Future Capabilities in Space Servicing and Assembly: Opportunities for Future Astrophysics Missions

Assembly and Servicing
STMD Technology Strategy

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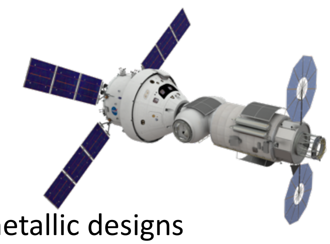
Nov. 1-3, 2017
TIM @ GSFC

Key Agency Structures and Materials Technology/Capability Needs

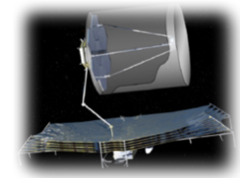
1) Human-Rated Composite Structures for Launch, Transit, Deep-Space Vehicles and Habitation



Capability Challenge
- 5-m class habitable structures
- 10m-class launch vehicle structures
- >30% mass reduction potential over metallic designs

Driving need
- Early exploration missions: Proving ground – Earth independent
- Launch vehicle structures - SLS Universal Stage Adapter for EM2 and Upper Stage Lox tank for EM3/EM4 early 2020's
- Cislunar habitats mid-2020's, Mars Hab/MAV 2030's

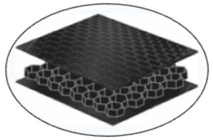
2) In-Space Manufacturing and Assembly of Large-scale Precision And Non-Precision Structures

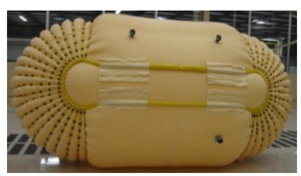


Capability Challenge
- ≥ 50 m modular solar arrays, < 1kg/m^2
- ≥ 10-12 m diameter aperture with 10s of picometers stability
- Factor of 2 life extension for exploration vehicles
- Hardware in the loop simulation for assembly agent V&V.

Driving need
- Large solar arrays needed for SEP vehicles in 2028 per the EMC
- Large aperture telescopes – 2030-2040 (LUVOIR)
- iSA and iSM technology to TRL 6 prior to mission formulation

3) Lightweight, Multifunctional Materials, Manufacturing & Structures for Deep-Space Exploration Systems





Capability Challenge
- Mass reduction of >30% compared to unintegrated systems.
- Example: integrating radiation protection and thermal control
- Deployable and Softgood structural systems with < 1/6 volume
- Advanced materials > stiffness (150 GPa/[g/cm3]), strength (3 GPa/[g/cm3]) and fracture toughness (0.3 N/mm)

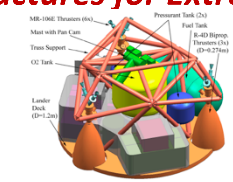
Driving Need

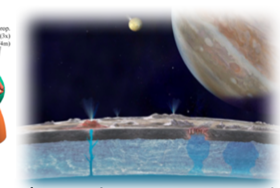
Europa – 2020's

Habitats needed for the Phobos/Mars Orbit Mission - 2033

Active structural control for large-aperture telescopes - 2035

4) Materials and Structures for Extreme Environments

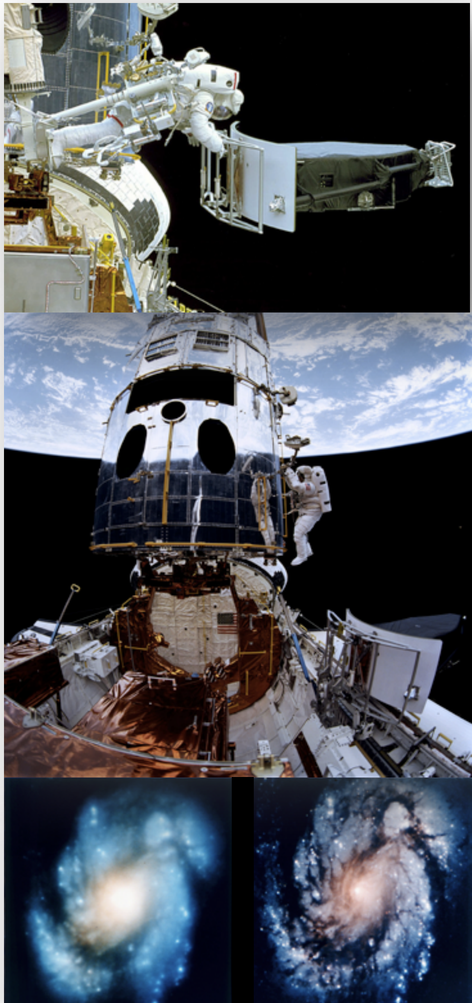




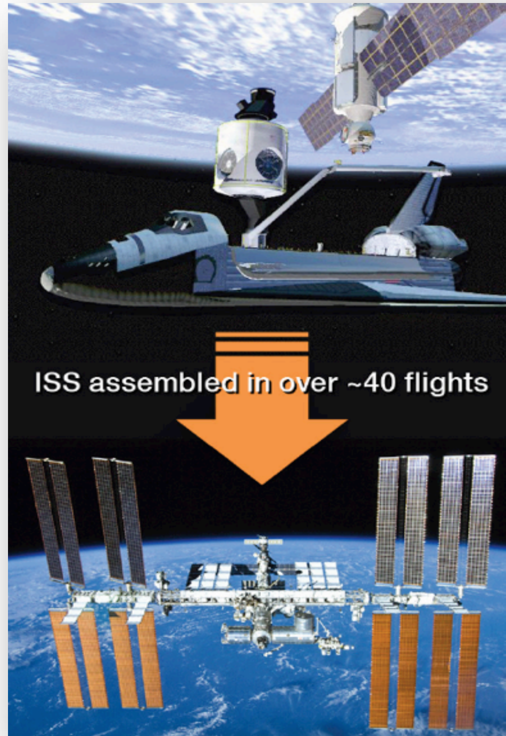
Capability Challenge
- High Temp Carbon-Carbon Rocket Nozzles (50% less mass and 50% more thermal margin over SOA metallic nozzles)
- Cold Temp Mechanisms operating at ~50K
- Seals and Coatings for dust environments
- Radiation Shielding material systems.

Driving need
- Initial exploration missions - Proving ground – Earth independent
- SLS Upper Stage nozzle extension for EM3/EM4 early 2020's
- Mars Descent Vehicles mid 2020's - 2030's
- Europa missions beginning in mid 2020's

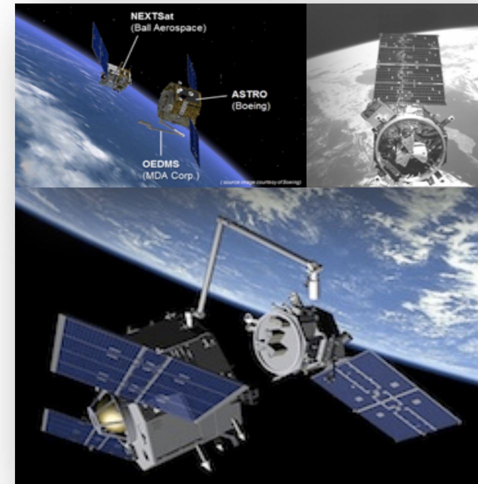
Background: History of Space Assembly Operations



STS-61 Hubble (1993 NASA)
(1993, 1997, 1999, 2002, 2009)



ISS (1998-2011 International)

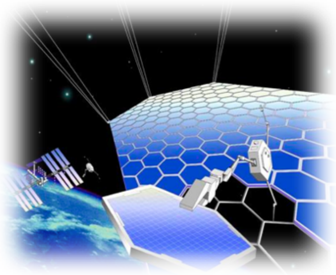


Orbital Express (2007 DARPA)
- Orbital Replacement Units
- Fuel Transfer

EASE/ACCESS STS-61B (1985 NASA)

ISA and ISM- Critical Technologies

ISA & ISM



In-Space Manufacturing / In-Space Assembly

- Compelling need: provides for new capabilities for space vehicle design/build, upgrade and maintenance to reduce cost and improve resilience
  - **Persistent Assets - servicing and repair extend lifetime**
  - **iSA enables large space assets – mitigates launch volume constraints**
  - **Disassembly and reuse for multi-mission vehicles**
  - **iSM reduces spares and enables earth independence**

This focus area is aimed at developing the technologies needed to deploy, assemble, aggregate, and/or manufacture large and/or complex in-space and surface systems without astronaut extravehicular activity (EVA). The benefit of this capability is that can alter the current spacecraft-manufacturing paradigm by enabling in-space creation of large spacecraft systems. The elimination of the need for the integrated system to survive launch loads and environments will simplify the integration and pre-launch testing. The capability can allow repurposing, upgrading, or reconfiguring assets in space.

The technology focus areas for this capability include:

- Materials and processes for in-space manufacturing
- Modular and "plug-and-play" open architectures
- Reversible joining
- Autonomous assembly
- Surface construction with ISRU
- Manufacturing certification
- High fidelity simulation for agent training and certification

Engineering Design and Technology For Resilience

Previous 10-15 years
Fixed, focused, governed

- Highly specialized platforms
- Fixed capabilities
- Costly
- Focused mission portfolio
- Long development time

Point Solutions for Asymmetric Warfare

Moving from Custom Build to ***Composability and Integration***

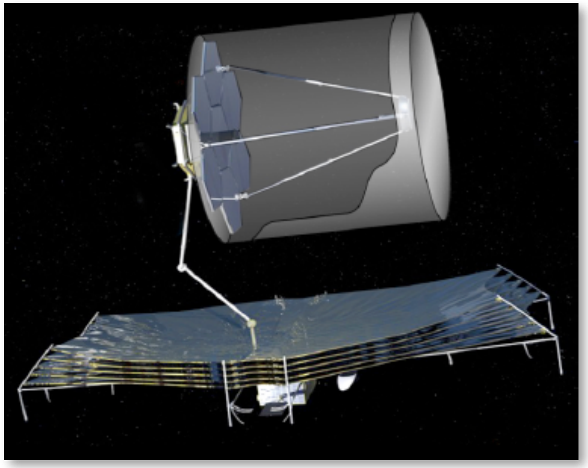
Now.....The Future
Modular, adaptable, autonomous

- Flexible platforms
- Adaptable to capabilities
- Affordable
- Resilient to new threats
- Short development time

Composable, Agile Solutions for Multiple Missions and Threats

Jeffery P. Holland, PhD, PE (SES)
Engineered Resilient Systems (ERS) Community of Interest (COI) Lead
Director, US Army Engineer Research and Development Center (ERDC)
Director, Research and Development, US Army Corps of Engineers

ISA & ISM: Science and Exploration

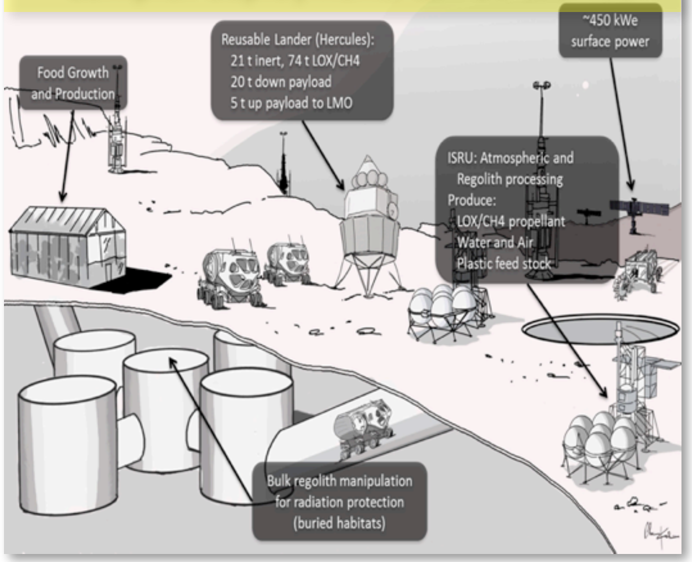


High Definition Space Telescope (HDST)

- 12-20 meter Primary Mirror
- High Dimensional Stability (10s of picometers)
- Deploy/Assemble
    - Thermal Sunshield
    - Primary Mirror
    - Secondary Mirror and Subsystems

In-Space Assembly and Manufacturing Provides for Affordability and Resilience

- Assembly provides aggregation of systems from multiple launches
- Servicing and repair extend lifetime
- Disassembly and reuse of radically changes the supply architecture
- Complex deployments can be averted



Surface ISRU – Manufacturing and Assembly

- Design with low strength materials (polymers/ceramics)
- Additive manufacturing of finite sized modules
- Assembly of processed parts into systems
- Reversible joining technology

Cis-Lunar Gateway?

- Module Based Design for Docking/Berthing
- Modular Subsystems for repair/assembly
- Long reach arms for berthing/disassembly

In-Space Robotic Manufacturing and Assembly (IRMA)

Objectives:

- **CIRAS** (Orbital ATK): Commercial Infrastructure for Robotic Assembly and Servicing (CIRAS) project is pursuing space-based, robotic assembly of flight hardware and space systems, using innovative technologies including NASA's Tension Actuated Long-reach In-Space Manipulator (TALISMAN) to reduce the costs and potential human hazards associated with hardware transfer and assembly activities.

  Partners: LaRC, GSFC, NRL, and GRC.

- **Archinaut** (Made In Space): Developing technology capable of building and assembling complex, large components in space on demand using additive manufacturing to deliver structures such as beams and struts.

  Partners: Northrop Grumman, Oceaneering Space Systems and ARC.

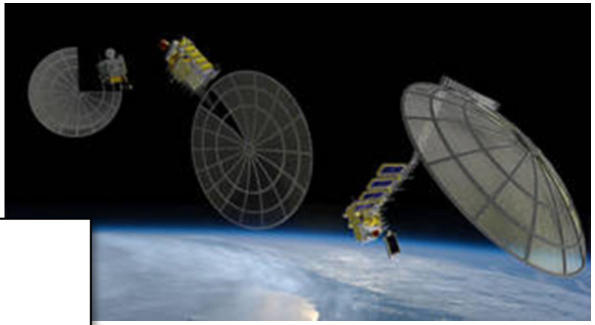
- Dragonfly (Space Systems/Loral): Enabling satellites to self-assemble in orbit. With optimized reflector stowage, robotic joint assembly and 3-D printed antenna support structures, more powerful satellites will fit within payload space aboard standard launch vehicles, thereby decreasing costs.

  Partners: LaRC, ARC, Tethers Unlimited and MDA.

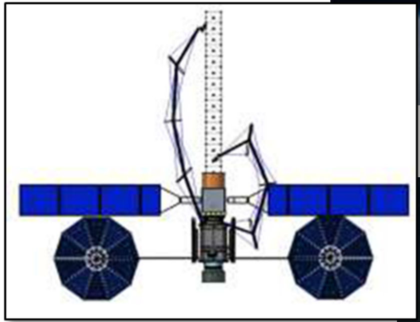
Current Status / Accomplishments:

- Archinaut successfully demonstrated additive manufacturing in a simulated space-like thermal-vacuum environment and performed chemical and structural characterization of manufactured parts.
- Dragonfly conducted successful ground demonstration of robotic deployment of a stowed reflector to an operational configuration. The demonstration utilized state of the art robotics, integrated assembly joints and command and control software.
- CIRAS project advanced the TRL of CIRAS in-space assembly components and processes, including the robotic arm, end effectors, assembly tools, reversible joining methods, control software, quick disconnect interfaces and modular truss structures.

LCC Phase	Implementation
Next Milestone	Option Period Closeout Reviews
Next Milestone Date	September 2018
Flight Readiness Review	N/A
Launch Readiness Date	N/A



MIS-Archinaut



OATK- CIRAS

SSL- Dragonfly

Robotic Refueling Mission 3 (RRM3)

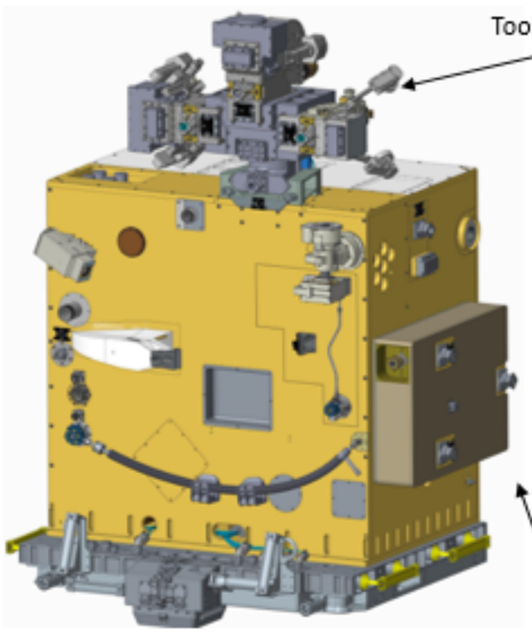
LCC Phase	Implementation
Next Milestone	ORR
Next Milestone Date	December 2018, TBD
Handover to SpaceX	January 10, 2018
Launch Date	February 9, 2018

Objectives

- Store and freeze standard cryogenic fluid in 0g.
- Maintain fluid mass for 6 months (zero boiloff).
- Robotically transfer fluid via zero vent technique.
- Robotically transfer xenon gas in 0g.

Current Status / Accomplishments:

- RRM-3 is performing a flight demonstration of tools, some of which will be used by Restore-L.
- A secondary mass gauging system, the Radio Frequency Mass Gauge (RMFG) instrument developed under the STMD evolvable Cryogenics (eCryo) Project is also being flown and demonstrated on RRM-3.
- Project is readying for payload delivery to KSC in December, 2017 for launch on Space-X Falcon-9 in January, 2018.



Restore-L

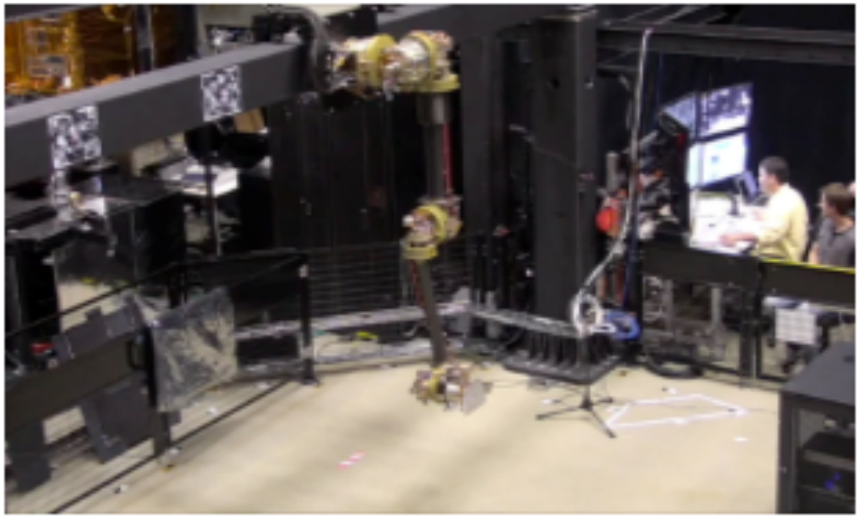
Objectives:

- Rendezvous with, inspect and perform autonomous capture of client satellite (not originally designed for robotic servicing) in Low Earth Orbit
- Demonstrate ability to refuel, relocate, release and safely depart from client satellite

Current Status / Accomplishments:

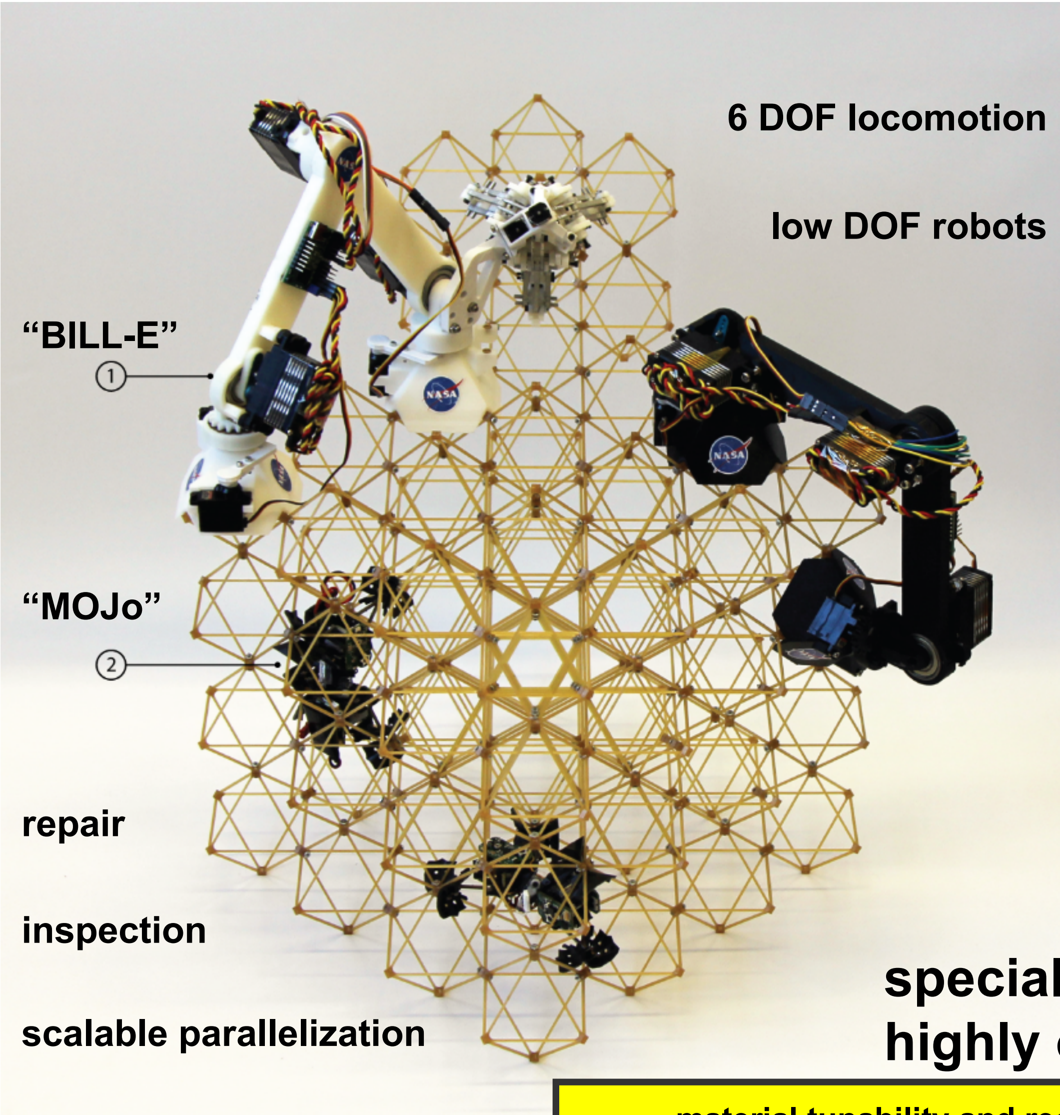
- Restore-L has completed project level SRR milestone and is through Key Decision Point B, and has been working on component level design, development, test, and evaluation.
- A spacecraft level PDR was completed by the spacecraft bus provider, Space Systems Loral.
- The project is readying for Mission level Preliminary Design Review (PDR) in the first quarter of FY18.

LCC Phase	Formulation
Next Milestone	Missoin Preliminary Design Review (PDR)
Next Milestone Date	November, 2017
Operational Readiness Review	March 2020
Launch Readiness Date	November 2020

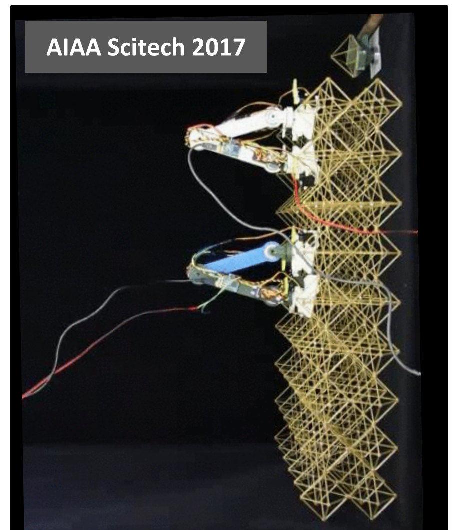


Autonomous Capture Test Cell at the ROC

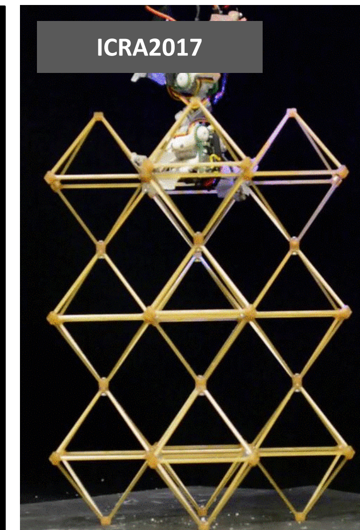
Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS)



scalable error-tolerant manufacturing of high performance ultralight structures by assembly of mechanical building blocks.



Bipedal Isotropic Locomoting Lattice Explorer (BILL-E)



Multi-Objective Journeying Robot (MOJo-bot)

specialized low-cost robot swarms for highly ordered structural environments

material tunability and reconfigurability = significant reduction in launch mass/cost for long-duration missions, increased capability / system robustness.

2017 (POC: kenny@nasa.gov)

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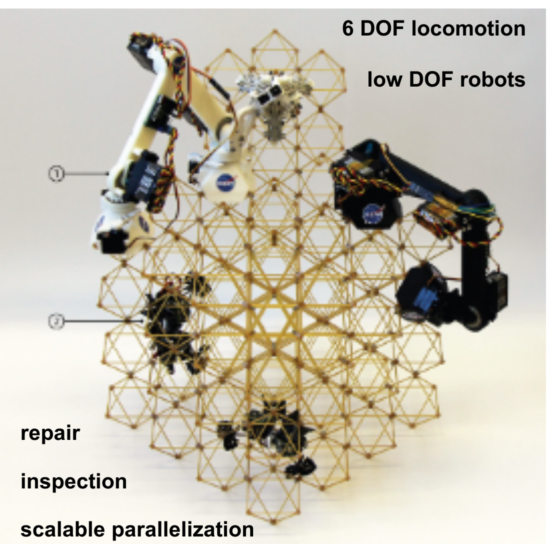
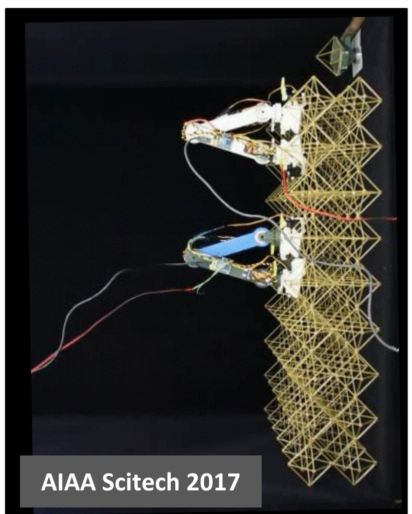
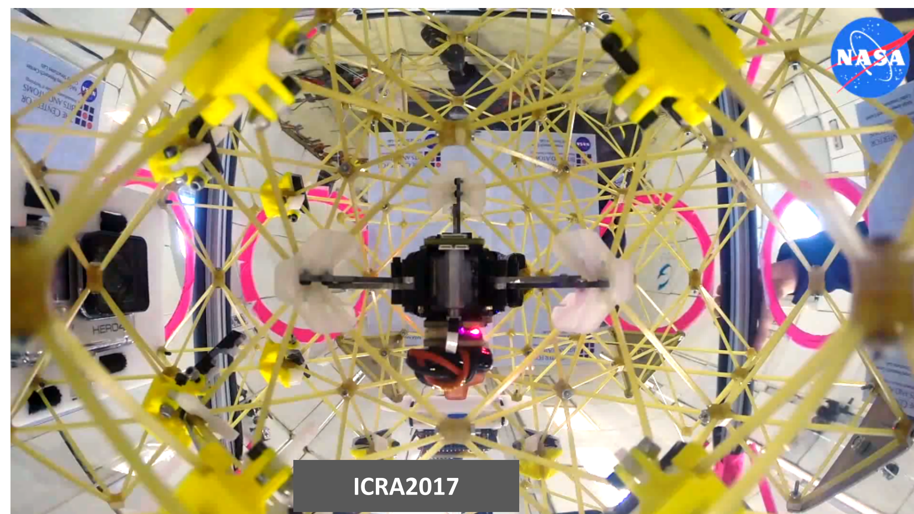






material tunability and reconfigurability = significant reduction in launch mass/cost for long-duration missions, increased capability / system robustness.

2017 (POC: kenny@nasa.gov)

Phase 1 SBIR – Joining Technology

ATSP Innovations
60 Hazelwood Drive
Champaign, IL 61820
Jacob Meyer (217) 778-4400
17-1-Z4.01-8593 LaRC
Reversible Adhesion Concept for In-Space Assembly

ROCCOR, LLC
2602 Clover Basin Drive, Suite D
Louisville, CO 80027
Stephanie Amend (801) 710-1252
17-1-Z4.01-9290 LaRC
Fully Adaptive Slit-tube Structures with Electrically Integrated Smart Joints

Cornerstone Research Group, Inc.
2750 Indian Ripple Road
Dayton, OH 45440
Chrysa Theodore (937) 320-1877
17-1-Z4.01-9457 LaRC
Multifunctional Self-Aligning Reversible Joint using Space-Qualifiable Structural Fasteners

Tethers Unlimited, Inc.
11711 North Creek Parkway South, Suite D113
Bothell, WA 98011
Robert Hoyt (425) 486-0100
17-1-Z4.01-9708 LaRC
The Automated X-Link for Orbital Networking (AXON) Connector

In-Space Assembly Seedling Study

(Sharon Jeffries, NASA LaRC)

Purpose: Identify beneficial applications of In-Space Assembly for human exploration and the capabilities necessary to enable those applications

ISASS Process

Investigated broad spectrum of assembly applications, tasks, and capabilities → **Identified wide range of potential ISA applications for human exploration** → **Developed potential solutions to address pressing human exploration challenges**

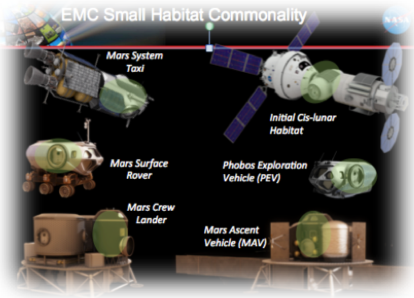
Key Observations

1. **Some degree of ISA is required for any human Mars architecture**
2. **Use of ISA can provide flexibility in launch vehicles and launch campaign**
3. **ISA can reduce risk and provide robustness to the exploration architecture**
4. **ISA can provide flexibility to the architecture**
5. **Use of ISA enables a robust mars landing and surface architecture**
6. **ISA must be designed into the architecture if implemented**

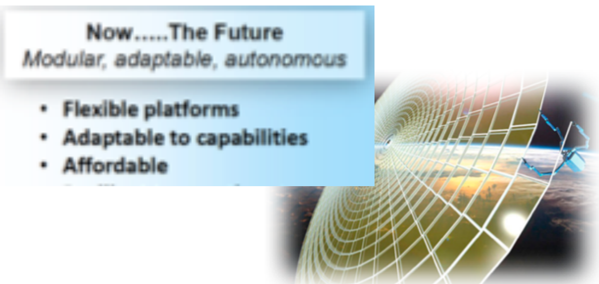
Summary

Structures/Materials/Nanotechnology

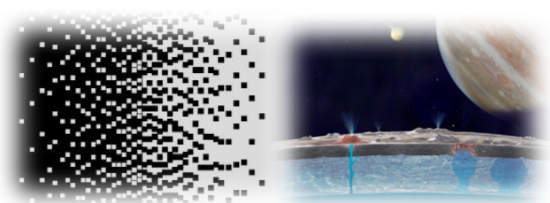
Human Composites



iSA & iSM



Advanced Structural Materials



Performance

- *30-50% lower mass*
- *Reduced packaging volume*

Resilience

- *Durability/Reparability*
- *Modular/Re-configurability*
- *Upgradable/Life Extension*

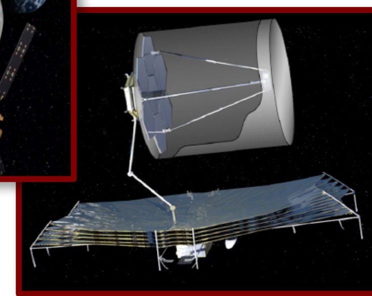
Affordability

- *30-50% lower production cost*
- *Lower life-cycle cost*

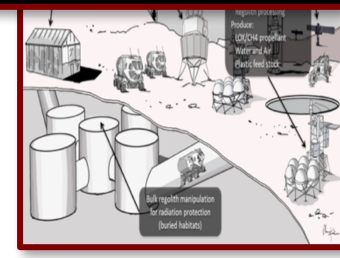
Urgency

- *Mars Architecture & Habitats*
- *Planetary and Astrophysics*
- *iSA & iSM rev tech*

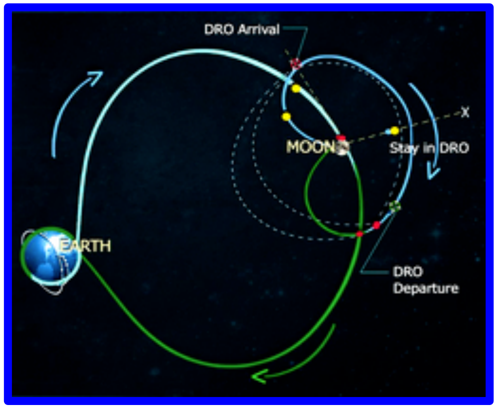
Human Cis-Lunar (EMC)



Planetary Science / Exoplanet Observatories

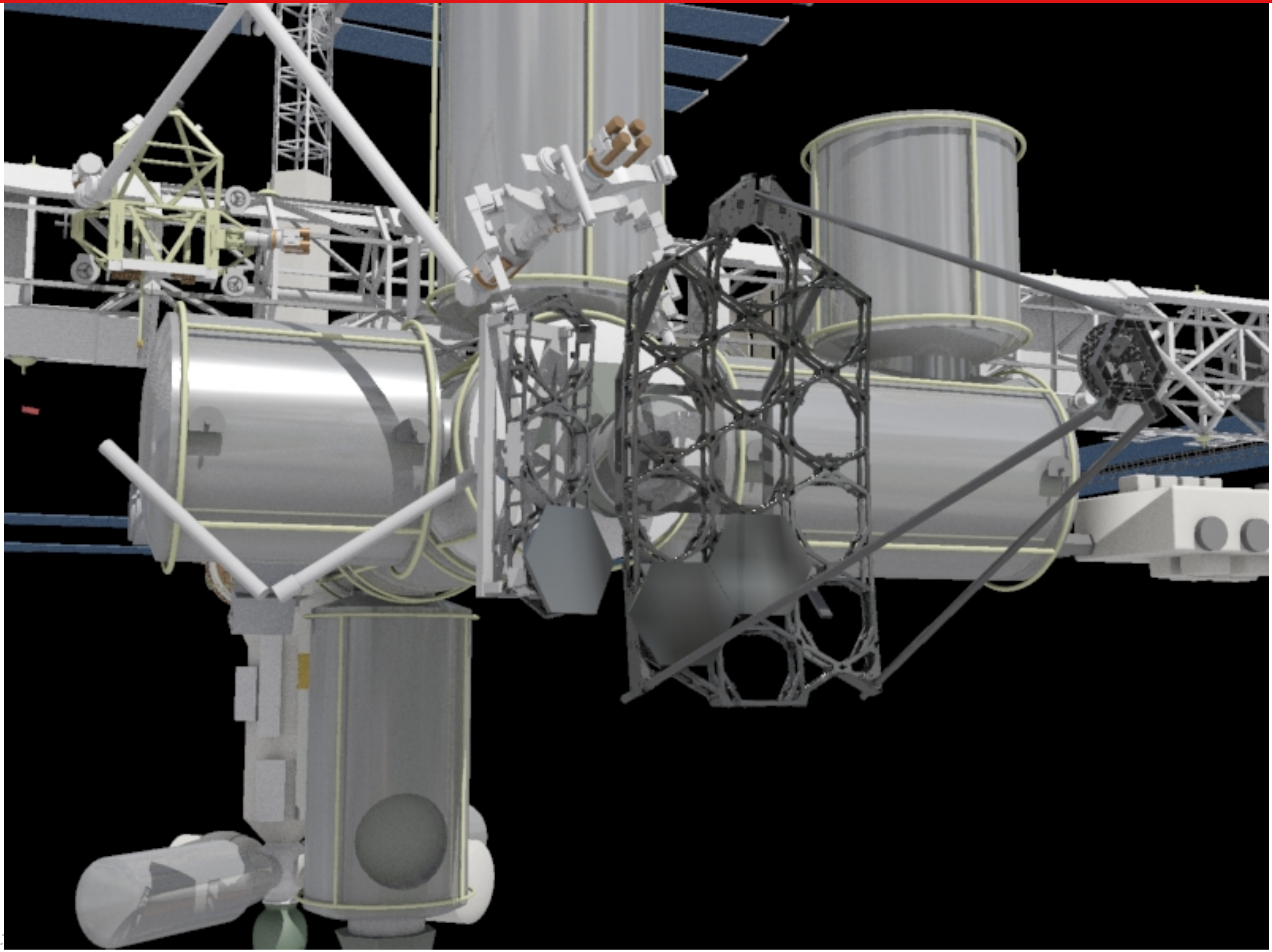


Human And Robotic Surface Systems



OGA and Commercial Space

Notional Pathfinder Demo



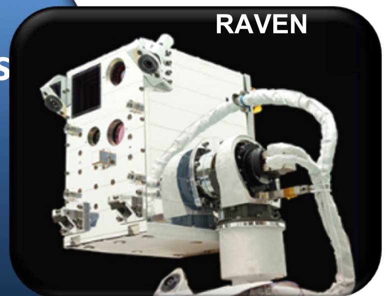
Why In-Space Assembly?

- **Provides new capabilities for space vehicle design / build, upgrade, and maintenance to reduce cost and improve resilience**
  - "Pay as you go"
  - Growth potential
- **"Launch Failure ≠ Mission Failure"**
- **Broader launch vehicle compatibility (mass and volume)**
  - More commercial involvement
  - Greater schedule flexibility

- **Enables large space assets**
  - Mitigates launch volume constraints
  - Averts complex deployments
  - Aggregates systems from multiple launches
- **Enhances persistent assets**
  - Servicing and repair extend lifetime
  - Upgrades for new or enhanced capabilities
- **Enables disassembly**
  - Reuse or repurpose systems or components
  - Radically changes supply architecture

Growing In-Space Assembly Capabilities

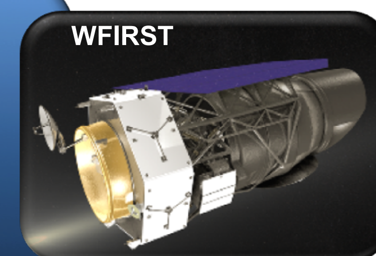
Autonomous Rendezvous & Docking/Berthing Advancements



Improved In-Space Imaging, Inspection, Diagnostics and Verification

Capable Robotics

Changing Design Philosophies (Cooperative System, Modular Designs, Standard Interfaces)



Advances in Autonomy

Power and Fluid Transfer (Standard Connections)