity Test
- LMP-103S propellant pumped from 2 x LMP-103S propellant Transport Containers (TC) into TT using air-driven peristaltic pump
- Total TT LMP-103S Load = 8.2 kg (18.1 lb)

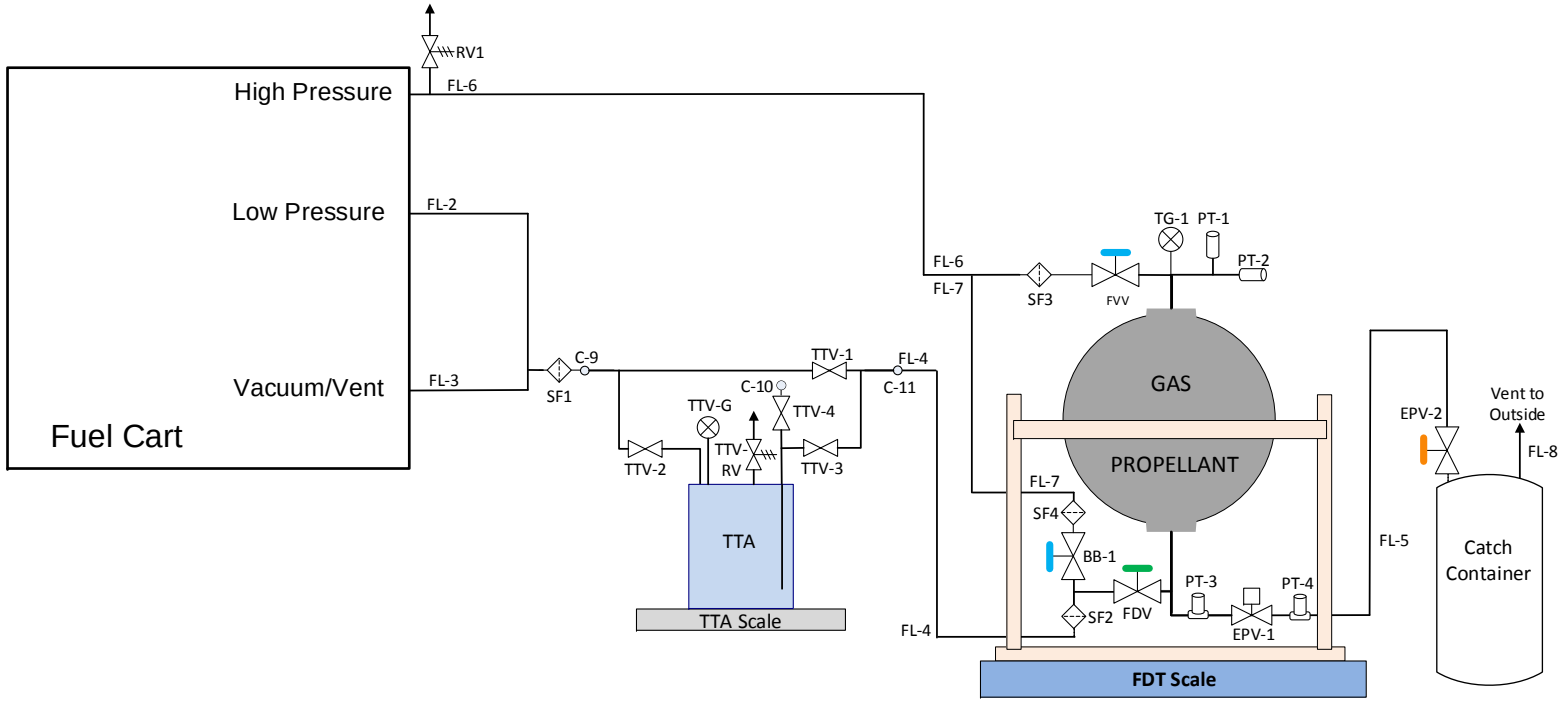


GPLE Transfer Tank (TT) Loading

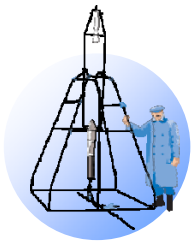


FDT Load and Expulsion

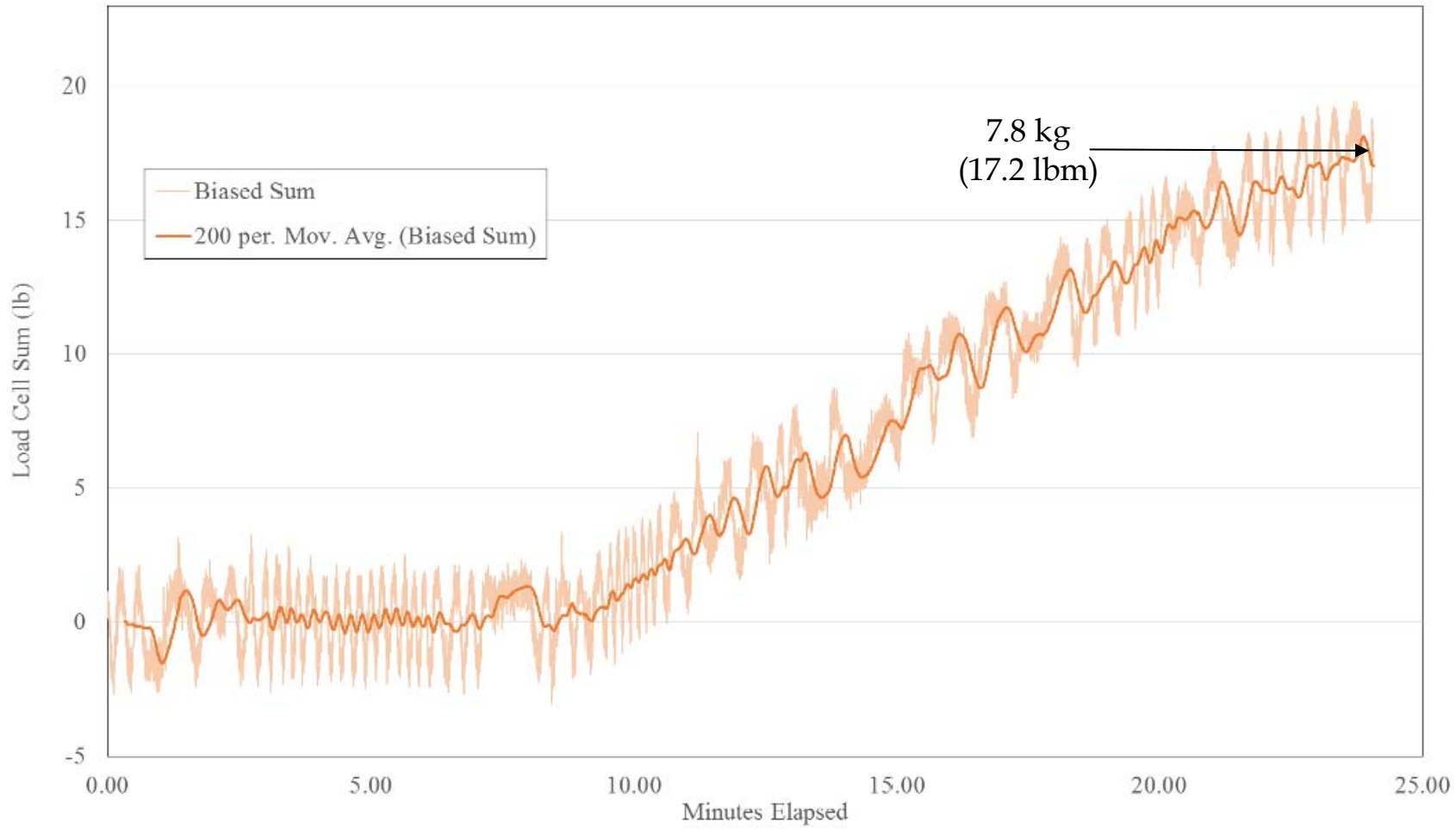
- Flight Development Tank (FDT) tank and feed lines evacuated
- LMP-103S propellant loaded into Moog, Inc. FDT
  - Total Load 7.8 kg (17.2 lbm)
- FDV isolated and pressurized to 350 psia – 24.13 bar(a)
- FVV isolated and EPV-2 partially opened
- EPV-1 valve remotely opened and LMP-103S expelled through EPV-2 into catch container



FDT Propellant Loading and Expulsion

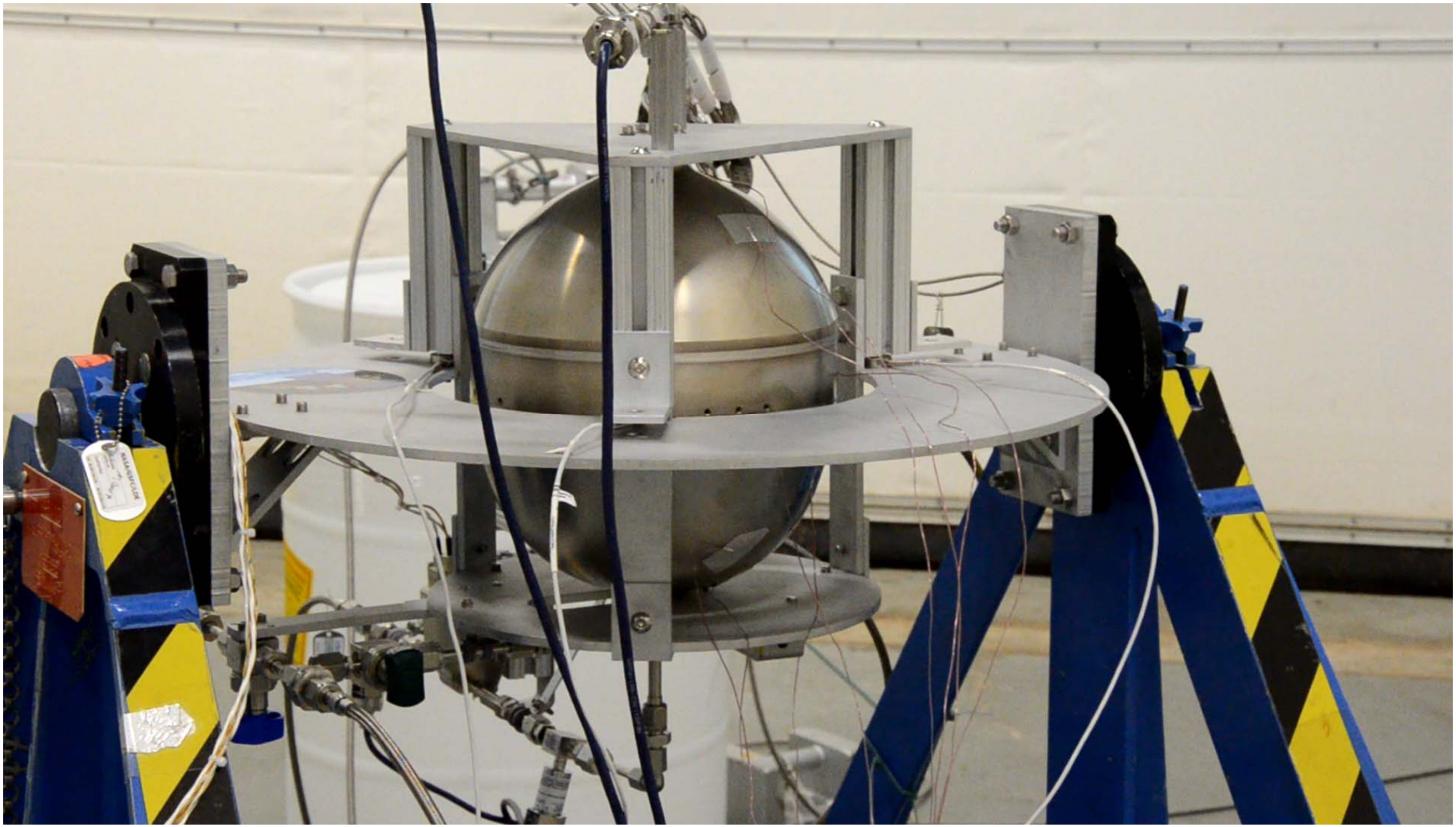


FDT Load

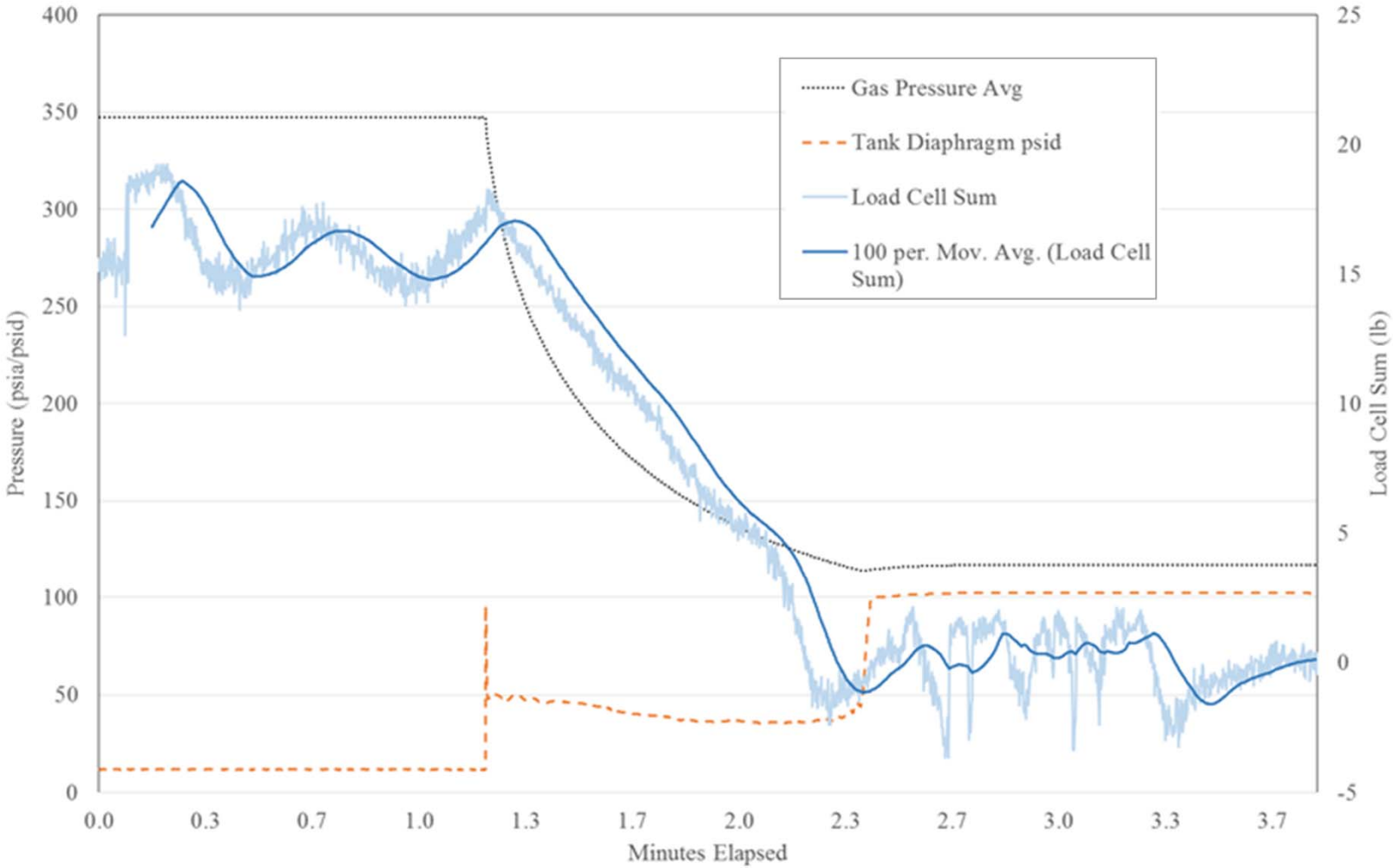


FDT Propellant Loading – Load Cell Data

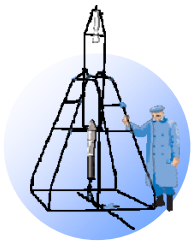
FDT Expulsion



FDT Expulsion

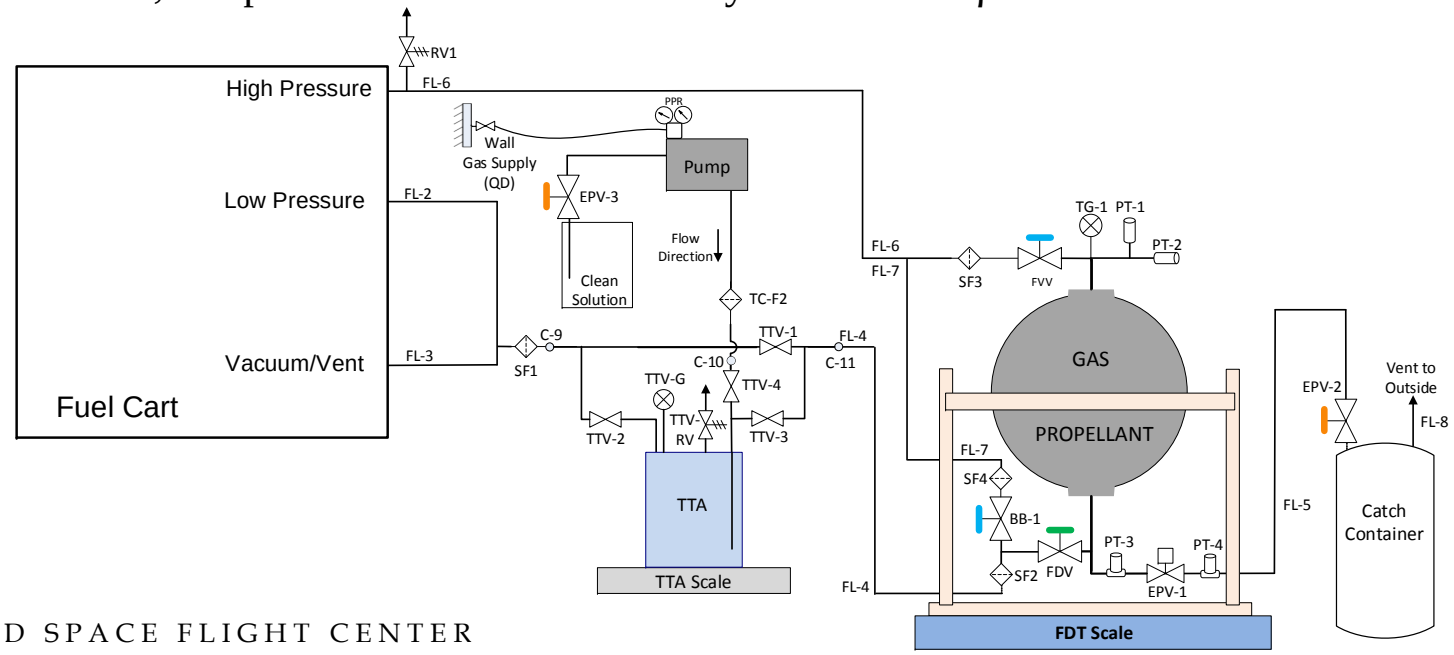


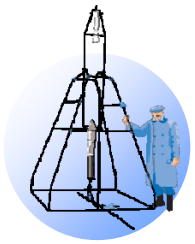
FDT Expulsion – Pressure and Load Cell Data



Decontamination – Plan

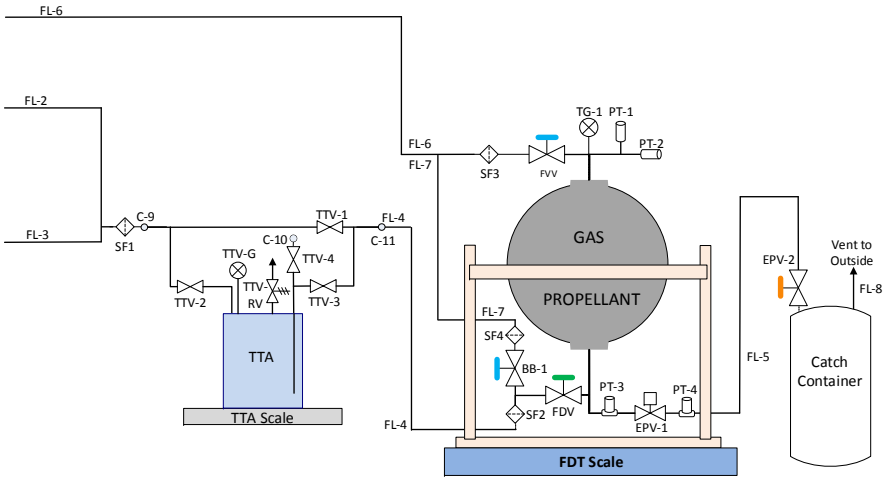
- Move FDT diaphragm from expelled position and disconnect FL-7 from BB-1
- Reconfigure set-up to include sample valve
- Transfer cleaning DI Water from milk jug into propellant TT
- Lift and swish, then push out of transfer tank into catch container waste tank
- Flush with DI water, sample and measure conductivity of water <5 µS/cm
- Sample valve re-positioned to Tee at EPV-1 inlet
- Transfer DI water from milk jug into propellant transfer tank and pushed into FDT
- Swish tank on dolly – rock about axis
- Flush with DI water, sample and measure conductivity of water <5 µS/cm





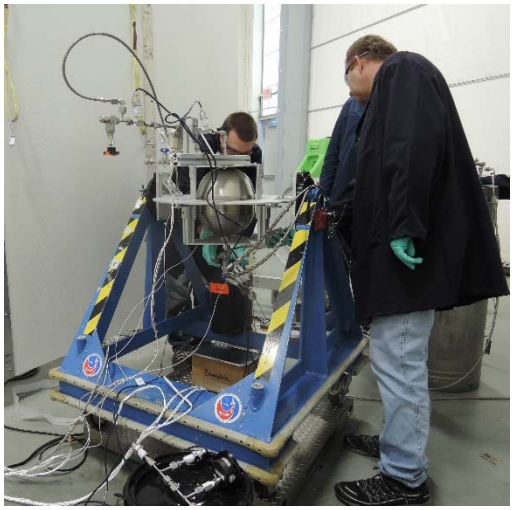
Decontamination

- No gas purging before liquid: Dry gas evaporates solvents in water leaving ADN salts
- EPV-2 valve clogged during venting and purge
  - This fact led to more complex decon than anticipated
  - GSE and FDT decon in less than 8 hours
- Two cycles to successfully decon TT
- Five FDT fill and drain cycles to successfully decon Tank

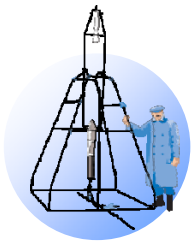


Post Expulsion Venting and Purge

FDT Decon Process

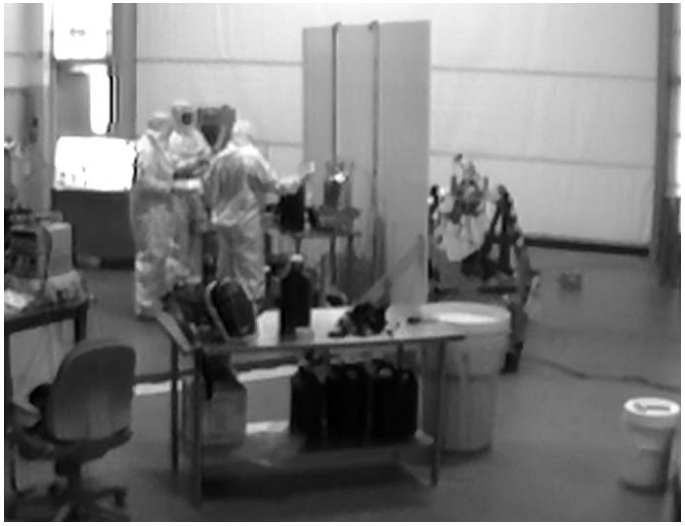


FDT Decon Process



Personal Protective Equipment (PPE)

- Personnel were required to wear the following during all propellant operations:
  - Chemical resistant gloves (e.g. Polychoroprene)
  - Splash resistant and static dissipative outer garments
  - Safety glasses
  - Grounding wrist straps – to be used only when:
    - Opening connections where undiluted, residual, propellant is expected
    - Working with open propellant filled shipping jugs
  - Proper Respiratory Protection
  - For high pressure operations with no propellant present (leak checks) only safety glasses

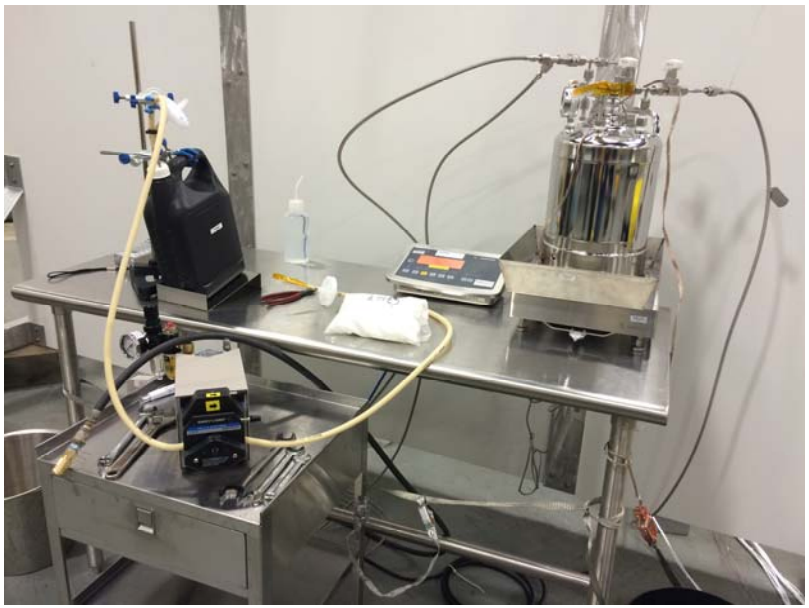


TC Open Container Operation

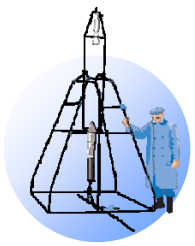
GPLD Personnel loading the FDT

Lessons Learned

- Leak check every connection
  - Seems obvious, however this fitting was behind TTV-4 and not in the pressure integrity path
  - Loose Transfer TT C-10 fitting during TT propellant filling
  - Small leak cleaned up with DI wetted rags in ~ 5 minutes
  - Operation continued with concurrence of WFF OSS
- Routing TC Vent away from personnel
  - After exhausting the 1st LMP-103S TC propellant vapor stirred up during propellant pump back into the shipping container
  - Ammonia vapor detected
  - TC vapor exhaust routed away from area
  - Operation continued with concurrence of WFF OSS
  - No respirators for 2nd open container operation
- No Gas purge before liquid
  - Decontamination should be performed with DI water
  - Follow by gas purge once DI tests clean

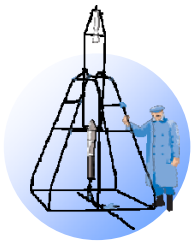


GPLD - Transfer Tank Processing Area



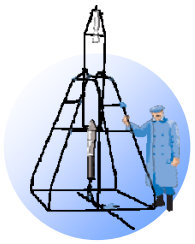
Accomplishments

- GSFC
  - Inaugural Range LMP-103S loading operation
  - GSFC Propulsion institutional knowledge and hands on experience in LMP-103S handling
  - Demonstration of the reduction in effort versus hydrazine loading
  - Propellant leak clean up and ADN salts decontamination without safety concerns
  - LMP-103S open container operation performed without respiratory protection
  - Loading and Decon Procedures
  - Established GSE and flight passivation and cleaning preparation processes
  - NASA / SNSB / Moog Inc. / ECAPS collaboration
  - LMP-103S U.S. Range acceptance - WFF
  - Risk Assessment Report - WFF
  - Hazard Report - WFF
  - Ground Safety Plan - WFF
  - LMP-103S propellant facilities identified for loading and the storage - WFF
- SNSB / ECAPS
  - Range certified Pressure Vessel System (PVS) loading cart
  - NASA propulsion propellant handling and range acceptance
- Moog Inc.
  - Green propellant compatible FDT development for GPLD and future customers



Hydrazine versus HPGP Processing

	Hydrazine		HPGP (LMP-103S)		Basis of Estimate
	Labor Cost	Cost	Labor Cost	Cost	
Loading	1	---	0.70	---	Based on DRAFT Schedule – GPM – MMS – GPLD
Decontamination	1	---	**Included in Load Hours**		Based on DRAFT Schedule – GPM – MMS – GPLD
Fire Watch	1	---	**Not Required**		Based on DRAFT Schedule – GPM – MMS – GPLD
Marching Army	1	---	**Not Required**		Assuming 2 weeks – Propellant Load to Launch
Physicals	1	---	0.125	---	SCAPE Comprehensive Physical vs Ordnance Handler
Training	1	1	0.125	---	WSTF TES, KSC SCAPE, Hypergol systems
Sampling		1		0.5	SCAPE – KSC
Drain Container Processing		1		0.3	KSC – GPM – MMS – GPLD
SCAPE Rental and Support (PPE)		1		0.15	Based on DRAFT Schedule – GPM – MMS – GPLD HPGP – SCAPE not required
Load Cart Final Decontamination		1	**Not Required**		Based on DRAFT Schedule –GPM – MMS – GPLD
Procedures	1		0.5		MMS – GPM – GPLD
GSE		1		2	GPM – MMS – Green Load Cart Build
Travel		1	**Not Required**		WSTF/KSC Training for SCAPE Certification
Facilities	TBD		TBD		Buried costs that could prove substantial
	Hydrazine	**1**	**HPGP**	**0.28**	~ 73% overall total cost reduction for HPGP



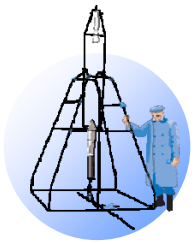
Summary

- GPLD successfully conducted at WFF December 2015
- GSFC propulsion personnel managed and performed the operation
- First loading activity at U.S. Range using LMP-103S
- Activity structured as a pathfinder activity for LMP-103S U.S. Range approval
  - Through this operation, WFF developed the necessary processes and documentation to accept, store, handle, and dispose of LMP-103S propellant
  - Due to LMP-103S safer nature, significant reduction in handling PPE
- GSE loading hardware and documentation can be leveraged for LMP-103S future spacecraft loading
- Collaborative effort between NASA GSFC and WFF, SNSB, ECAPS and Moog Inc.
- Realized greater than two-thirds savings in overall cost with HPGP versus Hydrazine equivalent loading
- Self-Contained Atmospheric Protective Ensemble (SCAPE) – Not Required
- Control room / operator separation – Not Required

Full SCAPE – MMS Propellant Loading

GPLD

GPLD Personnel – FDT loading



GFLD

Questions?