In-Space Robotic Manufacturing and Assembly (IRMA)
Update for NAC TI&E Committee

November 18, 2016

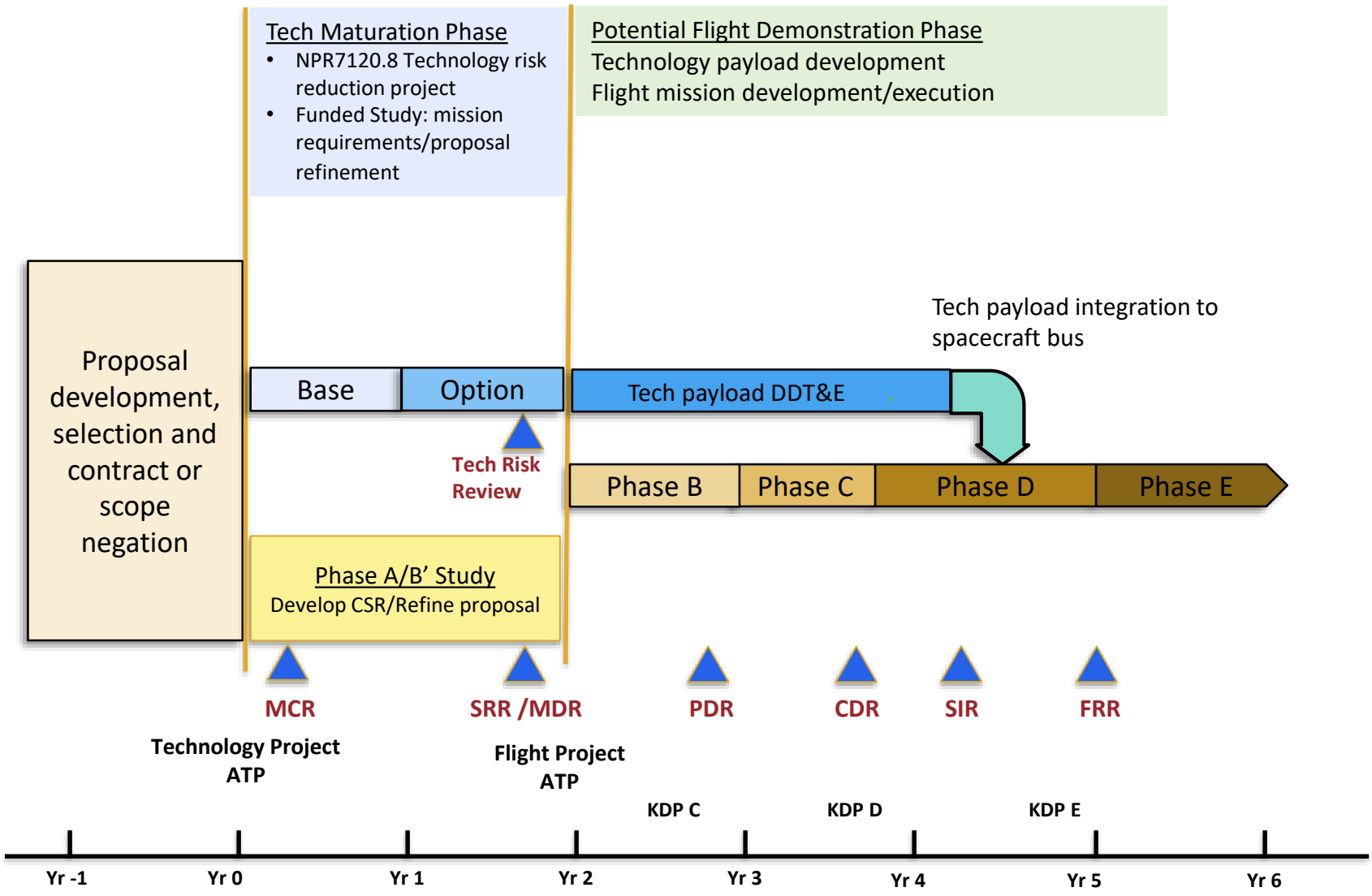
IRMA Portfolio Overview

- IRMA is managed by the Technology Demonstration Mission (TDM) Program for NASA's Space Technology Mission Directorate (STMD).
- Selected from the 2015 STMD Tipping Point BAA with the objective to invest in ground-based development to prepare technology for potential flight demonstration.
- Demonstration is intended to result in:
  - a significant advancement of the technology's maturation.
  - a high likelihood for utilization of the technology in a commercially fielded space application.
  - a significant improvement in the offerors' ability to successfully bring the space technology to market.
- TDM has awarded three contracts which will demonstrate robotic manipulation of structures and remote manufacture of structural trusses. The use of these technologies in relevant environments will ready them for potential flight demonstration and then commercialization.

IRMA Portfolio Overview

- Key to the Public-Private Partnership concept of these Tipping Point awards is shared investment.
  - Each selected award includes a corporate and/or customer contribution of at least 25% of the total proposed firm-fixed price.
- Each proposal utilizes structures and materials expertise as well as test facilities at two NASA centers
- Each selected proposal included a strong business case for commercializing in-space manufacture, assembly, and maneuvering to enable large structure assembly, satellite servicing, and even re-purposing of satellites.
- The industry partners are focused on the end goal and want to optimize development.
  - “If it doesn't feed the business use case, don’t do it.”

TDM IRMA Project Lifecycle
Secondary or Primary Mission



Archinaut
Made In Space, Inc.

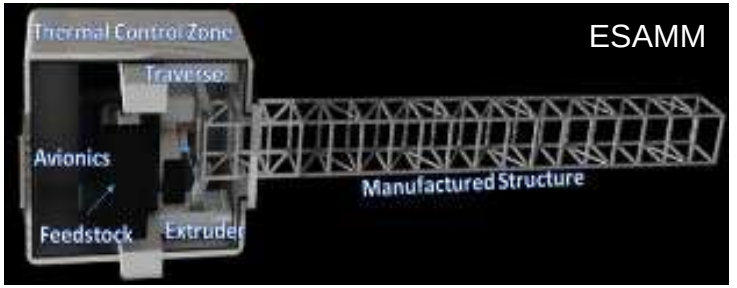
Vision for Made In Space, Inc.

Made In Space, Inc. (MIS)
Archinaut Technology Development

A 2 year ground based risk reduction effort to advance in space manufacturing and assembly technologies for infusion into exploration missions.	7120.8 Ground Demo	Formulation	LCCE: $20 M	TRL: 4 -> 6

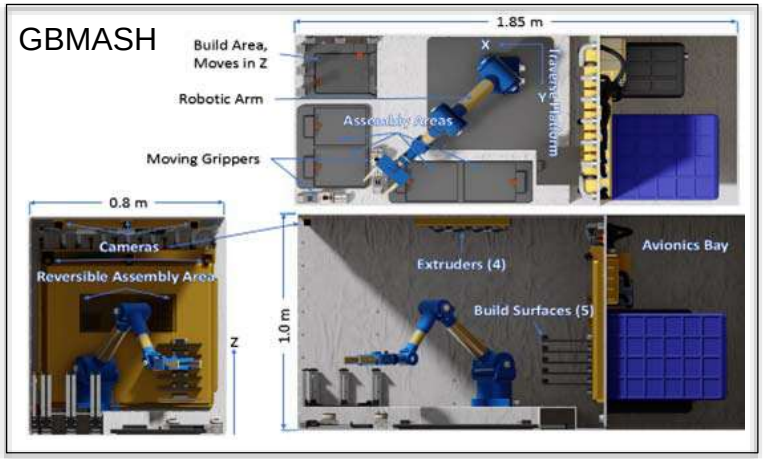
Objectives:

- Demonstrate extended structure additive manufacturing of structures in a relevant environment using Extended Structure Additive Manufacturing Machine (ESAMM)
- Demonstrate additive manufacturing and assembly of structures in a relevant environment using Ground-Based Manufacturing and Assembly System Hardware (GBMASH)
- Evaluate part quality through mechanical and structural testing



Current Status / Accomplishments:

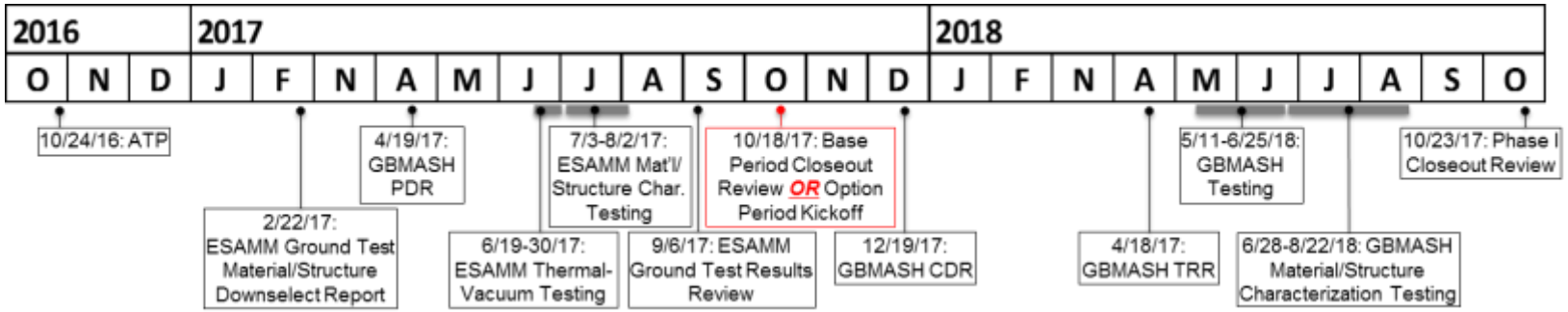
- Contract awarded October 27, 2016.
- Kick-off meeting held November 10, 2016 at ARC.



Team:

- **Made In Space**: Project lead; expertise in in-space additive manufacturing and telerobotics
- **Northrup Grumman Corp. (NGC)**: Lead sub-contract, system integrator
- **Oceaneering Space Systems**: Robotic arm development
- **Ames Research Center (ARC)**: Thermal-vacuum test planning, development, and execution

Schedule:



Made In Space, Inc.
Hardware Descriptions

- ESAMM (Extended Structure Additive Manufacturing Machine)
  - Capable of “out-of-volume” additive manufacturing in a simulated space (thermal-vacuum) environment
- GBMASH (Ground-Based Manufacturing and Assembly System Hardware)
  - Integrates four critical technology subsystems
    - Extruder that successfully operates in a space-like environment
    - Traversing system for out-of-volume printed part manipulation
    - Robotic assembly for printed and pre-fabricated simulated spacecraft components
    - In-Situ Inspection and Validation
  - Capable of additive manufacturing and assembly in a simulated space (thermal-vacuum) environment
- Optimast
  - On-orbit flight demonstration of ESAM technology, possibly as a secondary payload integrated into an EELV Secondary Payload Adapter (ESPA) ring to construct and inspect a truss
- Archinaut
  - System that is able to robotically create spacecraft in space which reduces spacecraft cost, reduces the limitations rocket launch places on spacecraft design (launch loads and volumes), and removes astronauts from harm’s way

Made In Space, Inc. Development Vision

PHASE I

ESAMM

Thermal-Vacuum Prototype

GBMASH

Optimast*: Flight Demo Mission Concept

PHASE II

Technology Development Goal

Archinaut: Communications Satellite Manufacture, Assembly and Construction

*Optimast (being developed with NGC in-kind contribution during Phase I)

Commercial In-space Robotic Assembly and Services (CIRAS)
Orbital ATK

Vision for Orbital ATK Commercialization

Previous Work

LaRC LSMS

Shuttle RMS

Lightweight Surface Manipulator System (LSMS)

- Highly efficient and modular tension / compression design for gravity environments
- Ground tested at Desert RATS 2008, Moses Lake, WA
- Long and successful design and test program of primary structure and multiple end effectors

In-Space State of the Art:

- Shuttle and ISS manipulators
- Massive co-located joints/motors
- Low packaging efficiency
- SRMS retired with shuttle

CIRAS Program

TALISMAN Servicing Mission Concept

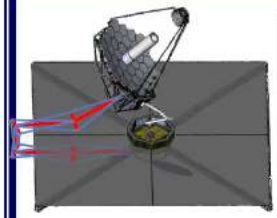
CIRAS Application:

- Dual TALISMANs
- Assemble/erect backbone truss
- Attach solar array modules
- E-Beam weld joints

Path to Flight:

- Phase I: TRL 4-6, develop TALISMAN technology, ground test all major components and interfaces with IPJR and E-Beam device
- Phase II: TRL 6-9, prepare, test and launch flight unit
- Future: SEP demo, commercial comm tower, further on-orbit tests

Future Applications



Large Telescope Servicing

Large SEP Tug

Mission Concepts:

- Reintroduce capability for long-reach operations in LEO/GEO
- Servicing government and commercial satellites
- Assembly, service and repair of large space structures including:
  - *Large aperture telescopes*
  - *Solar arrays / SEP*
  - *In-space construction / payload platform*
  - *Exploration Spacecraft*
- Asteroid Redirect Mission (ARM), multiple TALISMANs as grapple arms and/or legs
- Outpost construction and ISRU

Orbital ATK
Commercial In-space Robotic Assembly and Services

A 2 year ground based risk reduction effort to advance in space manufacturing and assembly technologies for infusion into exploration missions.	7120.8 Ground Demo	Formulation	LCCE: $20 M	TRL: 4 -> 6

Objectives:

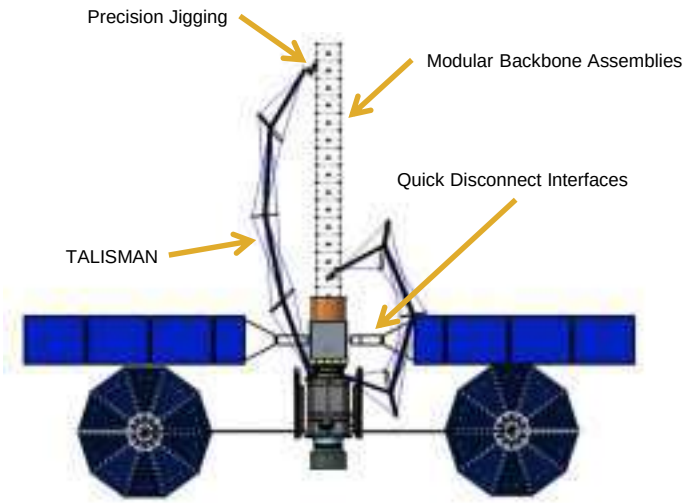
- Demonstrate robotic reversible joining methods for mechanical and electrical connections.
- Develop a feasible concept to validate space assembly geometries.
- Demonstrate repeatable module to module interfaces for in-space structural assembly.

Current Status / Accomplishments:

- Contract awarded on September 22, 2016 .
- Kickoff meeting held at Langley Research Center on October 6, 2016.

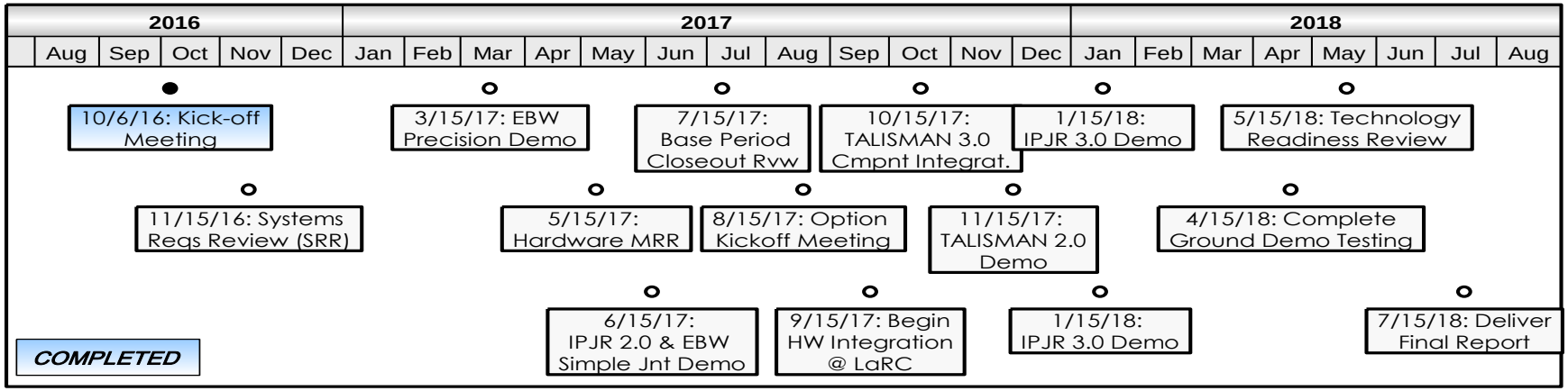
Team:

- **Orbital ATK**: Project lead
- **Glenn Research Center (GRC)**: conduct concept feasibility study
- **Langley Research Center (LaRC)**: develop TALISMAN system capable of being used for mission extension vehicle applications.
- **Naval Research Laboratory (NRL)**: Robotic software development

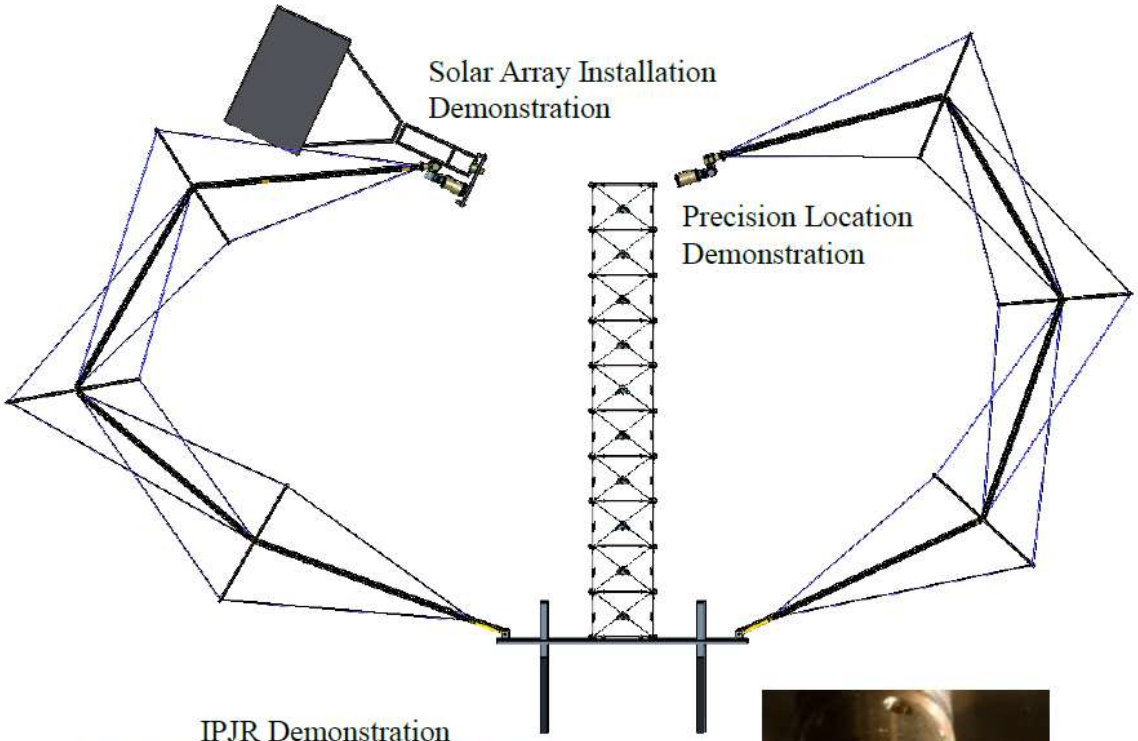


Vision: a robotic assembly, repair, maintenance and refurbishment capability to enable repurposing of spacecraft modules

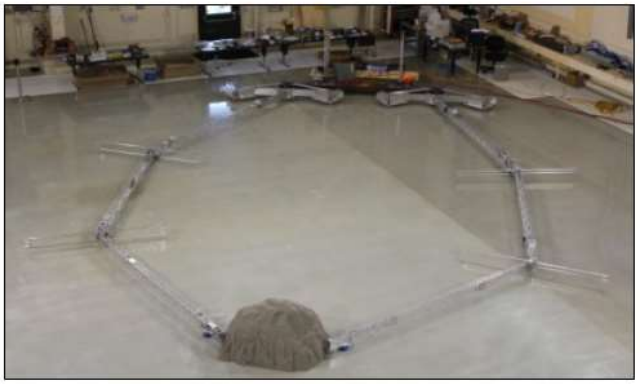
Schedule:

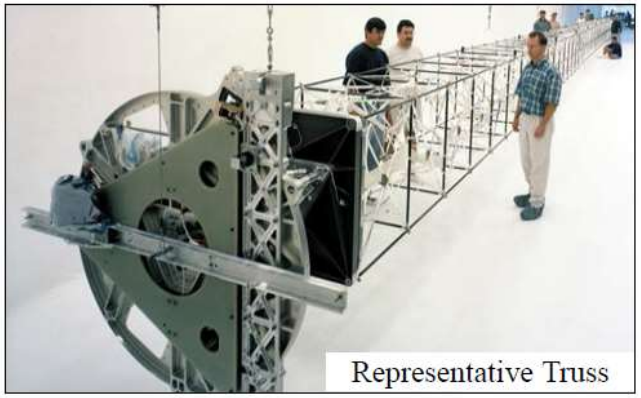


Orbital ATK's CIRAS
Ground Demonstration Hardware

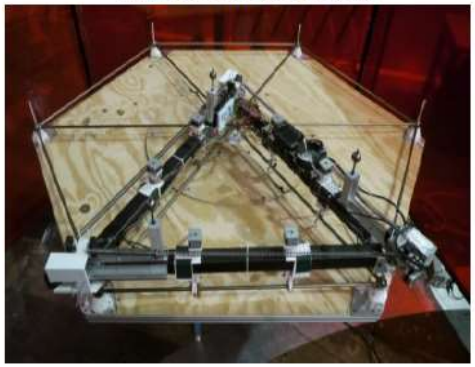


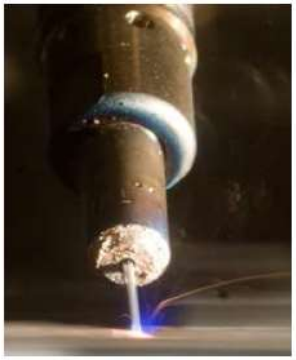
TALISMAN & End
Effector Demonstration





IPJR Demonstration



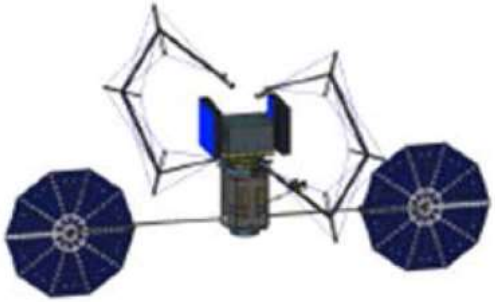


EBEAM Welding Demonstration

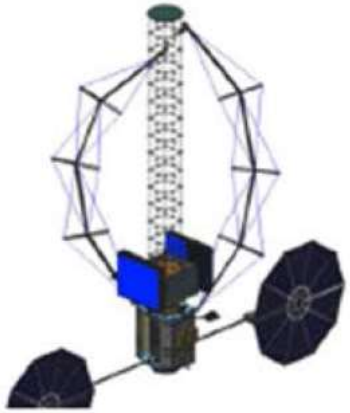
Orbital ATK's CIRAS
Flight Demonstration Approach

1: Launch, Demo Payload on MEV

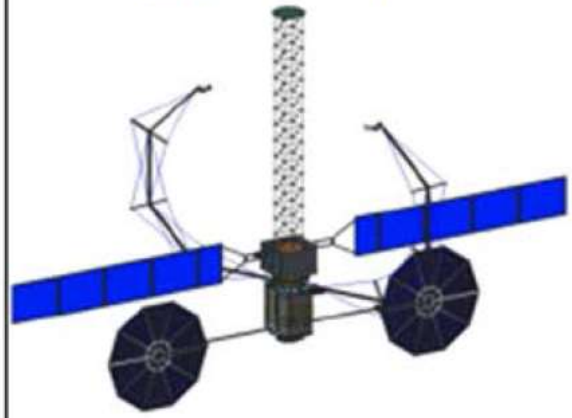
2: Deploy TALISMAN Arms



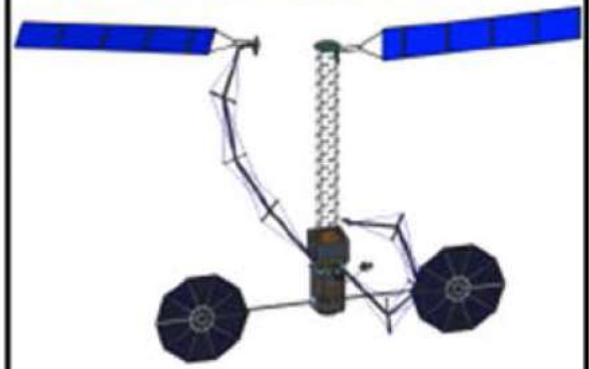
3A: Deploy Truss with TALISMAN
3B: Weld Joints w/ IPJR



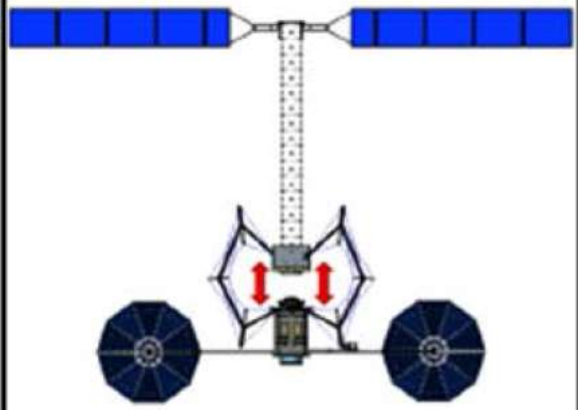
4: Deploy Solar Array Modules



5A: Disconnect Arrays and
5B: Reconnect in Modular Interface



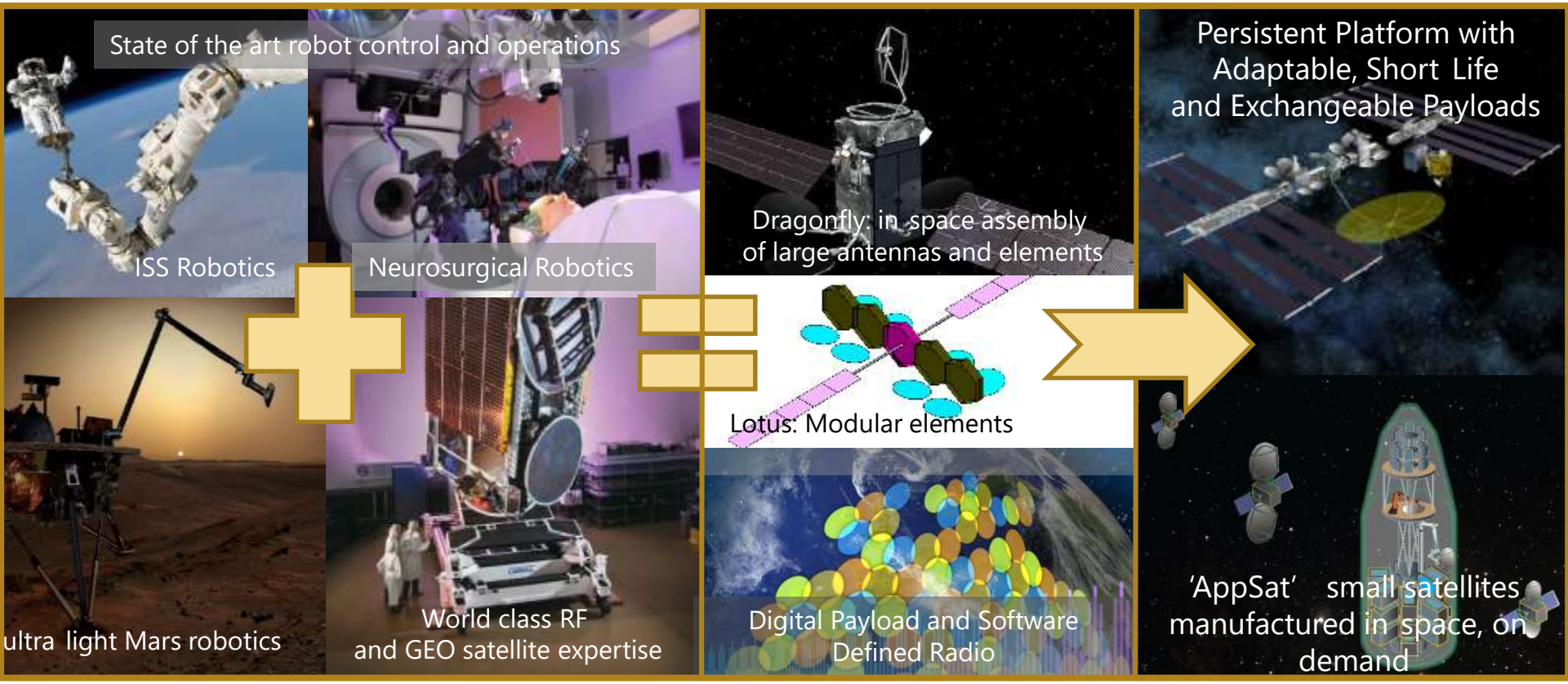
6A: Release Demo Payload
6B: Capture and Berth Payload



Dragonfly
Space Systems/ Loral

Space System/Loral's Vision of a Transformed GEO Ecosystem

Problem: GEO satellites are currently inflexible assets whose capability is fixed at launch and whose performance is constrained by launch vehicle fairing volume



GEO Ecosystem of the (not to distant) Future

- Persistent platforms that manufacture and assemble short-life RF payloads in space
  - In-space factories that produce on-demand small-sats aimed at specialized & transient markets

Space Systems / Loral Dragonfly

A 2 year ground based risk reduction effort to advance in space manufacturing and assembly technologies for infusion into exploration missions.	7120.8 Ground Demo	Formulation	LCCE: $20 M	TRL: 4 -> 6

Objectives:

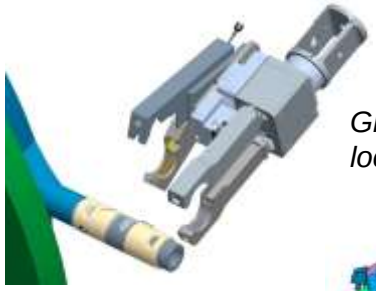
- Demonstrate effective stowage techniques for larger than traditional solid reflectors into a launch
- Demonstrate assembly interfaces originally designed for EVA operations can be modified for use robotically.
- Demonstrate assembly joints and additively manufactured antenna support structures meet EHF antenna performance requirements.
- Demonstrate a feasible Con-Ops for augmenting an existing GEO Commercial Satellite.

Current Status / Accomplishments:

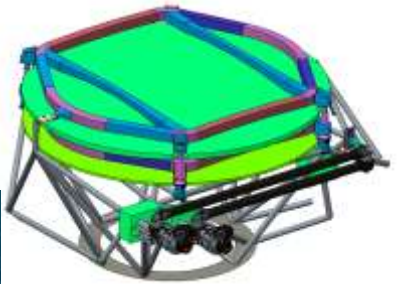
- Contract awarded on September 1, 2016.
- Kickoff meeting held in Pasadena, California on September 15, 2016.

Team:

- **Space Systems/Loral (SSL)**: Project lead; design and operations management of mission.
- **Langley Research Center (LaRC)**: develop robotic assembly interfaces
- **Ames Research Center (ARC)**: develop situational awareness software.
- **Tethers Unlimited (TUI):** In-Space Truss Manufacturing
- **MDA US & Brampton:** Robotic Arm and Advanced Robotic Control Software



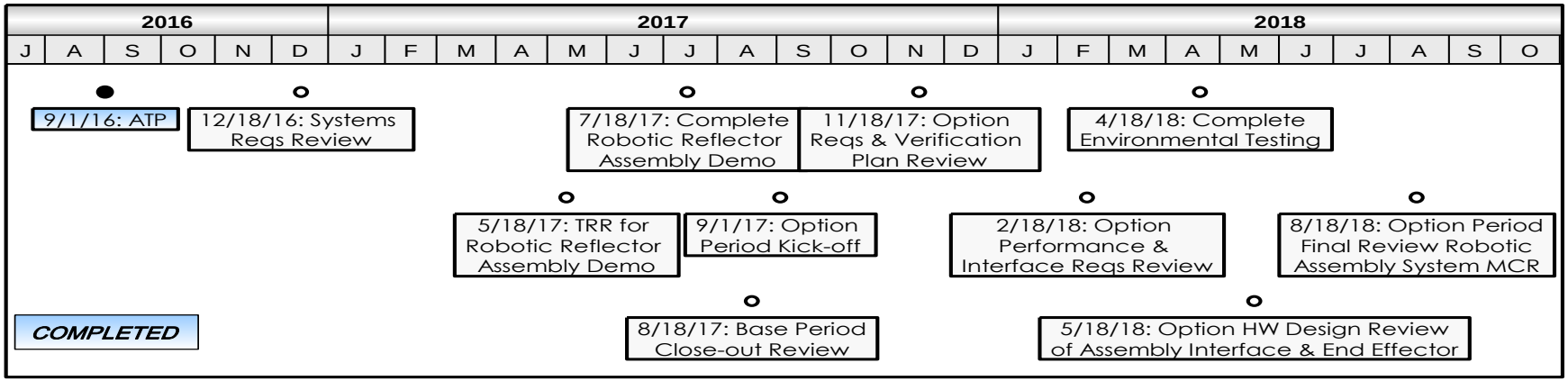
Gripper concept and auto-lock assembly joint



Condensed reflector stowage concept

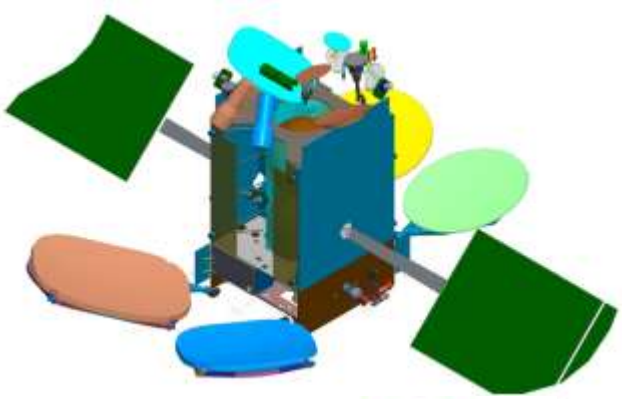
Vision: an ultra-lightweight robot assembles a large reflector on a comSat in GEO

Schedule:



SSL's Dragonfly Design Reference Mission #1

Existing Program

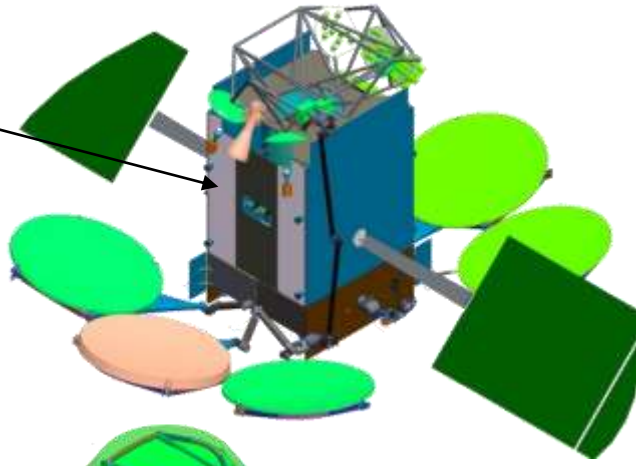


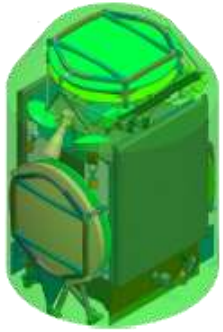
Two reflectors on Earth deck are undersize and have less than optimal optics

Add 2x 3.0m reflectors to the existing 4 x 2.4m for increased aperture area increased data capacity or increased coverages

Dragonfly

2 additional Reflectors over state of the art





SSL's Dragonfly Flight Operational Sequence