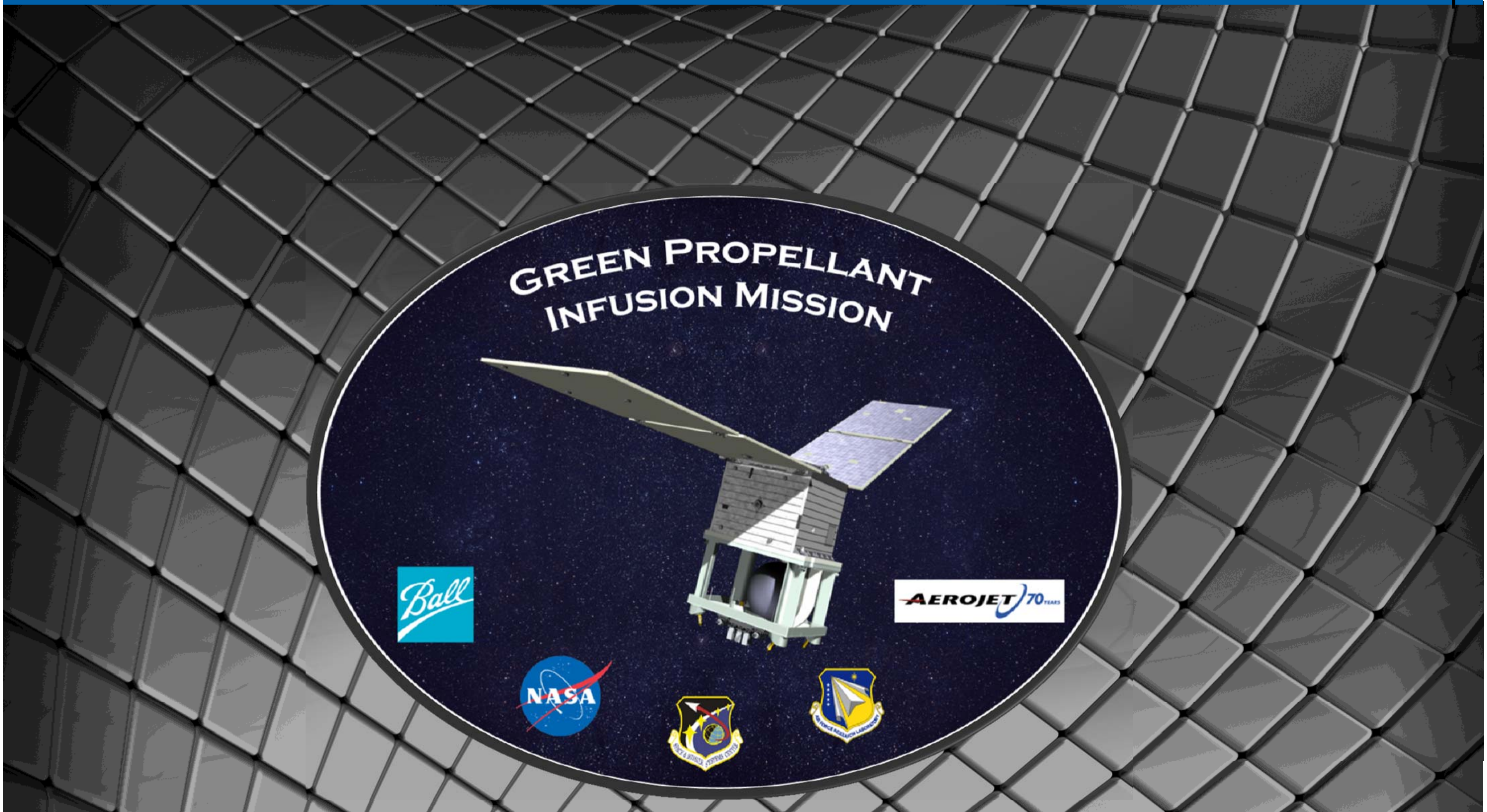
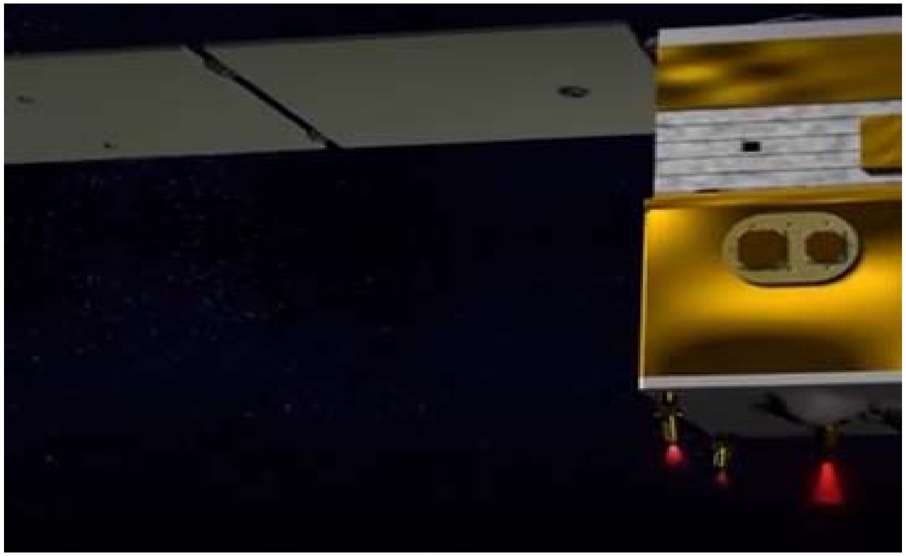


Technology Workshop for Discovery
Green Propellant Infusion Mission

April 9, 2014

Technology Demonstration Mission



"A high performance green propellant has the potential to revolutionize how we travel to, from and in space"

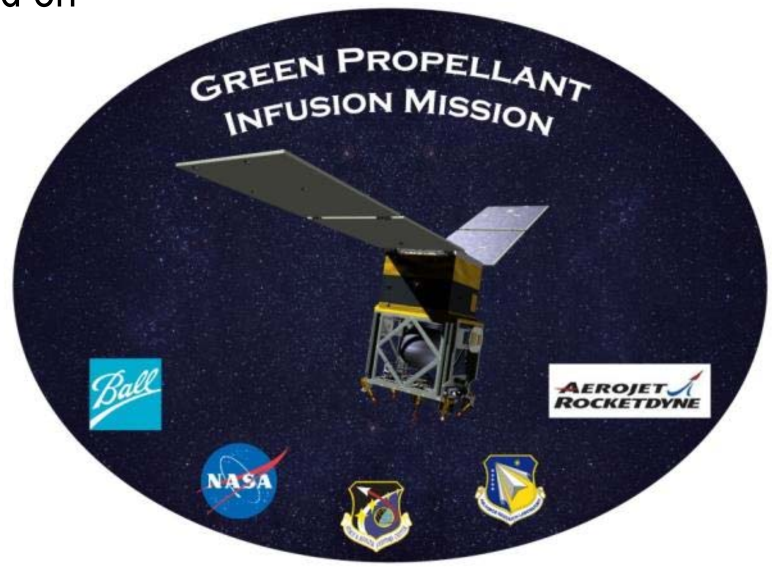
Michael Gazarik,

NASA Associate Administrator,

Space Technology Mission Directorate

GPIM Project Summary

- Project Description
  - Public/private partnership involving multiple government organizations and multiple contractors
  - Demonstrate advanced in-space propulsion system based on USAF developed AF-M315E "green" propellant
    - Over $15M of industry/government investment
    - More than a decade of research (handling, performance, etc.)
  - Mature technology to TRL9
  - Baseline mission:
    - Demonstrate ESPA class propulsion subsystem
    - Multiple orbit lowering operations/inclination change



- Project Status
  - Conducted CDR in March 2014
  - Component production and testing underway
  - Manifested Falcon Heavy STP-2 mission, August 2015

Why Green Propellant Matters

- Propellant Performance
  - ~50% higher density-specific impulse than hydrazine
  - Comparable system performance to bi-propellents
  - Lower temperature capability opens mission trade space
- Science
  - More payload capability or longer mission duration
  - Wide range of spacecraft sizes: large to nano
  - More launch options for benign secondary payloads without hazardous propellants
- Safety
  - Reduced toxicity enables easier handling and processing
  - Human Space Operations
- Economics
  - Reduced launch, range, and operations costs
  - US developed propellant and thrusters enable domestic sources
  - Supports "ship and shoot" concept of operations

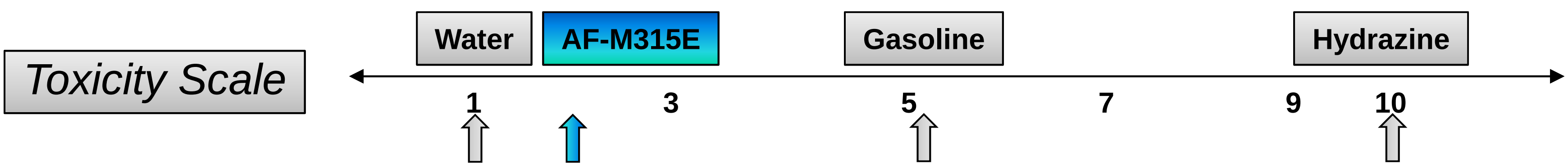
Aerojet Rocketdyne Technician handles AFM315E propellant

Traditional HAZMAT suit for fueling is not required

Flight proven green propellant system enhances U.S. industrial competitiveness

Propellant Comparison

	AF-M315E Propellant	Hydrazine/Bi-propellants
Performance	~50% greater density-impulse performance than hydrazine, competitive with bi-prop at system level	
Flammability	Vapor flammability essential non-existent, can even reduce small fires	Highly reactive/flammable
Handling	"Short sleeve" operations/ FedEx can deliver it	Requires HAZMAT suit for handling and redundant containment facilities
Human Spaceflight	Low vapor pressure, low toxicity, safer working enviroment, non-reactive, water bi-product	Reactive, easily evolves, can cause unanticipated failures (Apollo 15 parachute)
System Complexity	Comparable to hydrazine	50% less complexity than bi-prop (no pressure, no regulators, no oxidizer tanks, etc.)



Green Propellant is not only environmentally benign, it offers substantial improvements in performance, cost, and safety

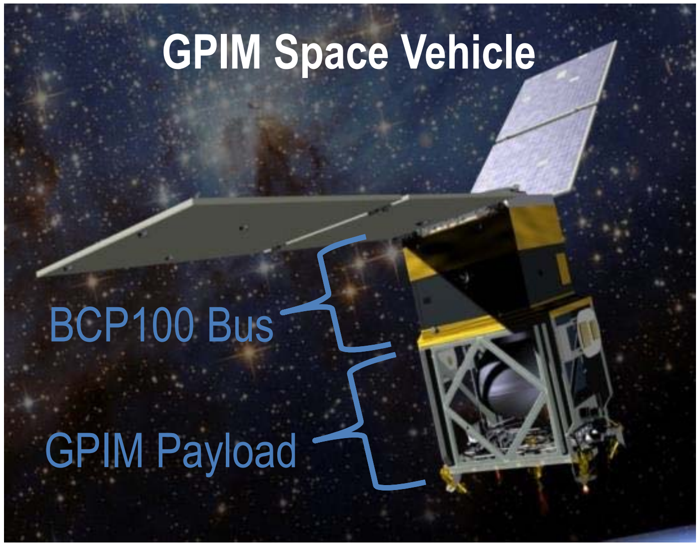
Examples of Performance Benefits to Planetary Missions

Mission	Propulsion Functions	System Replaced	AFM315E Enhancement
Asteroid Redirect Mission	• Asteroid De-spin • RCS	• Bipropellant	• 60% **reduction in system complexity** • Reduced propulsion system volume and 22" **bus length reduction** • **Significant cost reduction** • Lower risk with crew visit
WFIRST Mission	• Primary ΔVs • Mid-course corrections	• Hydrazine	• 10% **reduction in propellant mass** • System **dry mass reduction** of >30%.
Mars Geyser Hopper	• Landing • Geyser site hopping	• Hydrazine	• **Improved density*Isp** allows for two extra hops • **Provides an additional year of science** • Loosens launch constraints due to low temp
Spun Mars Ascent Vehicle	• All RCS functions	• Electric TVC N2 Gas generator/ Cold Gas Systems	• Isp density and **low temperature capability** replace complex electric system where hydrazine won't work due to density & temperature limits • Eliminates systems, complexity, and reduces risk
Int'l Lunar Network lander	• Vernier descent control • Landing propulsion	• Hydrazine	• Antares to Minotaur V **launch vehicle reduction** • Improved mass/Isp performance
Deep Space Microsat	• Primary ΔVs • Mid-course corrections	• Hydrazine	• **Increases primary ΔV** by 70% • RCS propellant by 100% allowing for follow-on science opportunities

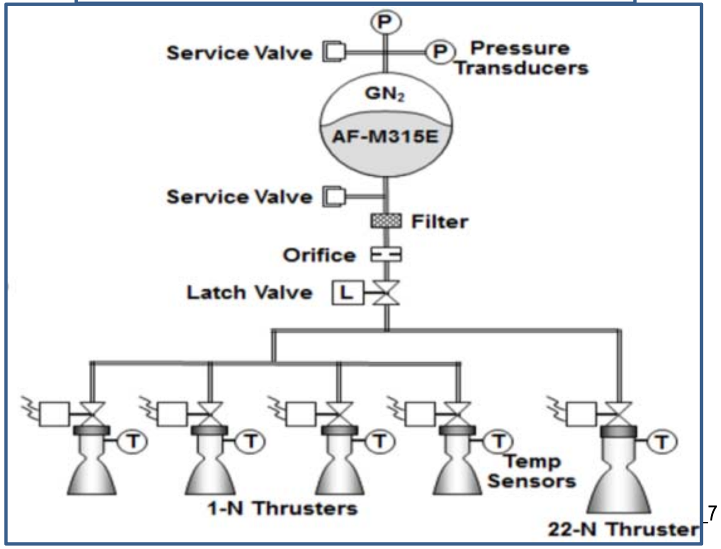
GPIM offers similar benefits to other science missions

GPIM Flight Objectives

- Space and ground demonstration/ validation of advanced propellant and propulsion system offering:
  - Increased propulsion efficiency
  - Significant improvements to ground & space crew safety
  - Reduced propulsion subsystem complexity
- Demonstrate 1 N and 22 N thruster performance:
  - 3-axis attitude control
  - Momentum dumping capability
  - Primary Divert (215 m/sec)
- Technology maturation
  - Components validation, TRL = 9 post flight
  - System flight validation, TRL = 7+ post flight

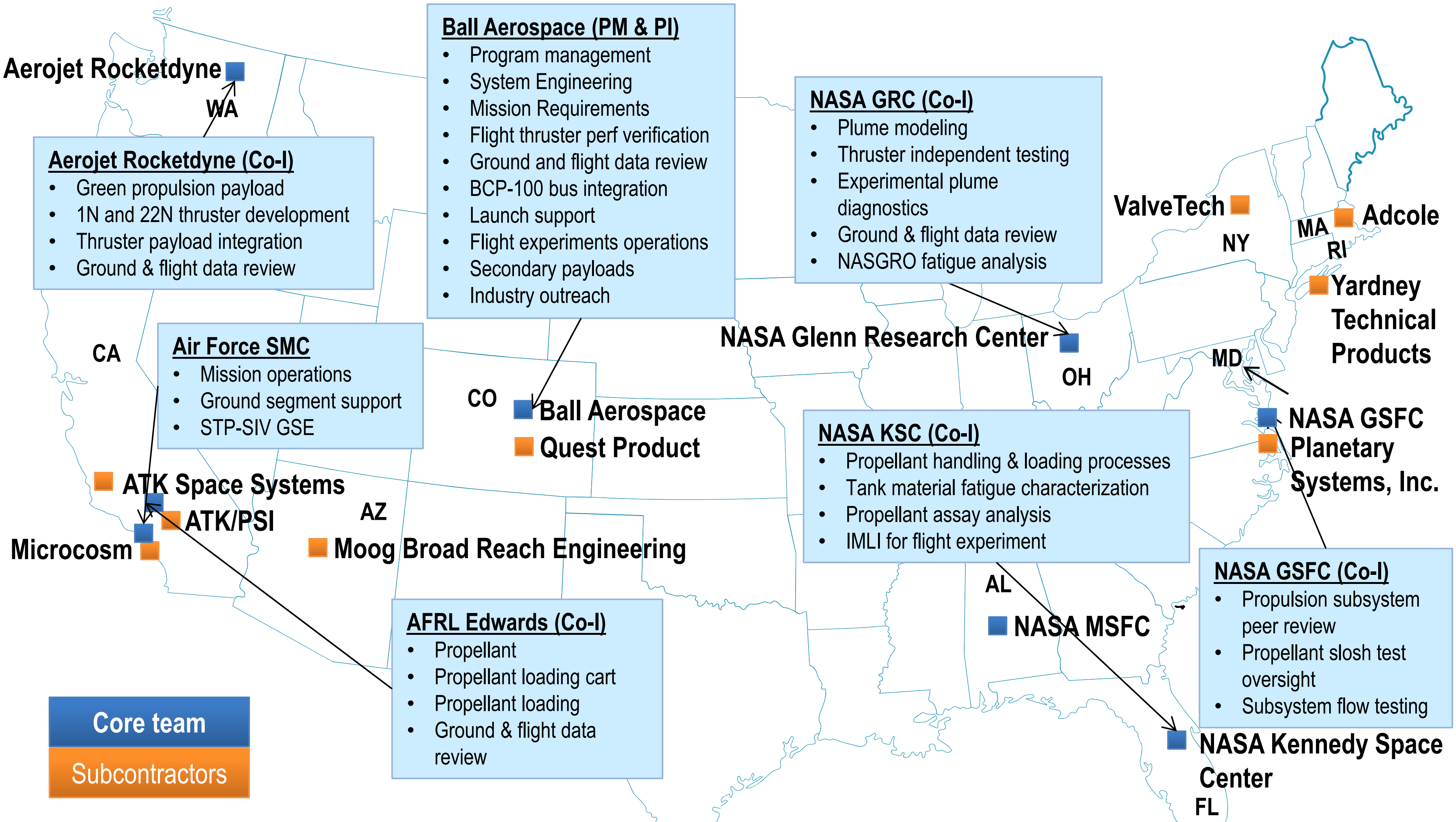


Propulsion Subsystem Schematic



GPIM will flight demonstrate advanced propellant and thrusters, advancing the technology to TRL 9

GPIM Team Contributors and Locations



Cross-cutting team includes all technology stake-holders: NASA, DoD, industry

Conclusion

- Innovative, Government – Industry partnership
  - Leverages 15+ years USAF investments
  - Collaboration includes 4 NASA Centers
  - 1N & 22N thrusters will be a part of Aerojet Rocketdyne catalog
- GPIM has potential for significant, lasting impact to:
  - Propulsion performance
  - Science return
  - Ground and space safety
  - National competitiveness
- Technology applicable to nearly all space missions:
  - Science
  - Defense
  - Commercial

Graphics courtesy of National Aeronautics and Space Administration

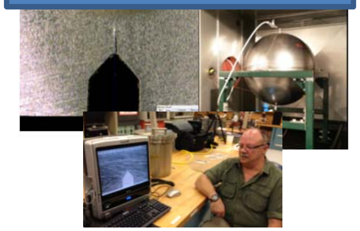
BACKUP

April 9, 2014

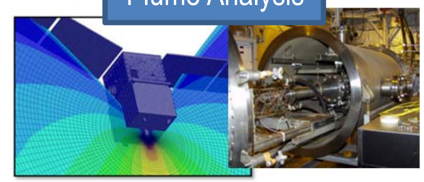
2013 / 2014 GPIM Progress

- Established project technical, schedule and cost baselines
- Completed SRR, KDP-B, PDR, IBR, KDP-C, CDR
- Completed plume modeling (GRC)
- Completed design and validation of 22N lab model thruster (AR)
- Initiated all propulsion subsystem procurements
- Initiated all bus procurements
- Initiated upgrades to test facilities (GRC, AR)
- Initiated propellant loading cart development (AFRL Edwards)
- Initiated DOT and hazard classification development (AFRL Edwards)
- Initiated development of launch site fuel handling procedures and fracture mechanics testing (KSC)
- Range Safety reduced hazard classification from ‘catastrophic’ (heritage storable propellant) to ‘critical’

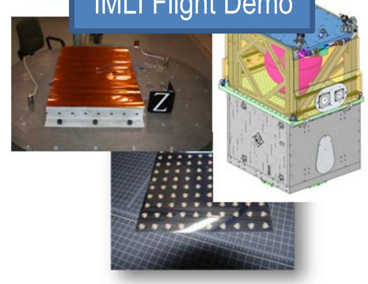
Materials Characterization



Plume Analysis



IMLI Flight Demo



22 N Thruster

GPIM Bus Components

Infusion