National Aeronautics and
Space Administration

Technology Demonstration Missions Program

Presented by:

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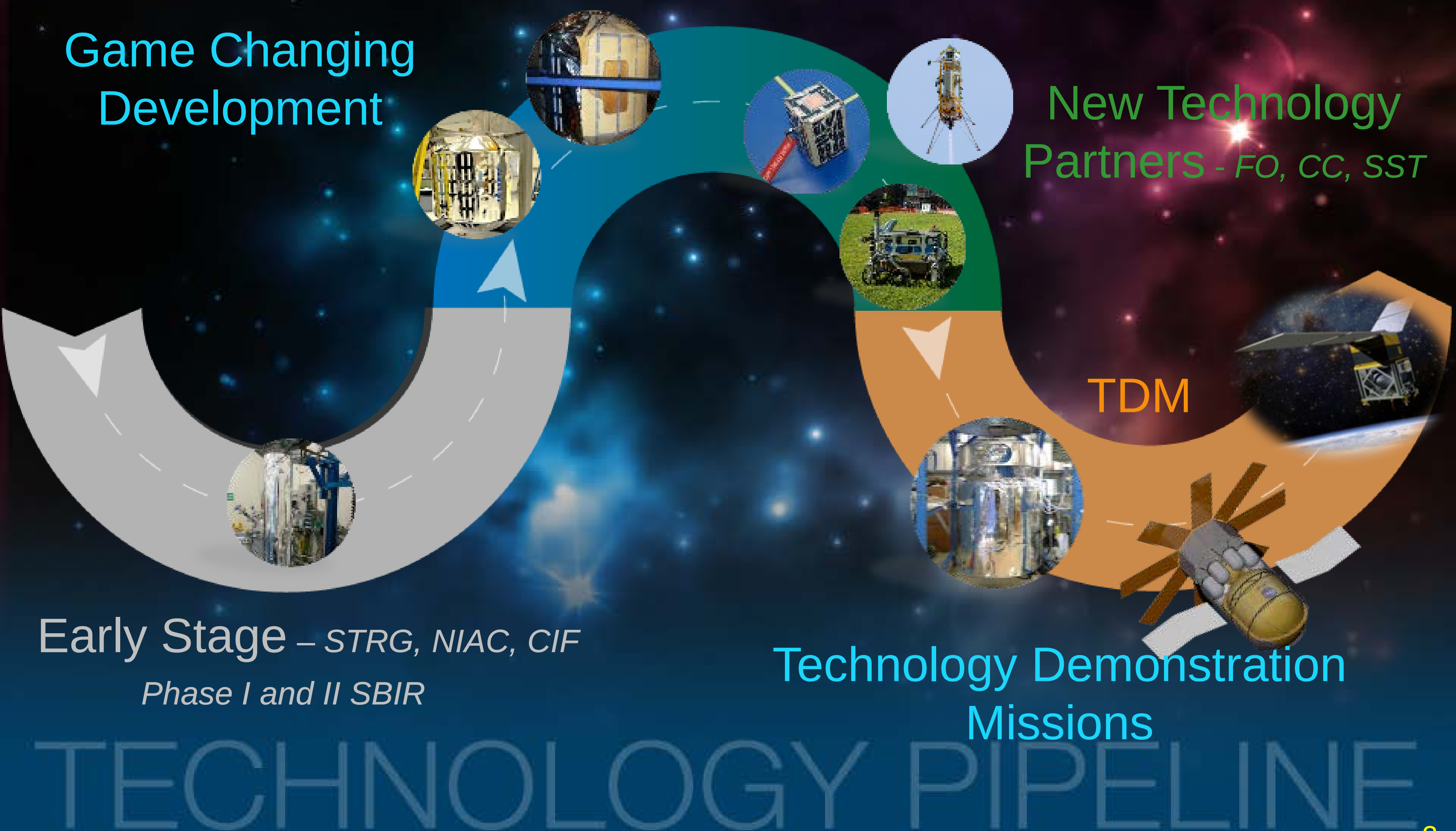
Program Executive

Space Technology Mission Directorate

Dec 4, 2014

www.nasa.gov/spacetech

Space Technology Portfolio



Why TDM

Bridging the Gap - TDM is STMD's Flight and Ground demonstration programs for breakthrough technologies in a relevant operating environment for infusion in future science and exploration missions

Projects, Teams and Partners

Technology Demonstration	Project Manager	Lead	Team	Partners
Composites for Exploration Upper Stage (CEUS)*	John Vickers	MSFC	LaRC, GRC	HEOMD/AES, SLS
Evolvable Cryogenics (eCryo) *	Carol Ginty	GRC	GSFC, MSFC, KSC, ARC	HEOMD
Deep Space Atomic Clock (DSAC)	Allen Farrington	JPL	NASA HEOMD/SCaN	HEOMD/ SCaN
Green Propellant Infusion Mission (GPIM)	John Jonaitis	Ball	GRC, Aerojet	AFRL, AF SMC
Laser Communications Relay Demo (LCRD)	Kevin Carmack	GSFC	NASA HEOMD/SCaN	HEOMD/ SCaN
Low Density Supersonic Decelerators (LDSD)	Mark Adler	JPL	GSFC/WFF, ARC, LaRC	SMD
Solar Electric Propulsion (SEP)	Mike Barrett	GRC	LaRC, GSFC, JPL, DSS, ATK	None
Terrestrial HIAD (Hypersonic Inflatable Aerodynamic Decelerator) Orbital Reentry (THOR)*	Kurt Detweiler	LaRC	WFF, ARC, Aberdeen, Orbital	None

* FY14 New Starts

TDM Portfolio
TRL Advancement and Technology Areas

Technology Areas	TDM	FY 11	FY 12	FY 13	FY 14	FY 15	FY 16	FY 17	FY 18	FY 19	Infu-sion
	Low Density Supersonic Decelerators (LDSD)		5			6					
	Laser Communications Relay Demonstration (LCRD)		6						8		
	Deep Space Atomic Clock (DSAC)		5				7				
	Green Propellant Infusion Mission (GPIM)			5			7				
	Solar Electric Propulsion (SEP)				5				7		
	Evolable Cryogenics (eCryo)				5				6		
	Composites for Exploration Upper Stage (CEUS)				5			6			
	Terrestrial HIAD Orbit Reentry (THOR)				5			6			

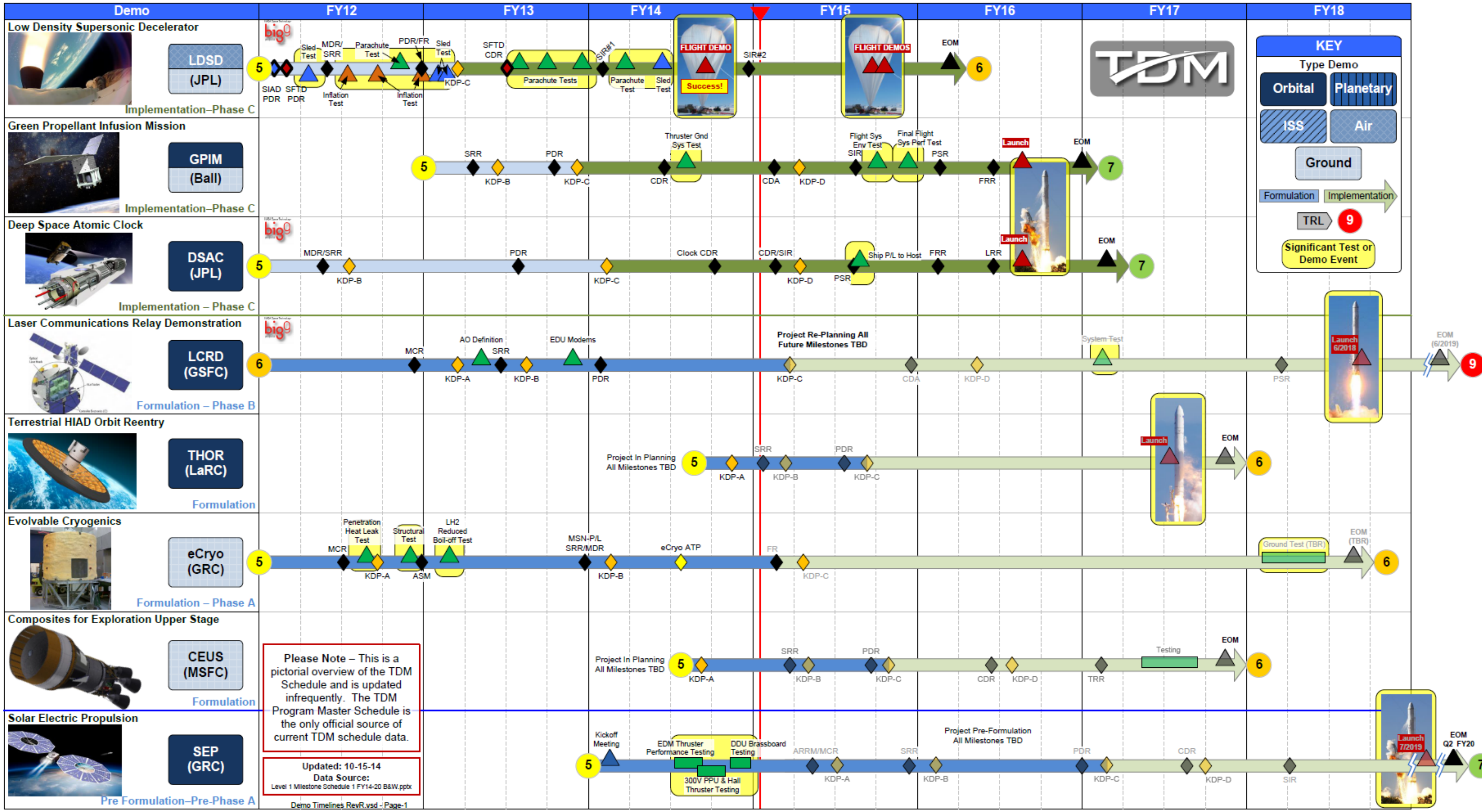
Technology Areas (TA)
- TA.1. Launch Propulsion
- TA.2. In-Space Propulsion
- TA.3. Space Power/Storage
- TA.4. Robotics
- TA.5. Comm./Navigation
- TA.6. Human Health
- TA.7. Human Expl. Dest.
- TA.8. Sci. Instr./Sensors
- TA.9. EDL
- TA.10. Nanotechology
- TA.11. Modeling/Simulation
- TA.12. Materials/Structures
- TA.13. Ground/Launch
- TA.14. Thermal

Infusion path to:
- Science
- Exploration

Technology Readiness Levels (TRL) 1 → 9

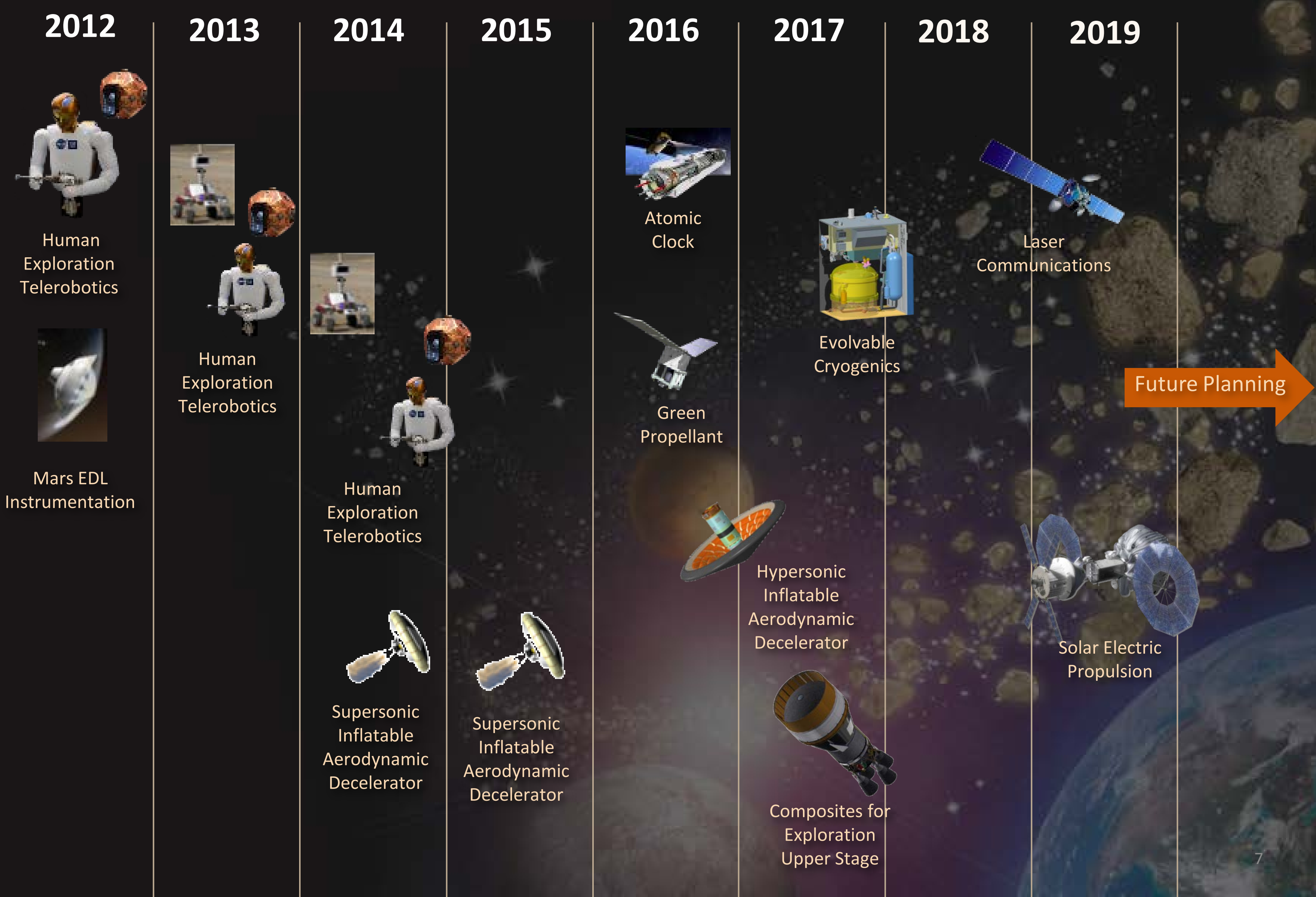
TDM projects increase TRLs in multiple technology areas

TDM Program



Demo
FY12
FY13
FY14
FY15
FY16
FY17
FY18
Low Density Supersonic Decelerator
LDSD (JPL)
Implementation–Phase C
SIAD PDR
SFTD PDR
Sled Test
MDR/ SRR
Parachute Test
Inflation Test
PDR/FR
Sled Test
KDP-C
SFTD CDR
Parachute Tests
SIR#1
Parachute Test
Sled Test
FLIGHT DEMO
Success!
SIR#2
FLIGHT DEMOS
EOM
Green Propellant Infusion Mission
GPIM (Ball)
Implementation–Phase C
SRR
KDP-B
PDR
KDP-C
Thruster Gnd Sys Test
CDR
CDA
KDP-D
Flight Sys Env Test
SIR
Final Flight Sys Perf Test
PSR
FRR
Launch
EOM
Deep Space Atomic Clock
DSAC (JPL)
Implementation – Phase C
MDR/SRR
KDP-B
PDR
KDP-C
Clock CDR
CDR/SIR
KDP-D
Ship P/L to Host
PSR
FRR
LRR
Launch
EOM
Laser Communications Relay Demonstration
LCRD (GSFC)
Formulation – Phase B
MCR
AO Definition
KDP-A
SRR
KDP-B
EDU Modems
PDR
Project Re-Planning All Future Milestones TBD
KDP-C
CDA
KDP-D
System Test
PSR
Launch 6/2018
EOM (6/2019)
Terrestrial HIAD Orbit Reentry
THOR (LaRC)
Formulation
Project In Planning All Milestones TBD
KDP-A
SRR
KDP-B
PDR
KDP-C
Launch
EOM
Evolvable Cryogenics
eCryo (GRC)
Formulation – Phase A
MCR
Penetration Heat Leak Test
KDP-A
Structural Test
ASM
LH2 Reduced Boil-off Test
MSN-P/L SRR/MDR
KDP-B
eCryo ATP
FR
KDP-C
Ground Test (TBR)
EOM (TBR)
Composites for Exploration Upper Stage
CEUS (MSFC)
Formulation
Project In Planning All Milestones TBD
KDP-A
SRR
KDP-B
PDR
KDP-C
CDR
KDP-D
TRR
Testing
EOM
Solar Electric Propulsion
SEP (GRC)
Pre Formulation–Pre-Phase A
Kickoff Meeting
EDM Thruster Performance Testing
300V PPU & Hall Thruster Testing
DDU Brassboard Testing
ARRM/MCR
KDP-A
SRR
KDP-B
Project Pre-Formulation All Milestones TBD
PDR
KDP-C
CDR
KDP-D
SIR
Launch 7/2019
EOM Q2 FY20
Please Note – This is a pictorial overview of the TDM Schedule and is updated infrequently. The TDM Program Master Schedule is the only official source of current TDM schedule data.
Updated: 10-15-14
Data Source:
Level 1 Milestone Schedule 1 FY14-20 B&W.pptx
Demo Timelines RevR.vsd - Page-1
TDM
KEY
Type Demo
Orbital
Planetary
ISS
Air
Ground
Formulation
Implementation
TRL
Significant Test or Demo Event

TDM Demonstrations Plan



Recent TDM Highlights

CEUS

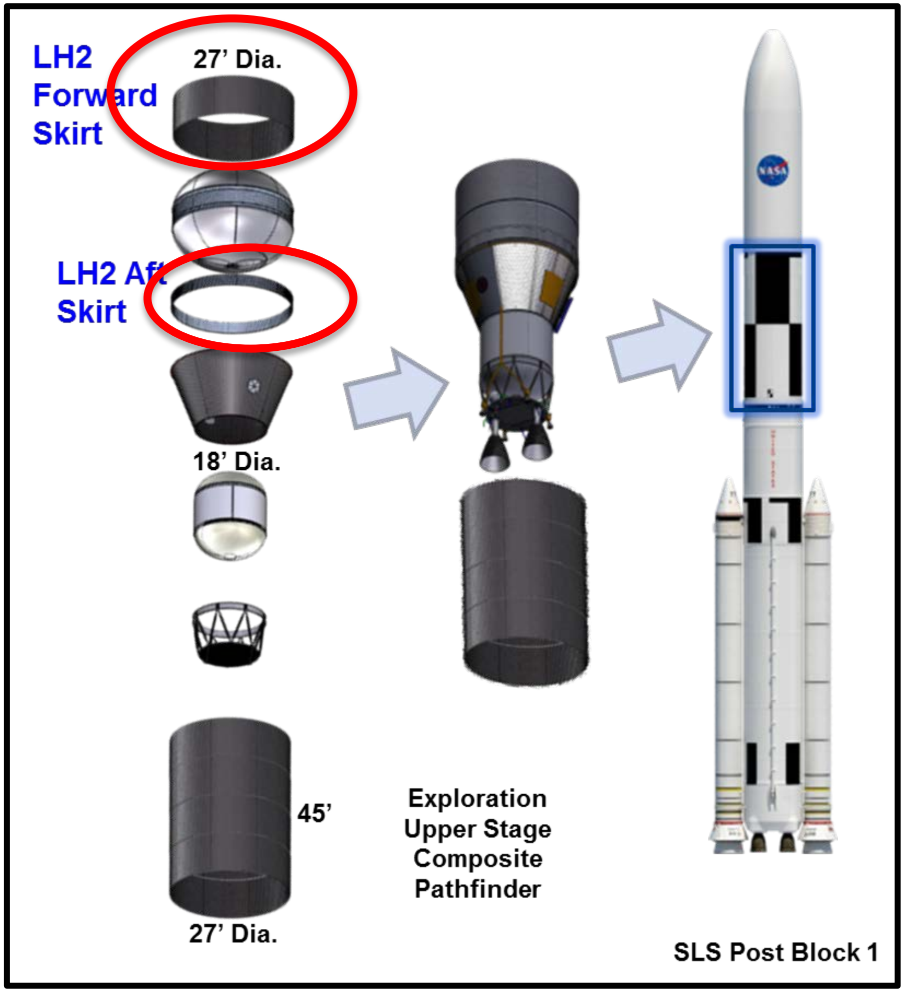
Composite Exploration Upper Stage – MSFC/ LaRC

Problem/Need – The Importance of the Idea

- SLS system trade studies show that an all composite structure could decrease the mass by 40% and increase the payload to LEO by 25 metric tons, Mass Gear Ratio (1:1) w/Payload.
- **Light weight structures is a high priority area within NASA** (e.g. Space Technology Thrust areas, Technology roadmaps)
- **The Problem**
  - No composites experience at this scale - (8.4 m diameter)
  - Building Block approaches are mainly empirical and conservative
  - Human data evaluation expensive/takes too long
  - Stacking of Conservatism, Damage Tolerance, Materials Allowable
- **The Need**
  - Agency's need for an affordable lightweight heavy lift vehicle - Greater payload capability is required to enable future exploration missions
  - Model-based end-to-end solution from conceptual through detailed design, analysis, and virtual manufacturing.
  - Feasibility
    - CCTD has shown that high performance materials and advanced manufacturing methods are achievable for 5.5 m diameter structures.

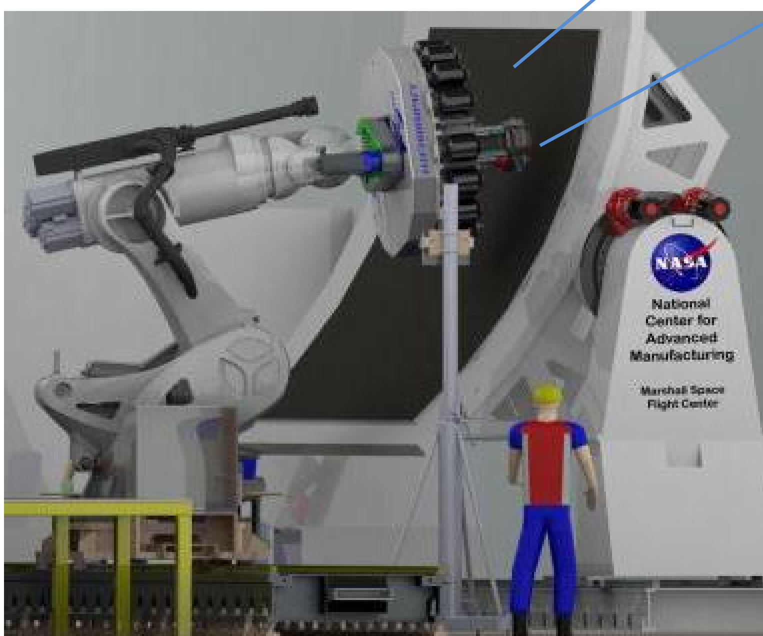
Composite Exploration Upper Stage (CEUS)

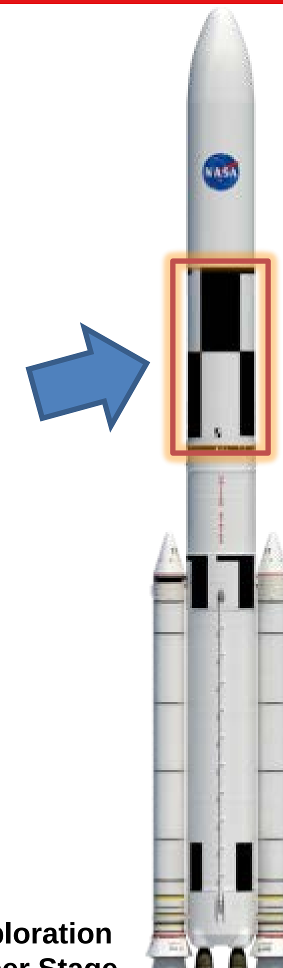
- The Exploration Upper Stage (EUS) is needed for the SLS to provide additional capability to travel to deep space.
- **This project will design, build and test a composite LH2 forward and/or LH2 aft skirt to demonstrate composite structures under relevant environments at the 8.4m diameter scale**



Develop In-house Capability at MSFC and at LaRC

- **A flexible robotic based system to enable next generation composite materials, manufacturing, design/analysis, and certification**
- **Fabricate 1/8th Arc Segment Panels and assemble into actual full-scale hardware, all fabricated in house.**





2014 Accomplishments (1 of 2)

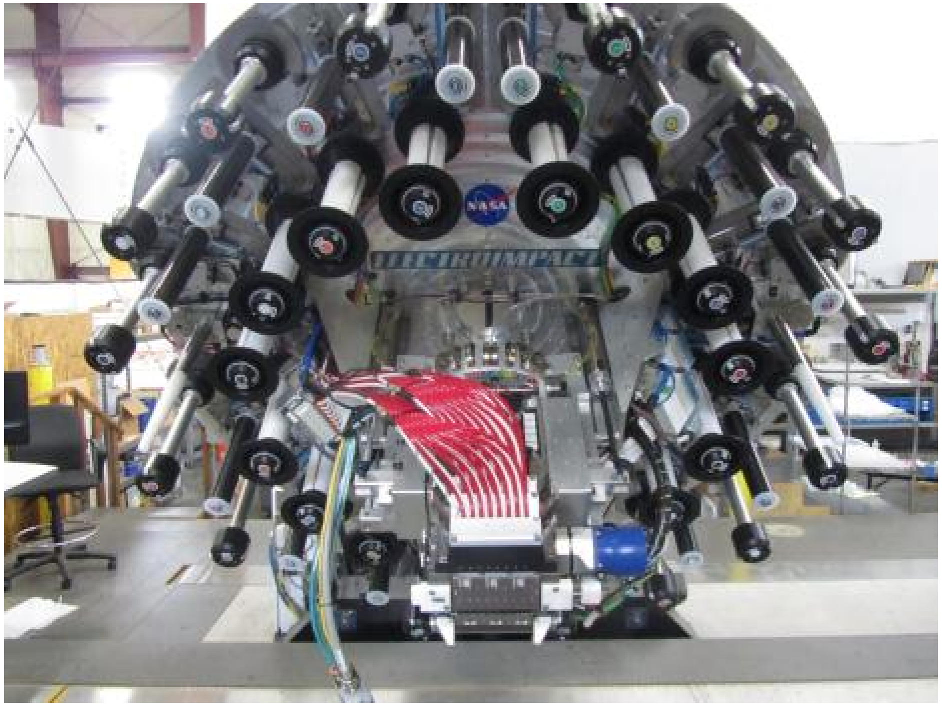
- **FY14 New Start**
  - KDP-A 6/9/2014
- **CEUS Technology Infusion Group (TIG) convened 9/4/14, provided Level 1 requirements recommendation.**
  - TIG membership included major stakeholders.
  - Received concurrence enabled proceeding with the L2 PLRA development
- **Automated fiber placement hardware delivered to LaRC**.
  - After acceptance testing in Dec 2014, coupon fabrication can begin.

LaRC Automated Fiber Placement (AFP) system at the vendor facility

MSFC Automated Fiber Placement (AFP) Robot at the vendor facility

2014 Accomplishments (2 of 2)

- **Procurement was awarded for pre-preg composite material.**
  - Initiated panel core trade study
  - Includes consideration of aluminum honeycomb, foam core, and alternative panel architectures.
  - Initiated investigation into damage tolerance requirements.
- Technical Interchange Meeting conducted among the Advanced Composite Program (ACP)/Aero, Composite Exploration Upper Stage (CEUS)/STMD and Materials Genome Initiative (MGI)/STMD



MSFC Automated Fiber Placement (AFP) Head at the vendor facility to be Integrated with Robot

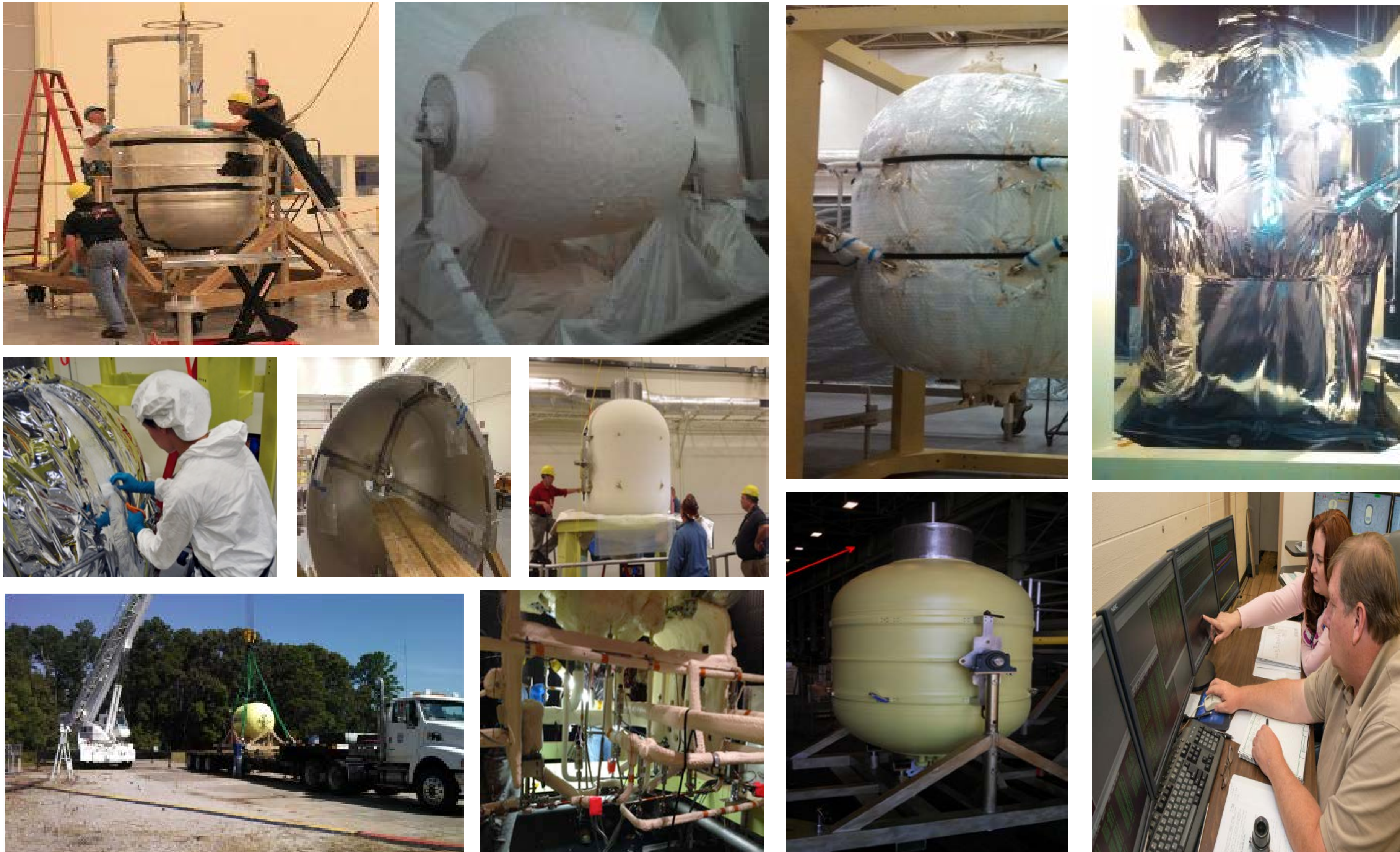
CPST → eCryo

Evolvable Cryogenics – GRC

CPST --→ Evolvable Cryogenics (eCryo)

- **Transition from CPST to eCryo project**
  - Key Decision Point (KDP)–A on 4/22/2014
  - The Project will work in close coordination with the SLS Program to define CFM technology development and demonstration priorities as well as infusion pathways and timelines onto SLS upper stage upgrades.
  - The CPST Project will be fully transitioned into the eCryo project at the end of FY14 with the following deliverables:
    - LOX Zero Boil-Off Industry Workshop, Engineering Development Unit (EDU) Industry Workshop, final report and lessons learned.
    - CPST/CNES Benchmark Modeling Workshop.
- **eCryo Formulation**
  - From April 2014 to December 2014
  - STMD EPMC portfolio decision on 12/2/2014

CPST Progress to Date



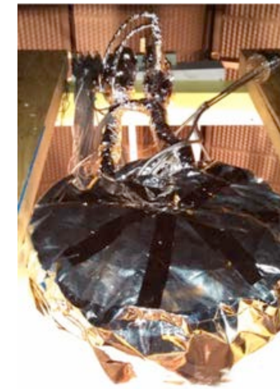
Engineering Development Unit (EDU) manufacturing and testing

CPST Project Completes EDU Testing

Model	Tool	Applicable Section of Test
Integrated Thermal Model	Thermal Desktop	From Tank Loading until TVS Performance Testing
Axial Jet and TVS Model	SINDA	During Axial Jet Operations (Ground Heat Load Measurement and On Orbit Heat Load Measurement)
LAD TVS Model	GFSSP	During LAD TVS Operations (On Orbit Heat Load measurement and LAD Outflow testing)
Tank Fill Model	GFSSP	During Tank Loading
Tank Boil Model	C3PO	During Tank Lockup periods (before vacuum, during initial vacuum pull, and heat Capacity Measurement)
Tank RF Mass Gauge Performance	FEM in Comsol	During Intervals of RF Mass Gauging
Cryo Tracker Performance Comparison	Hand Calcs	At all times of test where cryo is loaded
Purge Analysis	Hand Calculations	During Tank Loading

Low emissivity wrap completed

EDU in Test Stand 300 at MSFC



Aft MLI close out completed

CPST completed follow-on testing of the 2.4m cryocooler tank EDU at MSFC

RESULTS: Testing was successful in achieving nine of ten test objectives, reaching nine of fourteen stretch goals. A key success from the test was the **LAD outflow holding liquid for 30 minutes**, pushing the boundaries of this technology. This EDU test data will be used to validate and/or anchor numerous CFM models.

The effort was funded as risk reduction for manufacturing, integration, and ground handling of the future flight unit. The testing was extended to further understanding of the system performance of integrated cryogenic fluid management technologies such as liquid acquisition, pressurization, pressure control, and gauging.

EDU Workshop with High Industry/ NASA Attendance

Evolvable Cryogenics (eCryo) Project
Technology Workshop with Industry
Engineering Development Unit (EDU)
NASA Marshall Space Flight Center
November 18-19, 2014

eCryo Industry Workshop November 18-19, 2014		
Organization	Attendance	Attendees
Aerospace Fabrication & Materials*	In Person	2
Ball Aerospace	In Person/WebEx	2/1
Boeing Company	In Person/WebEx	3/2
Creare, Inc	WebEx	1
Keystone Engineering*	In Person	1
Lockheed Martin	In Person	1
Moog*	In Person	1
Northrop Grumman	In Person	1
Orbital Sciences Corp*	WebEx	1
Quest Thermal Group	WebEx	1
Redstone Aerospace*	WebEx	1
Sierra Lobo	In Person	1
Southern Research Institute*	In Person	1
United Launch Alliance	In Person	2
Washington State University*	In Person	2
Yeti Space	In Person	3
NASA GRC	In Person/WebEx	7/4
NASA MSFC	In Person/WebEx	14/1

CPST Transferring Knowledge to Industry

CPST Hosts Technology Maturation Workshops

Team- GRC, MSFC & KSC

Results from four major test activities, analytical studies and extensive modeling to confirm scalability and extensive performance model development advancing cryo technologies

1. *Passive and active thermal control*
2. *Liquid acquisition in microgravity*
3. *Chilldown of transfer lines*
4. *RF technology for propellant mass gauging in microgravity*

Workers in the Small Multipurpose Research Facility at GRC conduct liquid hydrogen reduced boil-off testing

Advancing NASA's ability to store and transfer cryo propellants in future space vehicles

eCryo Formulation

- Formulation of the eCryo Project occurs from April 2014 through December 2014.
- **The eCryo Project shall identify a project technology portfolio by:**
  - Developing a baseline plan of specific work products
  - Developing an optional path for a Radio Frequency Mass Gauge (RFMG) to support the Robotic Refueling Mission (RRM3) as a potential scope change
  - Developing an optional path for an IVF plan that will demonstrate the viability of an IVF system for the SLS EUS in a timely manner as a potential scope change
  - Developing an optional path for a cryo-cooler demonstration as a potential increase in scope
- **Received direction to prepare a briefing for STMD on December 2, 2014**
  - Include detailed budgets and schedules for all portfolio tasks and options
  - Produce a “menu” for decision making

eCryo 2014 Portfolio Down-select (1 of 3)

Task Number	Product	Description	Selection Decision
Base Portfolio			
1	Project Management	Project, resource, schedule, and data/CM mgmt., S&MA, CAMs. Assessments	Selected
2	Project Analysis	Portfolio analysis and Integrated System Studies (ISS)	Selected
3	Development & Validation of Analysis Tools (DVAT)	Increase capabilities of CFM analysis tools and validate these tools with experimental data, when possible.	Selected
4	Improved Fundamental Understanding of Super Insulation (IFUSI)	Ground test of various insulation blanket coupons to advance design for use on tanks up to 8 m in diameter.	Selected if fits into funding profile
5	Small Scale Vapor Heat Intercept (SSVHI)	Study, design, and test (at a reduced scale) concepts for vapor cooling of skirts attached to large tanks.	Selected, but delay start to FY 2016
6	Base Radio Frequency Mass Gauge (RFMG)	Avionics board development, large tank test at Michoud	Not selected

eCryo 2014 Portfolio Down-select (2 of 3)

Task Number	Product	Description	Selection Decision
Base Portfolio			
7	Intelligent Transfer & Autogenous Pressurization (ITAP)	Ground test addressing chill down, liquid transfer and thermodynamic behavior of unsettled propellant tanks with submerged pressurant.	Defer decision to FY 2016
8	Intelligent Transfer Test (ITT)	Ground test to validate automated chill down and liquid transfer approaches to conserve propellant	Defer decision to FY 2016
9	Structural Heat Intercept-Insulation-Vibration Experiment (SHI-I-VER)	Ground test rig (consisting of large tank, skirt and fluid penetrations) used to evaluate large insulation blanket construction, performance, and durability.	Selected. Re-phase by partially shifting FY15 funding into subsequent years

eCryo 2014 Portfolio Down-select (3 of 3)

Task Number	Product	Description	Selection Decision
Portfolio Options			
10	Remote Robotic Mission 3 (RRM3) RFMG	Flt RFMG development, test and RRM3 mission integration and ops support	Selected
11	Vapor Integrated Pressurization & Power System (VIPPS)	Develop and test concepts for an integrated cryogen pressurization and electrical power system for EUS	Selected
12	20K20W Cryocooler Demonstration	Advance TRL of 20W 20K cryocooler with LH2 zero boiloff test	Defer decision to FY 2016

Radio Frequency Mass Gauge (RFMG)

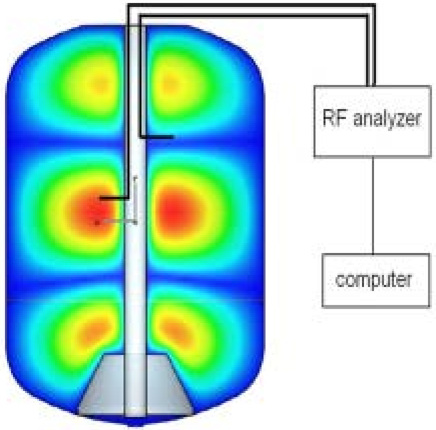
Radio Frequency Mass Gauge (RFMG) for the Robotic Refueling Mission 3 (RRM3) on the ISS

Benefits:

- First time this technology will be flown in space; generating valuable flight data that is needed to prove viability of this gauge
- Successful demonstration could lead to other infusion opportunities in future NASA missions
- Opportunity to partner with GSFC in a tech demo for the HEO Mission Directorate.

Project Deliverables	Schedule
RFMG Simulator	December, 2015
Flight Antenna	December, 2015
Flight Avionics	June, 2016
Support Launch	May, 2017
Data Acquisition & Processing	January – September, 2018

RRM3 Payload Concept

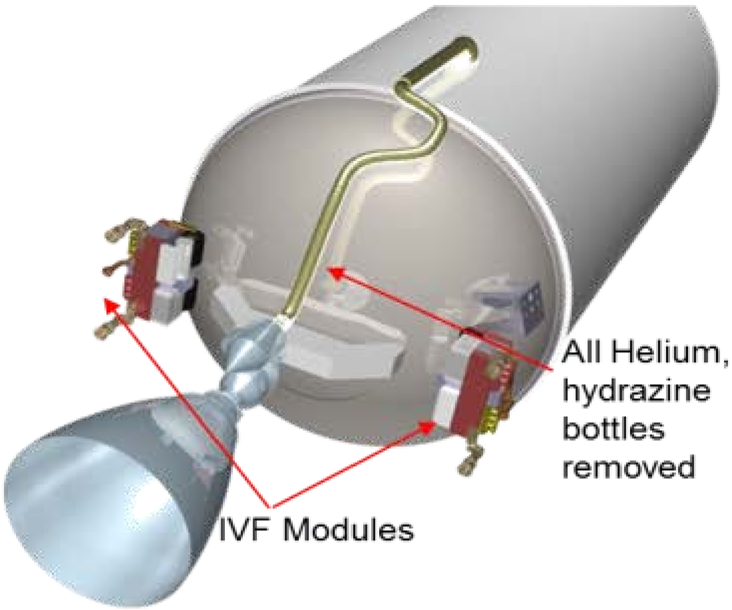


RFMG principle of operation

Integrated Vehicle Fluids (IVF) for Vapor Integrated Pressurization & Power System

Benefits:

- Utilizes cryogenic LH2 and LOx boil-off to feed IVF system (compressor, heat exchanger, accumulator, internal combustion engine).
- Potentially replaces helium pressurization and hydrazine systems and provide electrical power on upper stages
- Equip SLS with the knowledge to develop an integrated cryogen pressurization and electrical power generation system for the Expendable Upper Stage (EUS) suitable for SLS missions

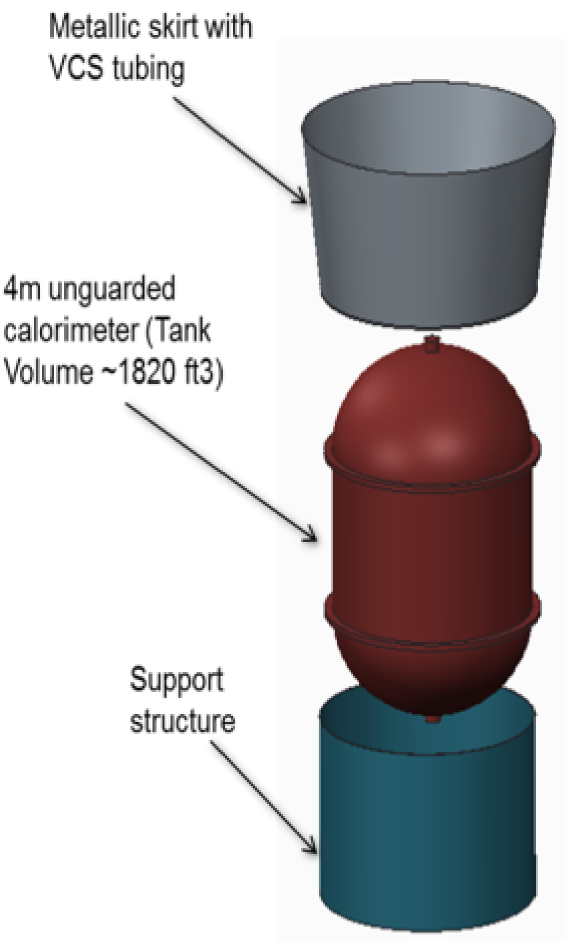


Structural Heat Intercept-Insulation-Vibration Experiment (SHI-I-VER)

Benefits:

Perform a large scale ground test (4m tank) that will:

- Provide insight as to how to design, fabricate, and install stage-sized MLI blankets.
- Quantify the combined effects of realistic blanket construction, tank penetrations, and tanks skirt/vehicle attachments on total heat leak and propellant boil-off losses.
- Quantify the effectiveness of at least one structure-born heat intercept approach using cryogenic propellant vapor
- Obtain information about the robustness of a large stage-like MLI blanket assembly in a launch vehicle vibrational environment.



(overall test article 14 ft by 14 ft by 23 ft)

2014 Accomplishments

- **Completed orderly termination of CPST Project while formulating eCryo Project**
  - Project met its termination phasing plan and generated eCryo funds from the CPST de-obligations
- **Completed EDU development testing**
  - CFM article manufactured IH and successful test series conducted
  - Achieved nine of ten test objectives; reached nine of fourteen stretch goals; Utilizing EDU test data to validate and/or anchor numerous CFM models
  - Industry infusion workshop to share results and lessons learned on November 18 -19
- **Implementing arrangement between NASA and CNES was signed**
  - New arrangement with CNES post CPST cancellation
  - Source of CFM data to validate eCryo models
- **Conducted LOX ZBO Technology Infusion Workshop**
  - Much gratitude for the large amount of data shared; much interest in large MLI blankets
  - Large attendance – 33 from Industry and 23 from NASA
  - Participated in the AIAA-JPC conference in Cleveland
- **Developed an eCryo base portfolio**
  - Conducted EPMC on portfolio baseline on 12/2/2014

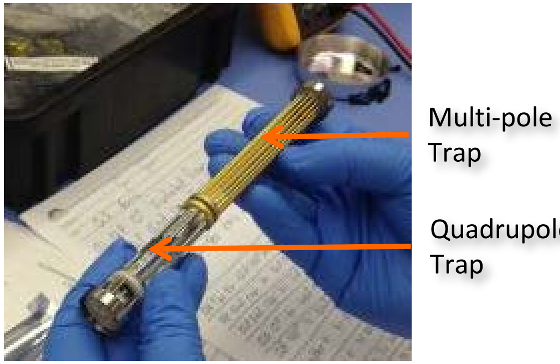
DSAC

DEEP SPACE ATOMIC CLOCK – JPL

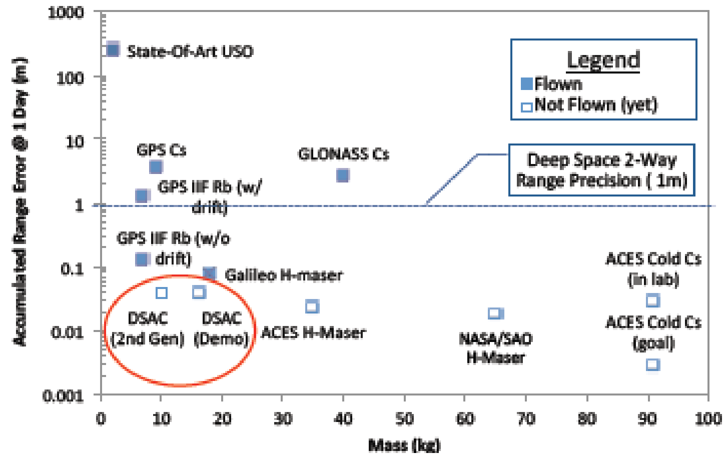
Deep Space Atomic Clock (DSAC)

Develop advanced prototype (‘Demo Unit’) mercury-ion atomic clock for navigation/science in deep space and Earth

- Perform a year-long demonstration in space beginning in 2016 – advancing the technology to TRL 7
- Focus on maturing the new technology – ion trap and optical systems – other system components (i.e. payload controllers, USO, GPS) size, weight, power (SWaP) dependent on resources/schedule
- Identify pathways to ‘spin’ the design of a future operational unit (TRL 7 → 9) to be smaller, more power efficient – facilitated by a detailed report written for the next DSAC manager/engineers

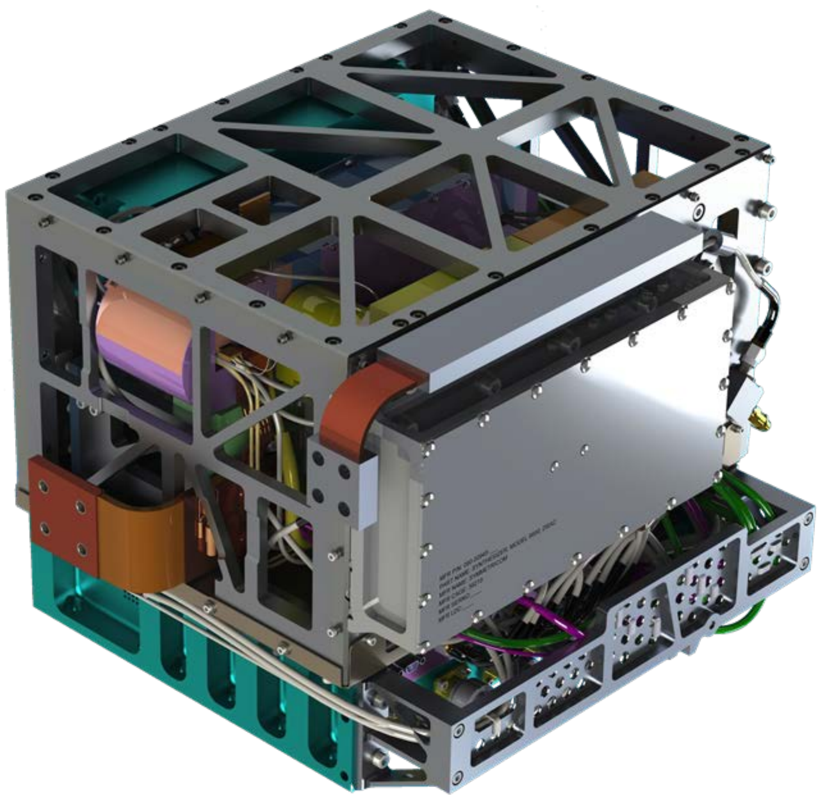


Titanium Vacuum Tube



DSAC Capability Description

- Drifts < 1 microsecond in 10 years
- Tracking increased, accuracy improved (10x)
- Enables on-board radio navigation
- Improve radio science - robust Europa tidal solution relative to baseline
- Enhance national security - GPS & secure command and control



Benefits & Infusions

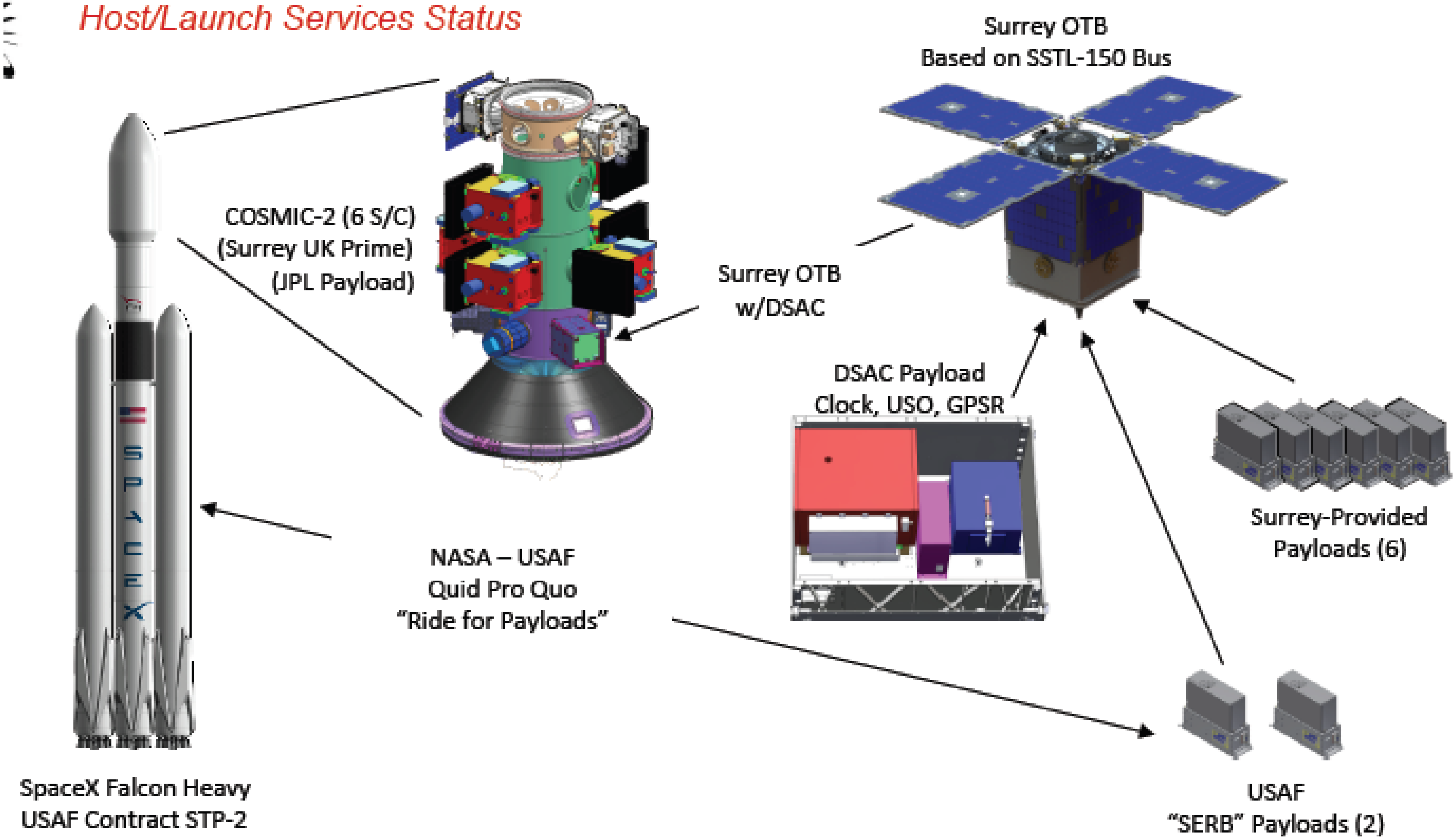
- Potential for on-board navigation to improve science planning and operations and increase science return
- Markedly improve Mar’s atmosphere and gravity field knowledge
- DSAC enabled gravity science (GS) determines dynamic gravity field up to 12 x faster than with current methods
- Atmospheric occultation measurement improves 10x over current methods

Example: Europa Flyby Gravity Science

- Europa Clipper pre-project interested in DSAC provided successful TDM and gravity science remains as an objective
  - Low risk - Clipper could still perform dedicated GS flybys near mission end after meeting other science objectives
  - Minimal impact to the flight system - modest modifications to the radio (to perform radiometric tracking/open loop recording on the uplink) and some additional data storage
  - Less complex mission system than other GS systems investigated by the Clipper team

Host/ Launch Space Flight Experiment

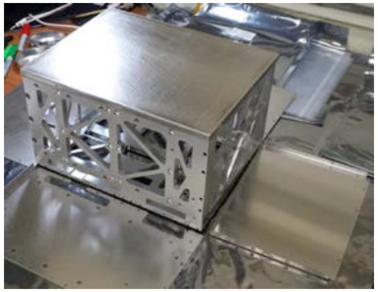
Host/Launch Services Status



FSA Contract in place with Surrey-US as hosted P/L on OTB.

MoA between NASA/STMD & USAF/SMC for ride share on STP-2 still waiting AF signature.

DSAC Flight I&T Underway


Demonstration Unit (for flight) frame & magnetic shield build-up prior to testing

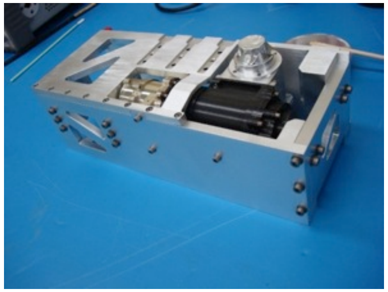
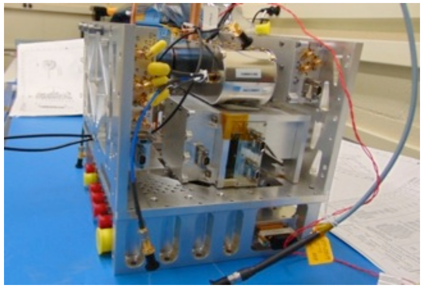
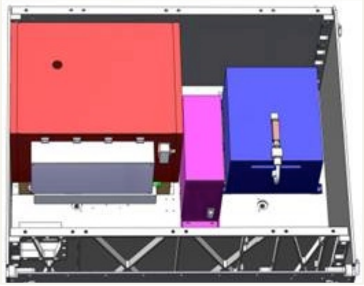
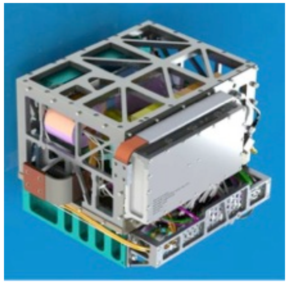


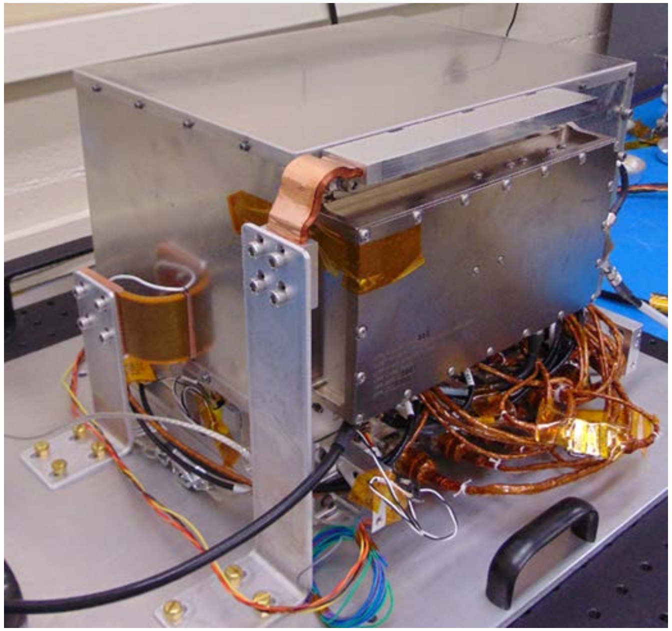
Photo Multiplier Tube (UV Detector)


Build up of the Demonstration Unit


Payload
Clock, USO, GPSR

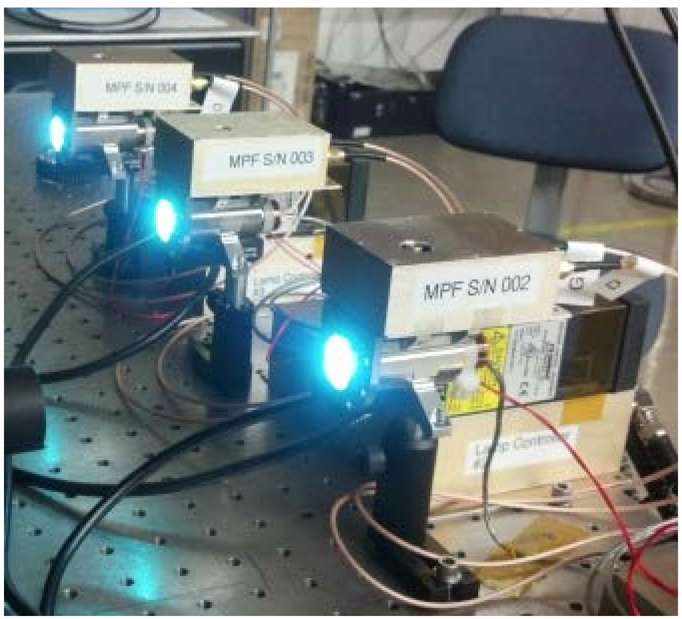

Preliminary Configuration of the Demonstration Unit

- The Demonstration Unit, which is the actual flight hardware, is completely assembled (the synthesizer is an Engineering Model)
- In the current configuration, the clock has run with Signal to Noise Ratio (SNR) pointing to 10-15 class stability performance
- Further environmental testing, performance optimization, and noise reduction activities remain for the rest of CY'14
- Flight Services Agreement was finalized and interfaces with Surrey are stable and working well to delivery


DSAC Demo Unit in flight configuration (with EM synthesizer)

2014 Accomplishments and Forward Plan

- Completed System CDR/ SIR on November 18th, 2014
- Clock will undergo environmental testing in Spring, 2015
- System level I&T (include thermal vacuum, EMI/EMC) in Summer, 2015
- Deliver to Host Spacecraft in Summer, 2015
- Launch in May, 2016 on Falcon 9-Heavy (USAF STP-2)



Mercury UV Lamp Testing

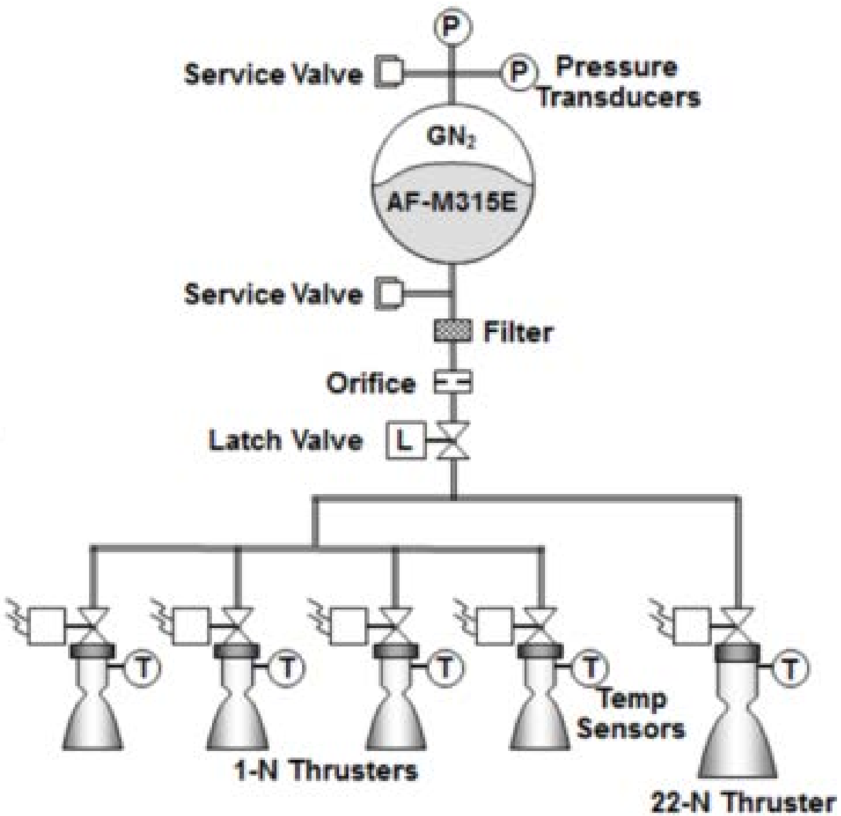
DSAC Demonstration Unit

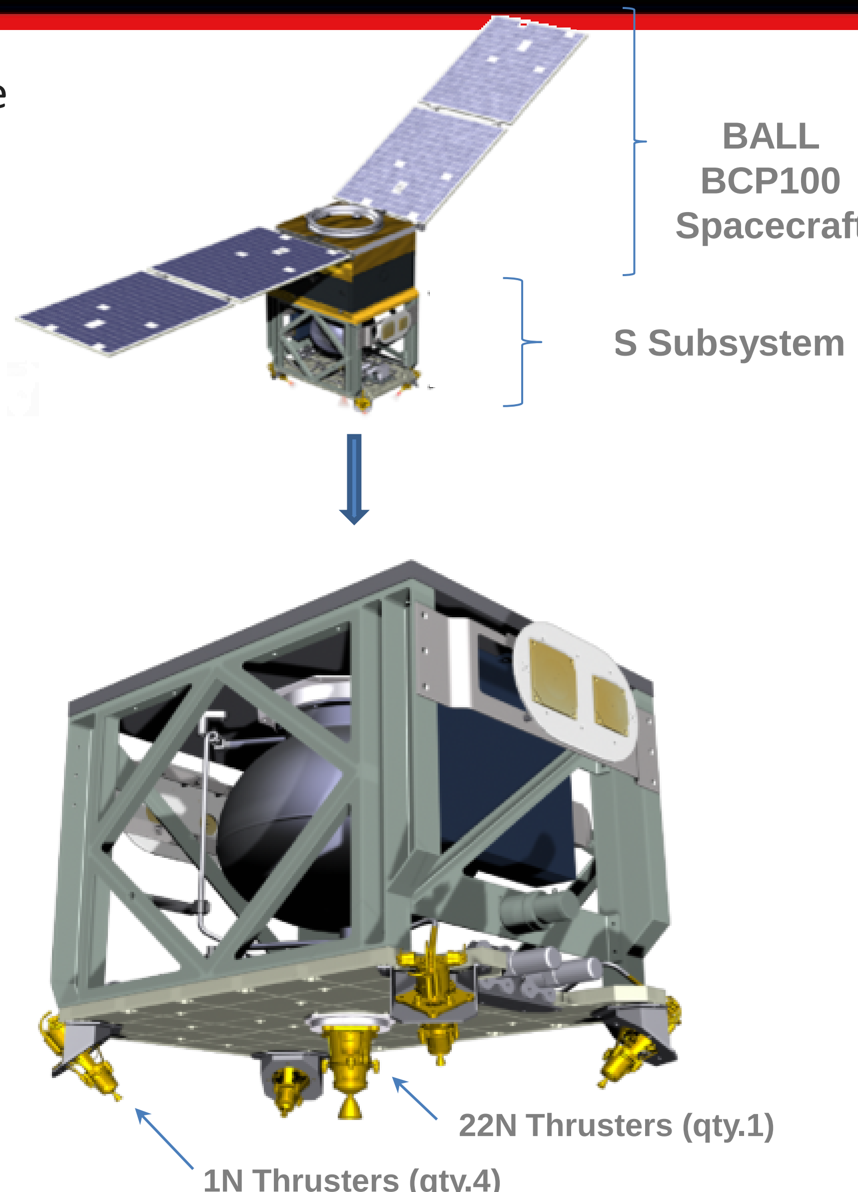
GPIM

Green Propellant Infusion Mission - Ball

WHAT IS GPIM?

GPIM is a multi-partner effort between NASA, the DoD, and industry to fly and demonstrate the AF-M315E, a green propellant based propulsion subsystem onboard a heritage Ball BCP100 spacecraft.

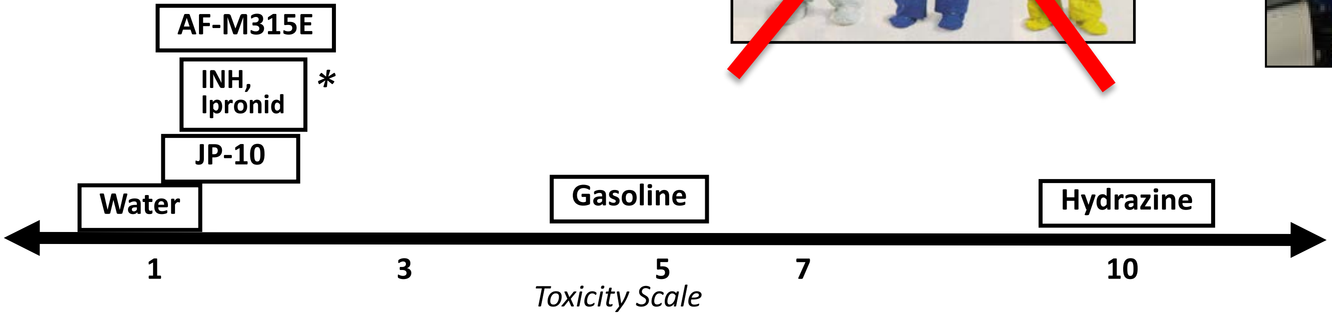




GPIM Propellant Characteristics

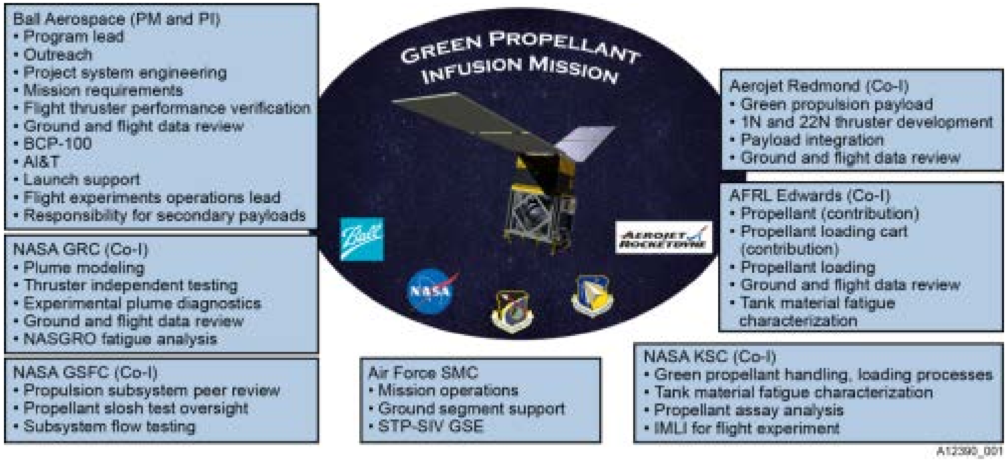
- AFM-315E was developed by AFRL in 1998 as an alternative to Hydrazine
  - Focus on reducing toxicity and increasing performance
- Propellant is an ionic salt blend of HAN (Hydroxylammonium Nitrate) solid oxidizer with water and a compatible fuel
- ~50% improvement in volumetric performance versus hydrazine

- **Less toxic (LD50) than caffeine**
- **Negligible vapor toxicity allows propellant loading with typical PPE (no SCAPE or monitoring requirement)**



GPIM Capability Description

- **Why it is important**
  - First flight demonstration of AF-M315E
  - TRL advancement of critical technologies (7+ to 9)
  - Partnerships
- **Improvements over State-of-the-Art**
  - Improved performance
    - More total impulse for a given tank volume
  - Less toxic
    - No SCAPE required for loading/handling ops
    - Class 1.3C for propellant, 1.4C for transport (FedEx shipping of propellant)
- **Benefits**
  - Mission enabling
    - Improved temperature range
    - Higher performance
  - Lower ground handling costs
  - Improved safety



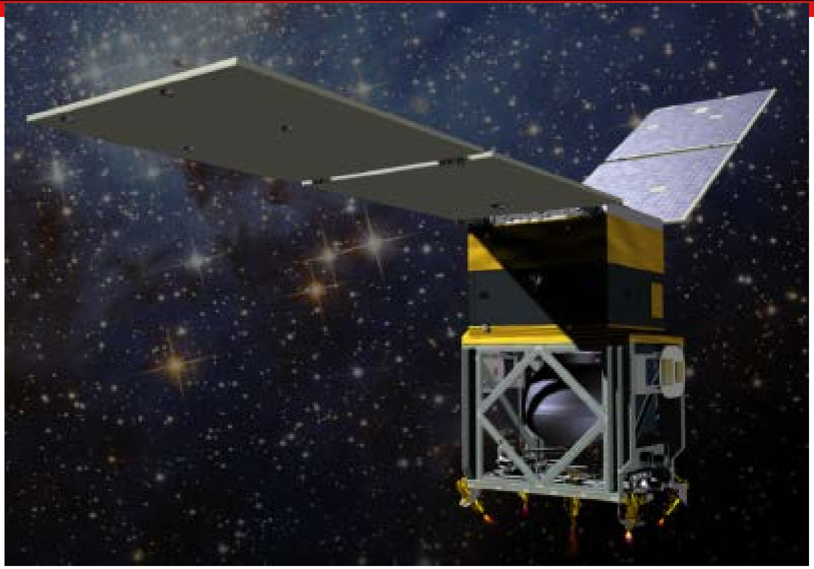
PI / Co-I Team

22 N Thruster

1 N Thruster

GPIM Demonstration Details

- **GPIM space vehicle consists of a BCP-100 bus module and AF-M315E green propellant propulsion subsystem (GPPS) module**
  - Launch on Falcon 9-H (USAF STP 2) in March, 2016
- **Objective is flight demonstration of green propellant propulsion components and subsystem**
  - 1 N and 22 N thruster performance (ground/flight)
  - 3-axis attitude control
  - Momentum dumping capability
  - Delta-V maneuvers
  - Components validation, TRL = 7+ to 9 post flight
  - System flight validation, TRL = 7+ post flight

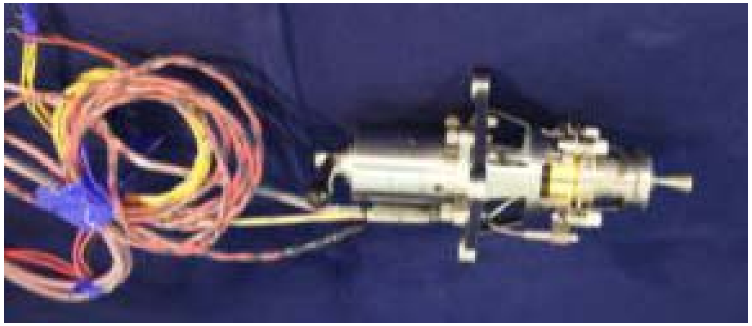


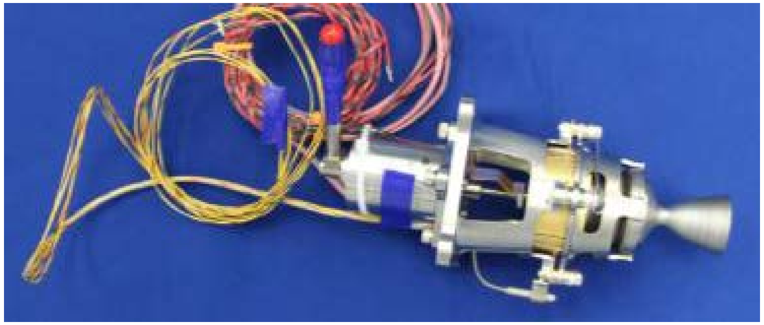
GPIM Spacecraft

- **Mission also includes 3 Space Experiment Review Board (SERB) Payloads**
  - Integrated Miniaturized Electrostatic Analyzer – re-flight (iMESA-R)- USAF Academy
  - Small Wind and Temperature Spectrometer (SWATS) – NRL
  - Space Object Self Tracker (SOS) - AFIT/AFRL

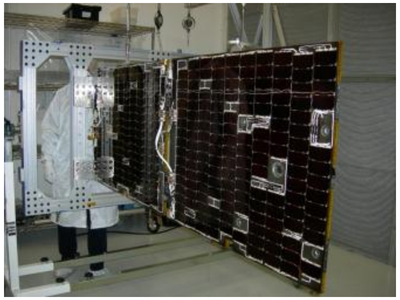
GPIM Mission Progress

THRUSTER DEVELOPMENT CONTINUES – 80% COMPLETE



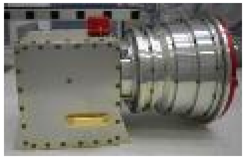


SPACECRAFT BUS – 100% COMPLETE

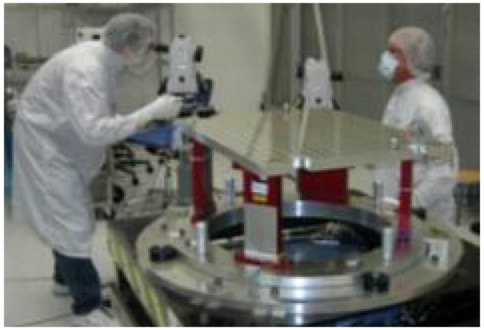


Solar Array

Battery



Star Tracker



Battery Payload Interface Panel (PIP)

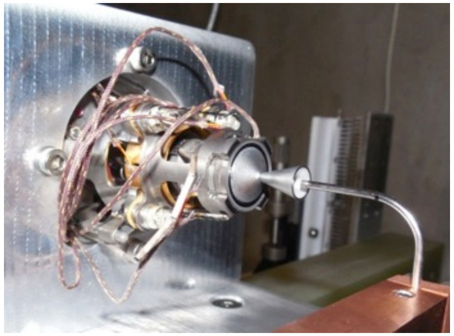
Magnetometer

Motorized Light Band (MLB)

Bus Complete (less SERB panel)

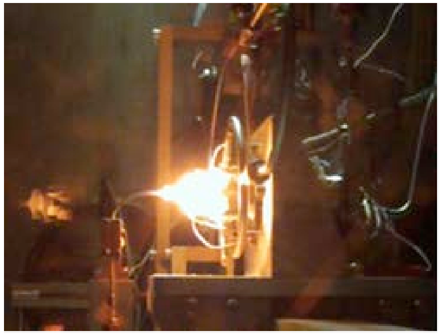
GPIM Thruster Development Progress

1N Thruster Unit #1



1N Thruster on thrust stand

Pre-fire



Hot-fire

1 N Engineering Model (EM) Thruster

- Successfully completed the life testing that exceeded mission duty cycle requirements

The 22 N Engineering Model (EM) thruster

- Completed Acceptance Test Procedure hot-fire & vibe testing late Aug. A minor helium gas leak detected during normal post-vibe leak check. NDE determined source and cause, and pressure testing with water revealed no liquid leakage, so life testing proceeded.
- During life testing, chamber leaked during mission cycle firing (~3.3 kg throughput of propellant). Testing was halted after ~5.1 kg throughput. Subsequently, inspection and analysis was performed to understand root cause.
  - Thermal cycles and thermal gradient from propellant impingement (fundamental to the design and the modes of operation) exceed the capability of the chamber material and appear to be the primary cause for the fracture.
- Several mitigation options considered, 2 deemed most beneficial from a technical, schedule & cost risk perspective
  - The baseline plan is “Use As-Is” with reduced mission duty cycle to stay within the recommended limits of operation.
  - Parallel effort to design/procure an Alumina/Iridium Shield & validate w/ hot fire testing as risk mitigation using IRAD funding recommended by AR.
  - When the fit of shield h/w & hot-fire testing is verified on non-flight h/w, re-eval of go forward plan will be considered.

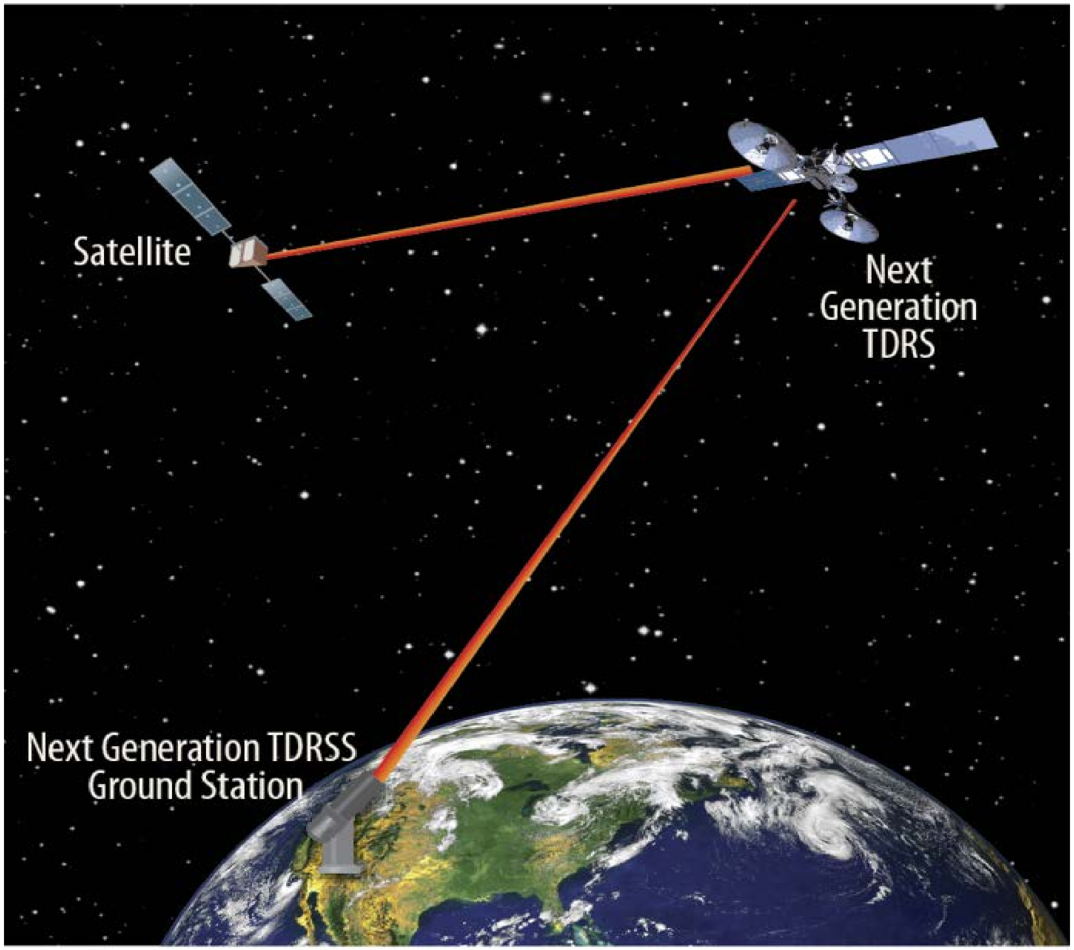
2014 Accomplishments

ACCOMPLISHMENT	RELEVANCE
Aerojet - Completed 1N EM thruster development and testing. Significant progress on 22N testing	Proof of concept validated for 1 N thruster. Procurement of flight model 1N thruster parts has started.
All - Conducted CDR (less CDA)	Major design evolution program gate
Ball - Completed the spacecraft bus	On time and within budget. Ready to proceed with integration of SERB Payloads and GPPS
GRC - Completed plume analysis, test verification	Verification that plume contamination, thermal loading are compatible with S/V
GSFC - Designed developed and built flow test fixture, slosh test fixturing. Testing underway	Completion of the system flow test is a CDA success criteria. Slosh testing to verify inputs for coupled loads analysis
AFRL - PGSE design/procedures complete, assy and evaluation in progress. Ongoing compatibility studies and propellant manufacture	PGSE required for AI&T testing at Ball, loading at SpaceX. Compatibility studies support infusion
KSC - Completed Fracture Mechanics test samples	Samples provided by ATK. Date used to complete analysis required for MSPSP

LCRD

Laser Communication Relay Demo - GSFC

LCRD Mission Description



LCRD will be capable of optical communications relay services between geosynchronous orbit (GEO) and Earth over an extended period, and thereby gain the knowledge and experience base that will enable NASA to design, procure, and operate cost-effective future optical communications systems and relay networks with communications rates 10 to 100 times faster than RF-based communication.

Demo Description

Demo Description:

- A minimum two year flight demonstration to advance optical communications technology toward infusion into Deep Space and Near Earth operational systems, while growing the capabilities of industry sources.

Objectives:

- Demonstrate bidirectional optical communications between geosynchronous Earth orbit (GEO) and Earth
- Measure and characterize the system performance over a variety of conditions
- Develop operational procedures and assess applicability for future missions
- Transfer laser communication technology to industry for future missions
- Provide an on orbit capability for test and demonstration of standards for optical relay communications

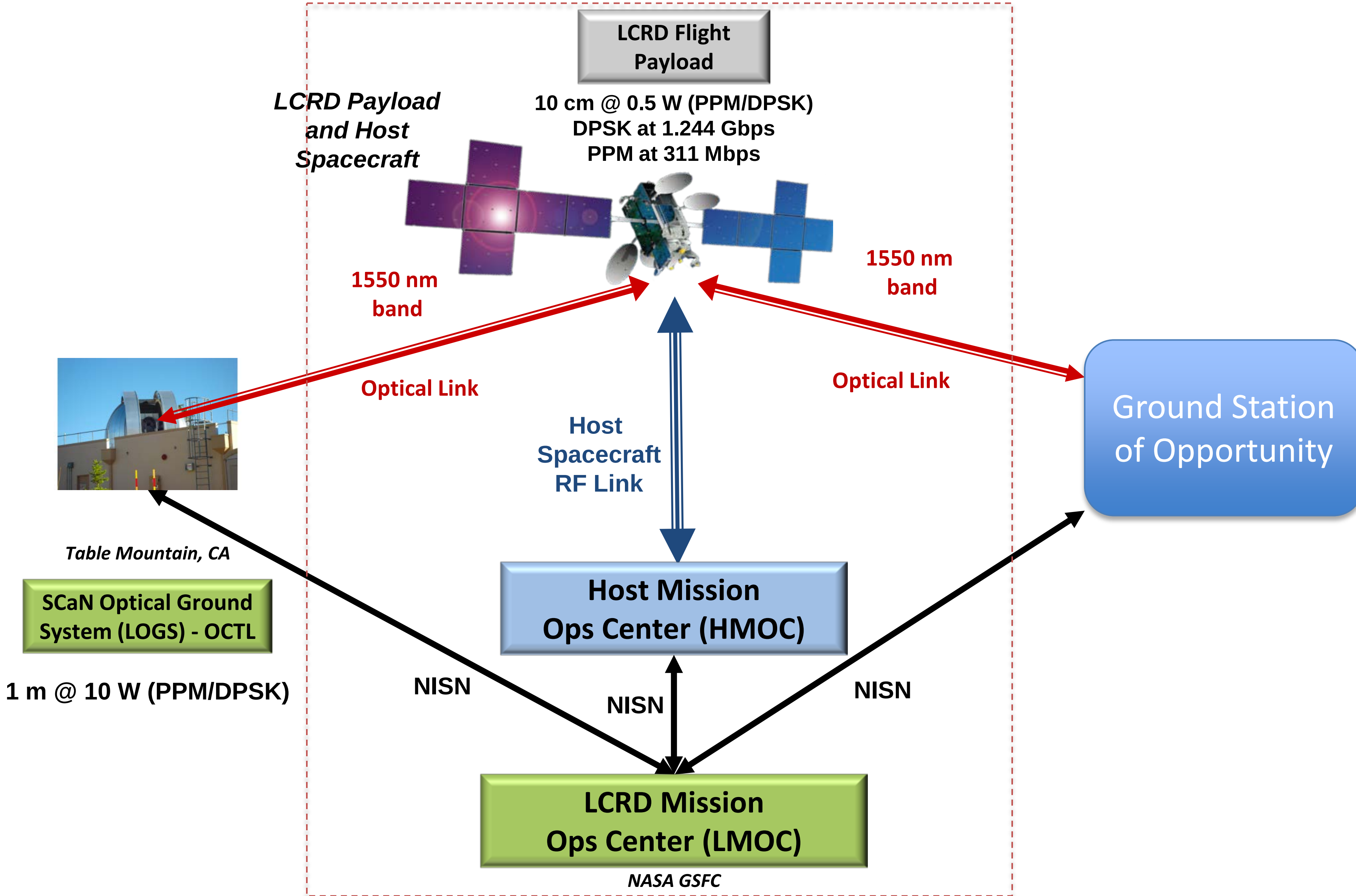
Anticipated Benefits:

- A reliable, capable, & cost effective optical communication technology for infusion into future operational systems

Anticipated NASA Mission Use:

- Next Generation TDRS, Deep Space and Near Earth Science
- ISS and Human Spaceflight

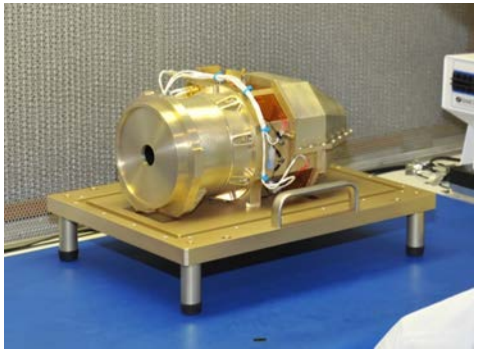
LCRD Demo Representation



LCRD Payload Progress

- **Flight Modems**
  - 100% of known flight EEE parts on-order, 91% received
  - Started integrated testing of Ground Modem #1
  - Negotiated flight board assembly contracts
- **Optical Module (OM)**
  - Flight Solar Window Assemblies completed bake-out & are ready for inspection
- **Controller Electronics (CE):**
  - Received Eng Development Unit, completed acceptance testing
  - Completed MRR, proceeding with flight build
- **Space Switching Unit (SSU):**
  - Completed Design Conformance Review at vendor
  - Received/reviewing latest specification from MIT-LL
  - Re-planning flight H/W architecture to accommodate encryption
- **Flight Software (FSW):**
  - Brass-board version of CE spacecraft-host telemetry output, through 1553 subsystem, ready for integration with CE EDU
  - Re-planning FSW architecture to accommodate encryption

LCRD payload integrated with SSL host



Optical Module Inertial Stable Platform

Controller Electronics Engineering Development Unit

2014 Accomplishments (1 of 2)

- **Project Management:**
  - New Management Team in place (May 2014)
  - Completed requested Trace exercise and De-scope effort
  - Completed Re-plan package
    - Descoped Ground Station and transferred to SCaN
    - Reduced FY15 funding request
  - Begin new Re-plan once encryption technical approach is understood. Will factor in FY15 reduced funding & FY16 funding constraints to support KDP-C commitment
  - LCRD commercial application RFI released in Sept. 2014 and responses arrived in late Oct. 2014
- **Spacecraft:**
  - Study Contract Extended
  - Payload I&T moved from GSFC to SSL to reduce LCC
- **Mission Operations:**
  - Near term staffing reductions and post-checkout moved to SCaN Advanced Communications
- **Ground:**
  - Near term staffing reductions and post-checkout for LMOC moved to SCaN Advanced Comm
  - De-scoped White Sands (GS-2) and moved JPL (GS-1) to SCaN Advanced Comm

2014 Accomplishments (2 of 2)

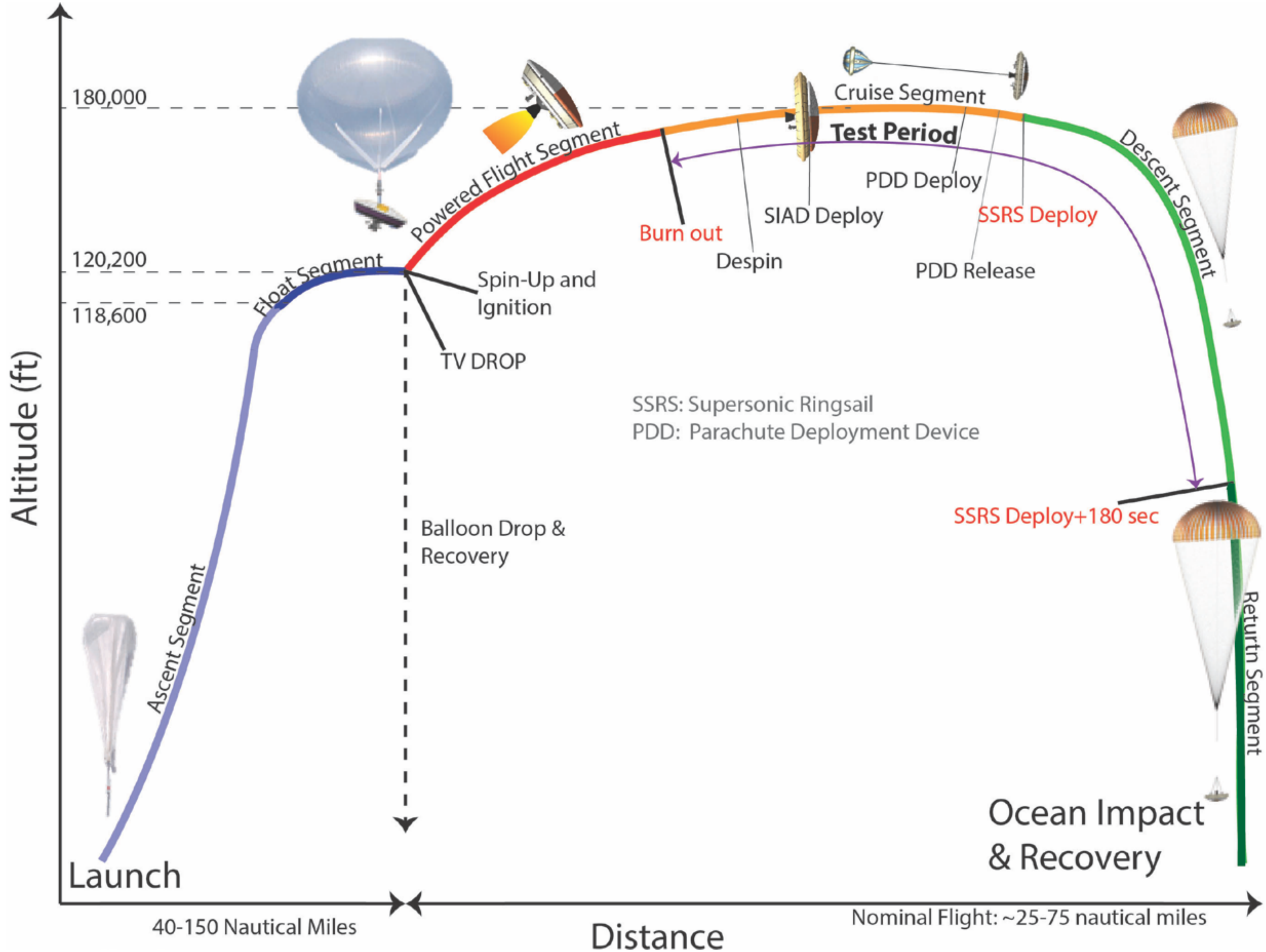
Payload Progress:

- **Modems:**
  - 100% of the known flight EEE parts are on-order and 91% of the flight EEE parts have been received
  - Started integrated testing of Ground Modem #1.
  - Negotiated flight board assembly contracts
- **Optical Module (OM):**
  - Flight Solar Window Assemblies (SWA) completed bakeout & are ready for the government Mandatory Inspection Point (MIP) #1.
- **Controller Electronics (CE):**
  - Received Engineering Development Unit (EDU). CE EDU is undergoing in-house testing.
  - Completed Manufacturing Readiness Review (MRR) and proceeding with flight build.
- **Space Switching Unit (SSU):**
  - Completed Design Conformance Review (DCR) at SEAKR
  - Received and reviewing the latest specification from MIT-LL.
  - Re-planning flight hardware architecture due to addition of encryption
- **Flight Software (FSW):**
  - Implementing brass-board version of the Controller Electronics spacecraft-host telemetry output through 1553 subsystem. Ready for integration with CE EDU.
  - Conducted successful TIM with MIT-LL regarding Pointing Acquisition and Tracking (PAT) software
    - Re-planning flight software architecture due to addition of encryption

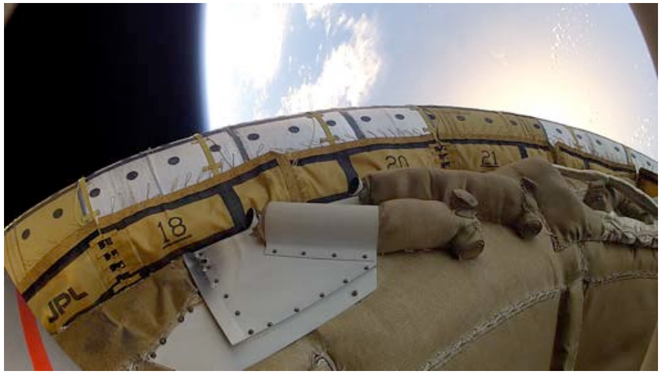
LDSD

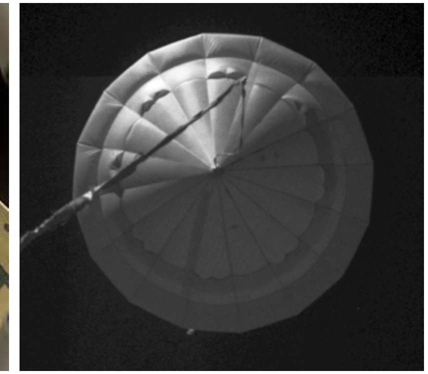
Low-Density Supersonic Decelerator - JPL

LDSD Supersonic Flight Dynamics Test (SFDT)



LDSD Successful SFDT #1 Flight

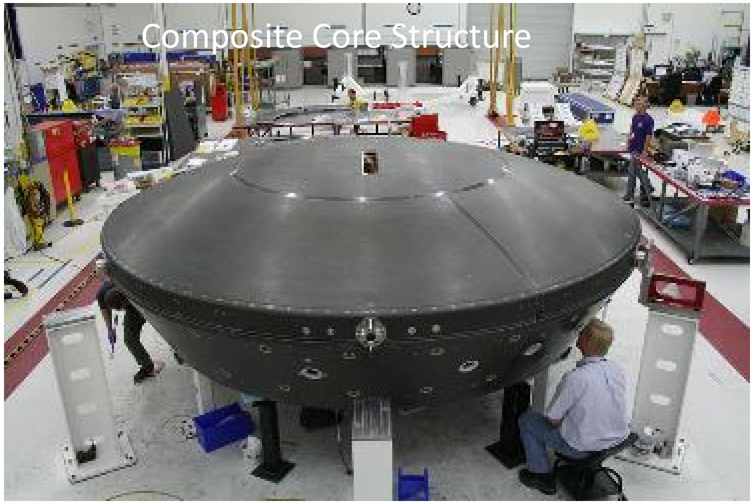


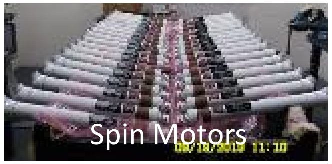


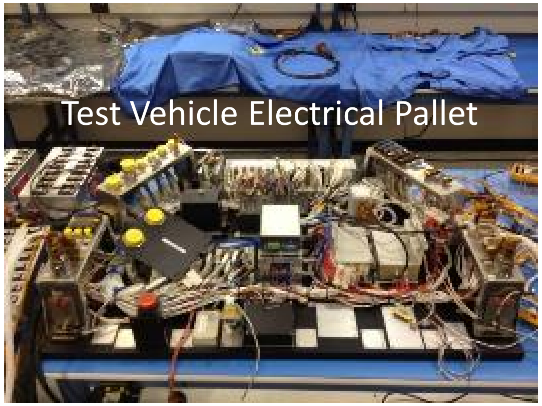
LDSD's SFDT-1 shake-out flight was successful; several accomplishments and notable firsts:

- **Largest blunt body aeroshell ever flown supersonically**
- **SIAD-R was a phenomenal success**
  - Largest Inflatable Aerodynamic Decelerator (IAD) *ever* deployed and tested at supersonic conditions
  - Minimum vehicle disturbances: SIAD inflated to rigid in <1/3 sec using off-the-shelf auto gas generators
  - Extremely rigid geometry: Max measured aeroelastic deflection of <4 mm during operation, <12 mm during parachute deploy at an internal pressure of <3 psi
  - No observed aerothermal damage or degradation
- **Largest ballute (PDD) ever successfully flown at supersonic conditions**
- **First ever supersonic pilot deployment** of the l**argest supersonic parachute ever deployed**
- **Unprecedented quantity and quality of data collected**
  - Several orders of magnitude increase in the amount of data available on supersonic aerodynamic decelerators
  - Most detailed set of data ever collected on any of the three decelerators flown
  - Parachute experts now have new known unknowns about initial inflation of the chute at supersonic speeds

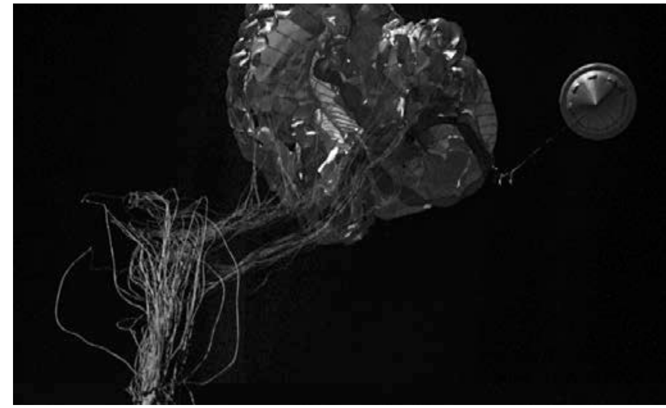
LDSD Built its *Own* Ride



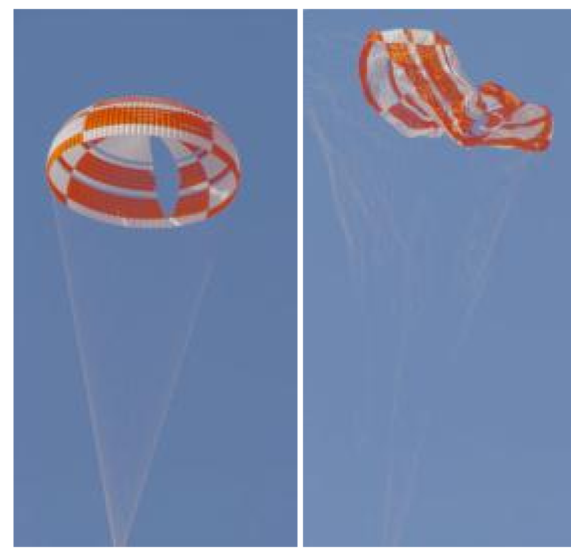




2014 Accomplishments & Status



- **Supersonic Flight Dynamics Test (SFDT) #1 in 6/28/2014**
  - Met all success criteria for this first shakeout flight
  - Met all four bonus goals for the first flight
  - Parachute failed structurally
    - But it was not part of success criteria
- **Parachute Development Test (PDV) -1b – 10/9/2014**
  - Deliberately tested it to failure to understand design margin and workmanship issues
    - Post test analysis showed workmanship issue
- **Issued contracts to 2 parachute suppliers for FY15**
  - Changed from Disksail to Ringsail design
  - Pursuing parallel path with both vendors
  - Planned PDV test in late Spring, 2015
- **STMD is pursuing different SFDT flight options in FY15 & 16**
  - FY15 budget constraint



SEP

Solar Electric Propulsion – GRC

SEP Demonstration Mission

Demonstration Description

- Develop and fly a spacecraft in the 50kW class that uses flexible blanket solar arrays for power generation and electric propulsion (EP) primary propulsion that is capable of delivering payload from LEO to higher orbits.

Objectives

- Demonstrate high-power EP technology and high-power solar array system (SAS) technology in relevant space environments.
- Demonstrate orbit transfer with an integrated high-performance SEP spacecraft
- Demonstrate an SEP system that is extensible to next-generation, higher power SEP systems.
- Provide a cross-cutting high-performance orbit-to-orbit transportation capability

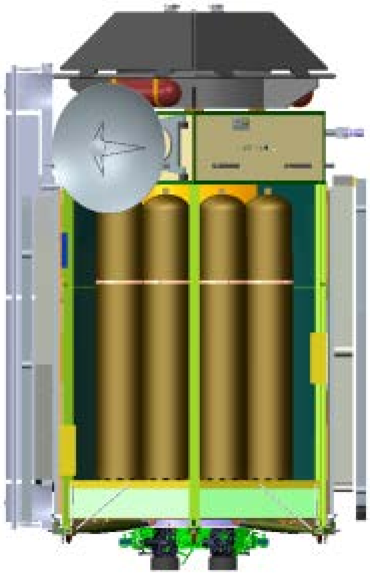
Benefits

- Compared with current systems, SEP systems will weigh 2x less at launch and use 4x less stowed volume for the electricity produced, and will be able to withstand 4 times more radiation.
- Because the spacecraft will weigh much less at launch, each launch vehicle will be able to carry more supplies or science instruments.
- The solar arrays will be several times lighter, stronger, and more compact while operating in a much harsher radiation environment than current large commercial satellites.

Demonstration Description

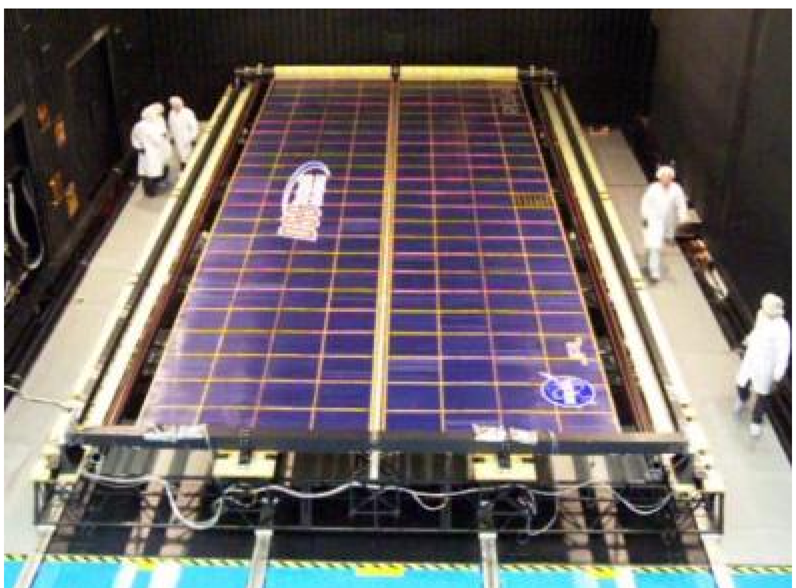
Solar Electric Propulsion

- 40 kW-class SEP used to propel Asteroid Redirect Robotic Mission (ARRM) spacecraft to target asteroid, and return with asteroidal material to crew-accessible Lunar Distant Retrograde Orbit
- Two 25 kW-class solar array wings
- Long-life, 13-kW class electric propulsion
- Four 30”x 120” composite tanks; 8 mt Xenon load
- Planned Launch Date: June 2019; currently working toward MCR in February
- Launch Vehicle: Delta IV or SLS

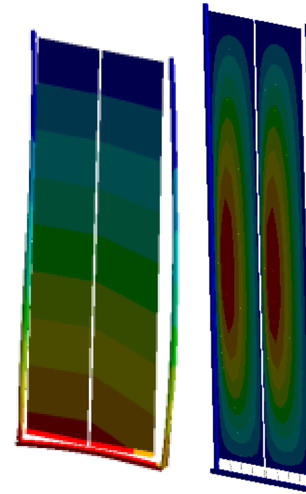


Mega-ROSA Solar Array

Thermal vacuum deployment and vacuum deployed dynamics testing complete.



Thermal and structural models validated with test data



Extensibility to 100kW-class (left) and 250kW-class (right) shown with Mega-ROSA hardware

12.5 kw Hall Thruster Testing

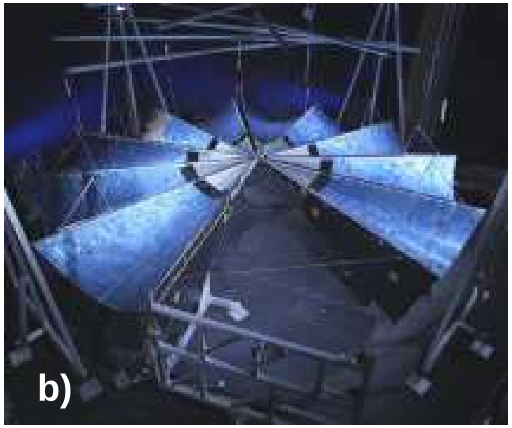
12.5 kW Hall thruster design and fabrication team in front of VF12

2014 Accomplishments & Status (1 of 3)

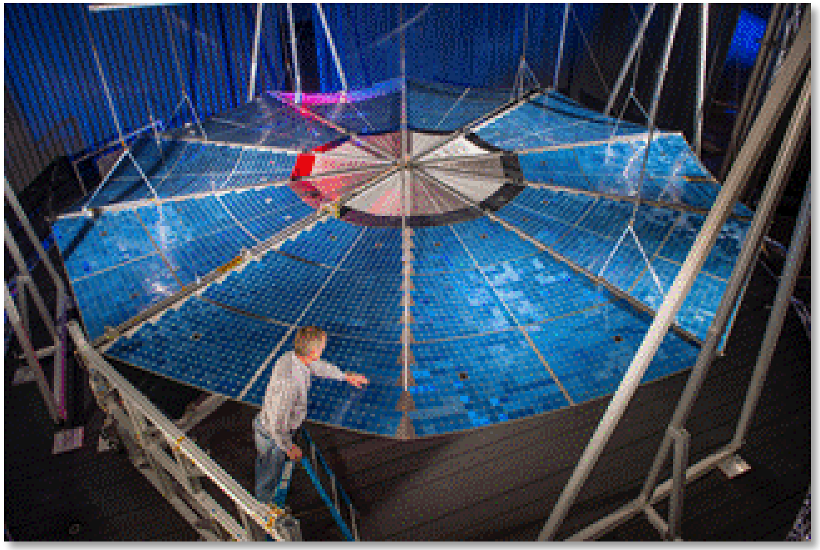
- **ROSA Solar Array Brought to TRL 5**
  - The final review for the DSS Mega-ROSA contract was held on June 25. Additional tasks were subsequently added. The review included:
    - Vacuum deployment demonstration results at ambient, -65□C, and +65□C temperatures
    - Test results for deployed and stowed dynamics, and deployed strength and stiffness
    - Analytical correlations to structural and thermal test data
    - Electrical power and performance analysis (W/kg and W/m3)
    - Extensibility concept to >250 kW system power
  - Compared to the SOA:
    - 20X greater deployed strength,
    - 4X greater specific volume,
    - 3X higher operating voltage,
    - 1.7X greater specific mass,
    - 1.5X more power per wing

2014 Accomplishments & Status (2 of 3)

- **Mega Flex Solar Array Brought to TRL 5**
  - The final review for the ATK Mega Flex development contract was held on April 29. Additional tasks were subsequently added. The review included:
    - Vacuum deployment demonstration results at ambient, -65□C, and +65□C temperatures
    - Test results for deployed and stowed dynamics, and deployed strength and stiffness
    - Analytical correlations to structural and thermal test data
    - Electrical power and performance analysis (W/kg and W/m3)
    - Extensibility to >250 kW system power



Deployment testing in thermal vacuum chamber
a) stowed,
b) partially deployed,



2014 Accomplishments & Status (3 of 3)

12.5 kw EP Thruster Testing

- Achieved ~60% efficiency at Isp >3,000 sec at 12.5kw and 800V.

Procurement Authorization

- Received Agency authorization to release Solar Array RFI and Electric Propulsion RFP in 11/13/2014 - expected release in Spring, 2015

STATUS

- Extended Solar Array System contracts with DSS and ATK for additional analysis, will be completed by December, 2014
- Performing detailed performance and thermal characterization testing on TDU-1 in VF5 (operation up to 12.5kW performed)
- Completing TDU-2 assembly for vacuum testing at JPL
- Finishing 120 V_{in} /800 V_{out} PPU testing
- Monitoring BAA contracts
  - Boeing, ExoTerra, SSL, LM
  - Results will inform procurement strategy
- Assessed ability to launch, install and operate a 25 kW class wing

SSD

Solar Sail Demonstration – L'Garde

Solar Sail Demonstration

Demo Description:

- Small Sailcraft as a secondary on a Falcon 9 1.1 extending a 1200m2 Solar Sail on a 1 year mission. The demonstration of the propellantless propulsion potential of a navigable solar sail.

Objectives:

- Demonstrate segmented deployment of a solar sail
- Demonstrate attitude control plus passive stability and trim using beam-tip vanes.
- Execute a navigation sequence with mission-capable accuracy.
- Fly to and Possibly Maintain Position at sub-L1 and/or Pole Sitter Positions

Anticipated Benefits:

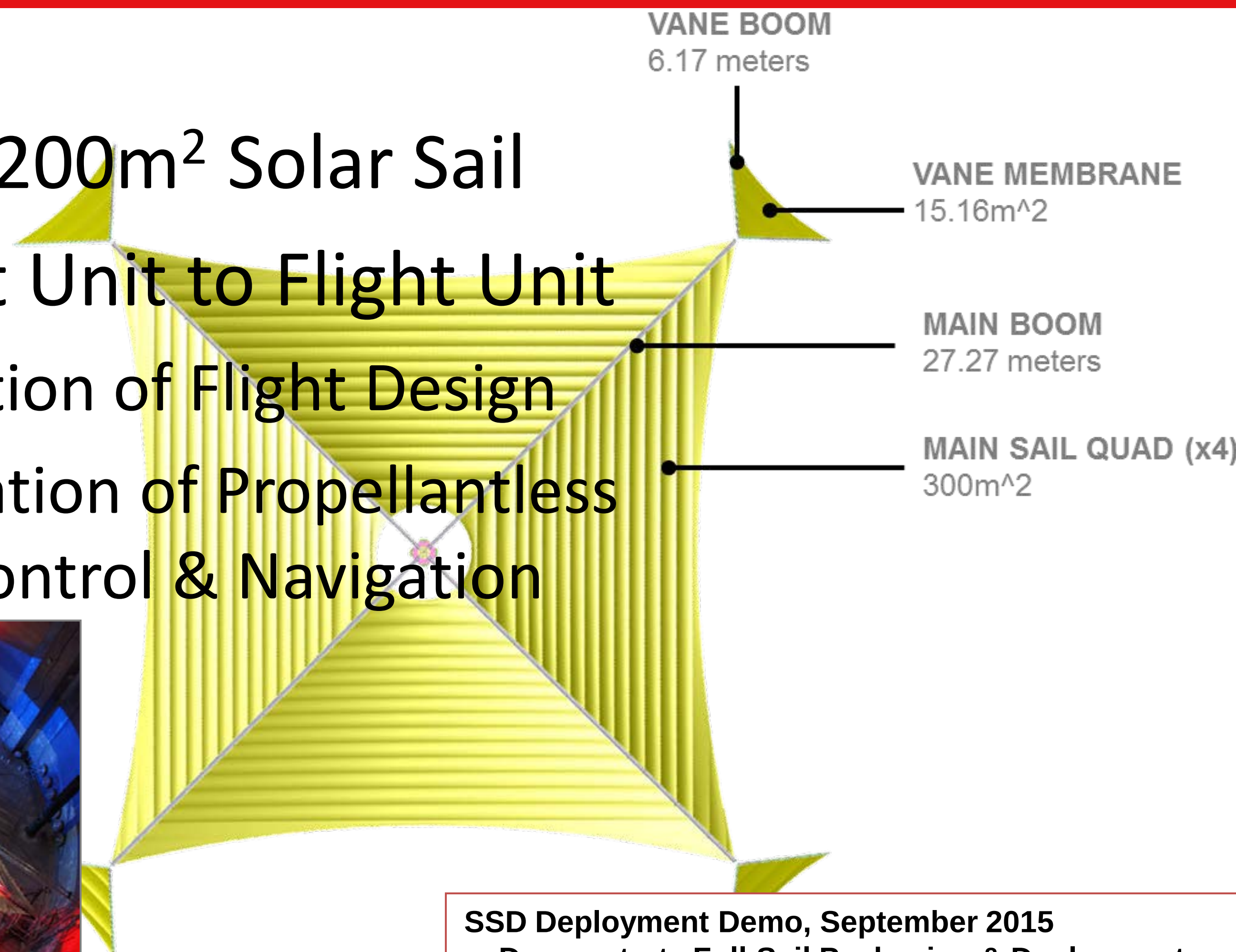
- The demonstration of the Sunjammer sail will allow mission planners and designers to put this revolutionary technology on their critical path. The flight will open the floodgates of solar sail missions that are possible and researched in numerous studies and papers.

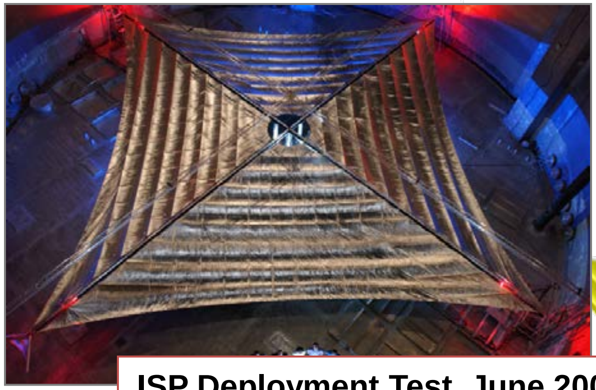
Anticipated NASA Mission Use:

- In-Space Propulsion, Heliophysics, Propellantless Propulsion,

SSD Description

- 318 m^2 to 1200m^2 Solar Sail
- Ground Test Unit to Flight Unit
  - Full Validation of Flight Design
  - Demonstration of Propellantless Attitude Control & Navigation





ISP Deployment Test, June 2005
- **318 m^2 (13 m Main Boom) Solar Sail**
- **Ground Test Unit deployed in vacuum**
- **Uncontrolled Vanes**

SSD Deployment Demo, September 2015
- **Demonstrate Full Sail Packaging & Deployment**
- **Demonstrate Flight Configuration of Sailcraft**
- **Validation of Flight Unit Fabrication & Packaging Procedures**
- **Demonstrated Articulation & Control of Vanes**

SSD Project History

- **Project Initiated in 2011**
- **De-Scoped Review – June 2014**
- Reduced scope to Ground Demonstration only
  1. Sailcraft de-scoped to a flight-like Solar Sail Assembly within a canister simulator
  2. Flight-like canister design to proceed for CDA (in October 2014).
  3. Protoflight avionics de-scoped to Engineering Model avionics.
  4. Qualification testing with flight-like canister and re-deployment demo deferred to FY16.
  5. Navigation, calibration, and attitude control analyses deleted.
  6. All software development de-scoped from Class B to Class C, or less as appropriate.
- **Critical Design Audit (CDA) Readiness Review 10/1/2014**
- **Contract Extension Review on 10/9/2014**
  - L'Garde contract period-of-performance ends on 12/15/2014
  - The STMD Executive Program Management Council (EPMC) decided to limit the remaining contractual Period of Performance to be used for Project close-out activities and re-designate the upcoming Critical Design Audit as a Close-Out Review.

THOR

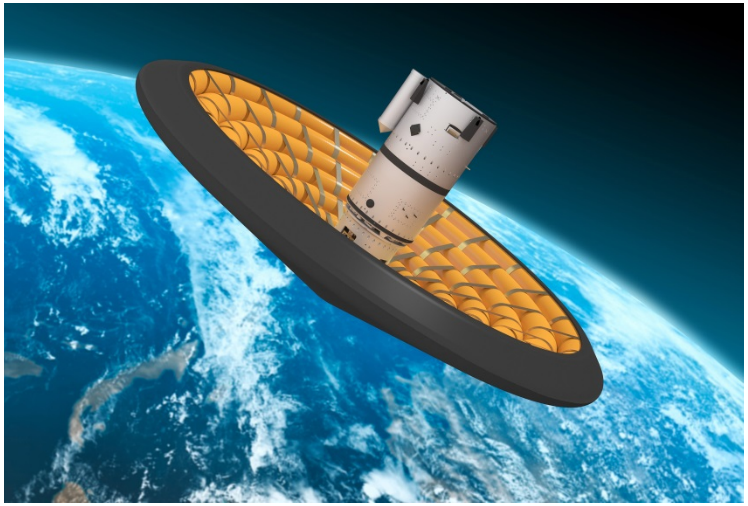
Terrestrial HIAD (Hypersonic Inflatable Aerodynamic Decelerator) Orbital Reentry - LaRC

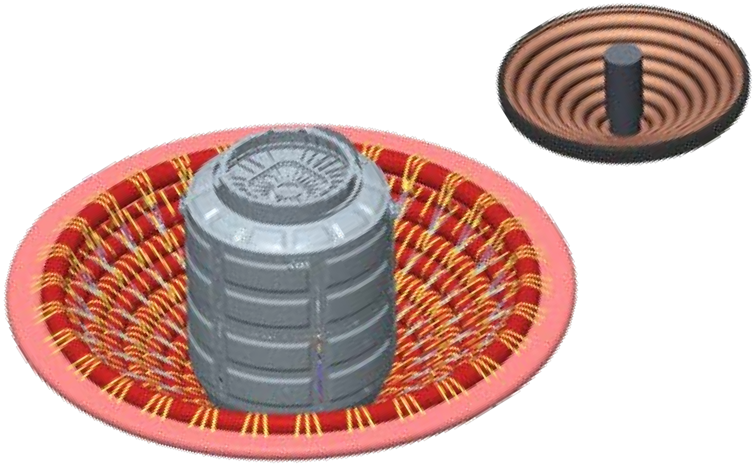
THOR Mission Description

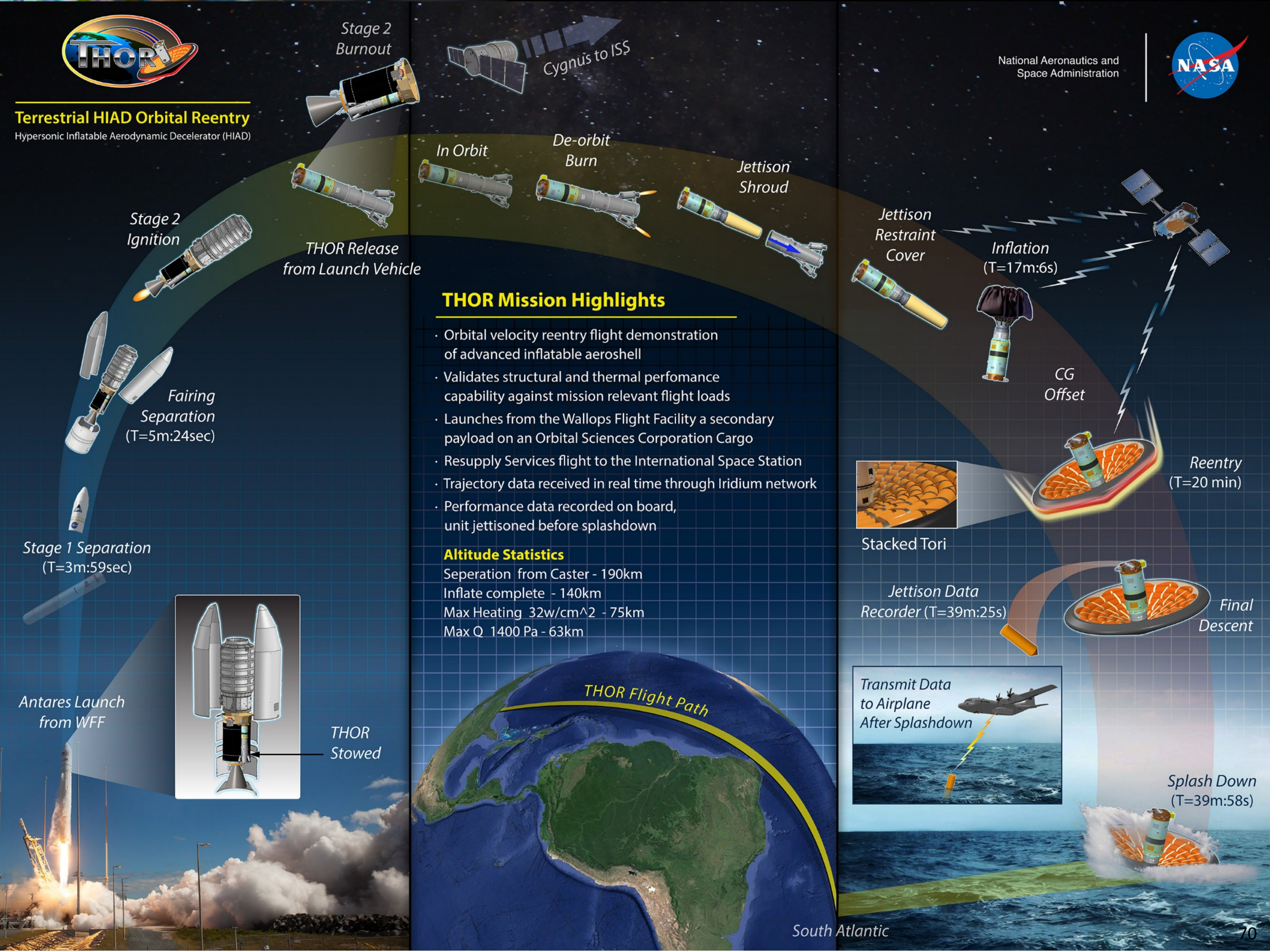
Concept: Conduct high energy reentry flight test on sub-scale heat shield and significantly advance STMD HIAD Gen 2 Technology Readiness Levels for enabling affordable humans to Mars architectures.

Approach: Utilize existing STMD flight hardware (IRVE-3 BTP [$4M]) as a hosted payload taking advantage of available mass and usable volume capability in Antares launch vehicle.

Goal: Verify the heat shield capabilities and obtain data in Mars MSL / LEO return class flight environment (heat rate, heat load, and deceleration), demonstrating viability of STMD HIAD Gen 2 system, while taking advantage of a low cost orbital ride share opportunity.







THOR
Terrestrial HIAD Orbital Reentry
Hypersonic Inflatable Aerodynamic Decelerator (HIAD)
Stage 2
Burnout
Cygnus to ISS
National Aeronautics and
Space Administration
NASA
In Orbit
De-orbit
Burn
Jettison
Shroud
Stage 2
Ignition
THOR Release
from Launch Vehicle
Jettison
Restraint
Cover
Inflation
(T=17m:6s)
THOR Mission Highlights
· Orbital velocity reentry flight demonstration of advanced inflatable aeroshell
· Validates structural and thermal perfomance capability against mission relevant flight loads
· Launches from the Wallops Flight Facility a secondary payload on an Orbital Sciences Corporation Cargo
· Resupply Services flight to the International Space Station
· Trajectory data received in real time through Iridium network
· Performance data recorded on board, unit jettisoned before splashdown
Altitude Statistics
Seperation from Caster - 190km
Inflate complete - 140km
Max Heating 32w/cm^2 - 75km
Max Q 1400 Pa - 63km
CG
Offset
Fairing
Separation
(T=5m:24sec)
Reentry
(T=20 min)
Stacked Tori
Stage 1 Separation
(T=3m:59sec)
Jettison Data
Recorder (T=39m:25s)
Final
Descent
Antares Launch
from WFF
THOR
Stowed
THOR Flight Path
Transmit Data
to Airplane
After Splashdown
Splash Down
(T=39m:58s)
South Atlantic

2014 Accomplishments & Status

- New Start – KDP-A on 8/16/2014
- Technology Infusion Group (TIG) convened 10/21/14, provided Level 1 requirements recommendation.
- System Requirements Review (SRR) completed 10/23-24/2014
- Impact of Antares Launch Failure (10/28/2014) on THOR mission launch manifest is TBD at this point
  - STMD issued guidance to THOR project to delay launch vehicle interface related procurement
  - THOR payload procurement continues on critical path


National Aeronautics and
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