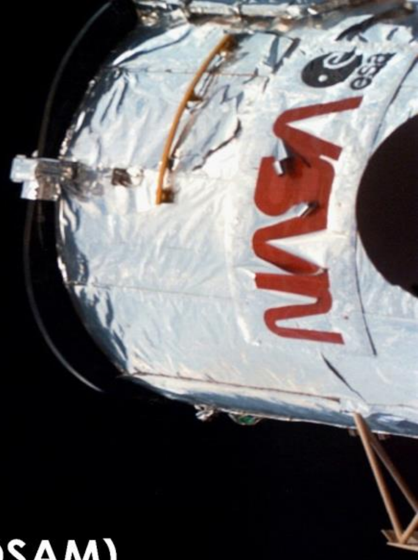
National Aeronautics and
Space Administration



On-orbit Servicing Assembly and Manufacturing (OSAM)
Technology Transfer Workshop

Journeying Longer and Seeing Farther

Sept 22-23, 2020

Autonomous Assembly and ModSim

John R. Cooper, Ph.D. (Session Chair)
B. Danette Allen, Ph.D.
Jason Neuhaus
Jessica Friz

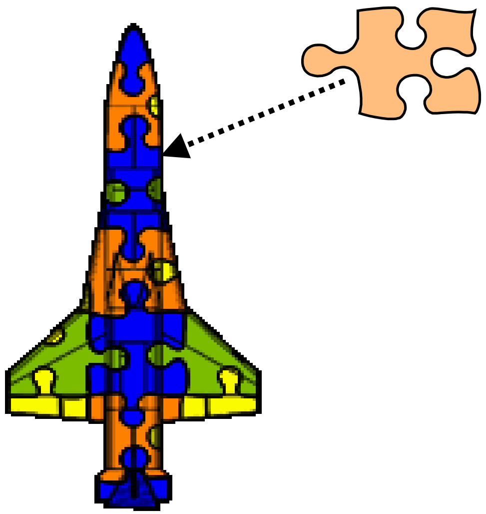
Modeling and Simulation

LaRC Modeling and Simulation Goals for OSAM

- Predict performance of assembled spacecraft in the space environment
  - Performance changes to spacecraft over lifespan (e.g. including past original plans for persistent assets)
- Verification and Validation of Concepts, Designs, and Orbital Performance
  - Assembly concepts
  - Autonomy algorithms
  - Structural performance (including joining mechanisms)
  - Metrology system performance
  - GNC performance (e.g. spacecraft mass properties changes over lifespan)
- Develop a toolbox of modular and reusable software components
  - Individually validated with laboratory and in-space testing
    - Continuous models updates based on data from laboratory and in-space hardware tests
  - Combine components to predictively simulate larger structures, alternative algorithms, etc.
- Target applications of modeling and simulation for OSAM
  - Overall spacecraft performance (predictive validation or digital twin)
  - Concept simulations for early design phases
  - Assembly supervisory simulation
    - E.g. presenting assembly progress information and status to a human supervisor

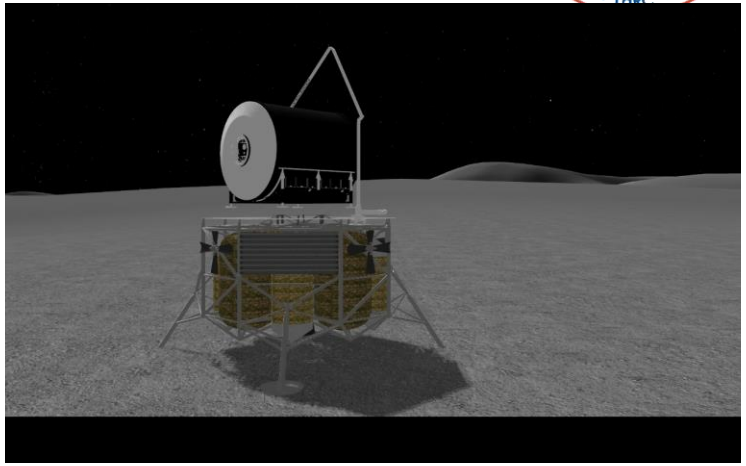
Langley Standard Real-time Simulation in C++ (LaSRS++)

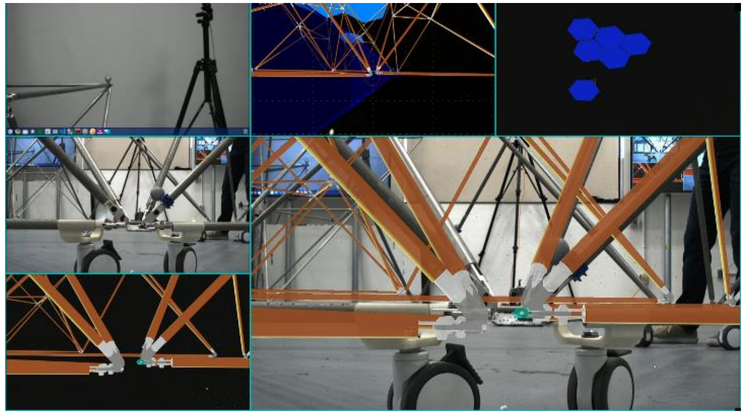
- Used at NASA Langley for over 20 years
- Adapted from previous LaSRS framework with a focus on object-oriented design to increase modularity and re-usability of code.
- Capable of hard real-time operation with hardware in the loop, desktop, and fast-time simulations
  - Designed with Sim to Flight philosophy where software components work within simulations and on ship systems (flight hardware).
- Prior spacecraft simulations include: Ares I-X, Sierra Nevada Dream Chaser, HL-20, Orion Crew Capsule, Mars airplane, Apollo, Altair, and HLS Lunar Landers



LaSRS++ Math Modeling

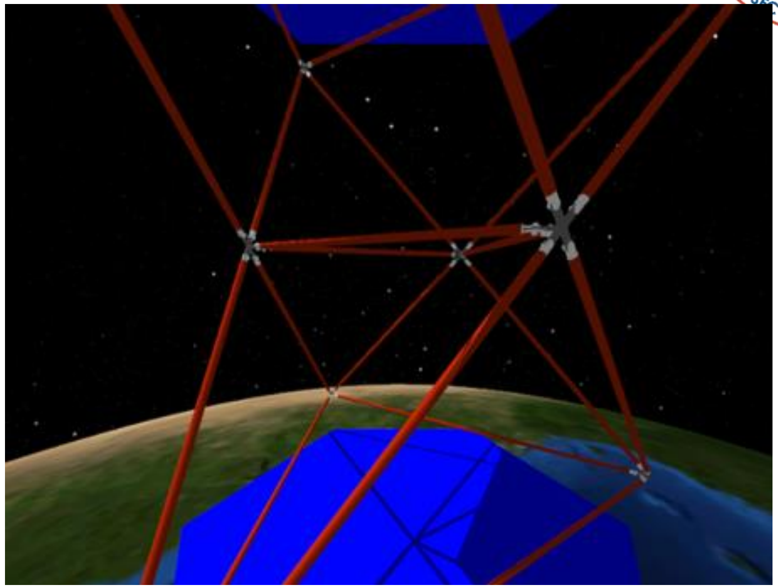
- Standard 6 degree of freedom equations of motion
  - Ability to run multiple interacting vehicles simultaneously
- Available rigid multi-body full-dynamics equations of motion
  - simple joint modeling using constraint force equations
- Kinematic solutions available but largely avoided
  - Comparable mass properties between moving assembly agents and main spacecraft
  - Lack of aerodynamic friction

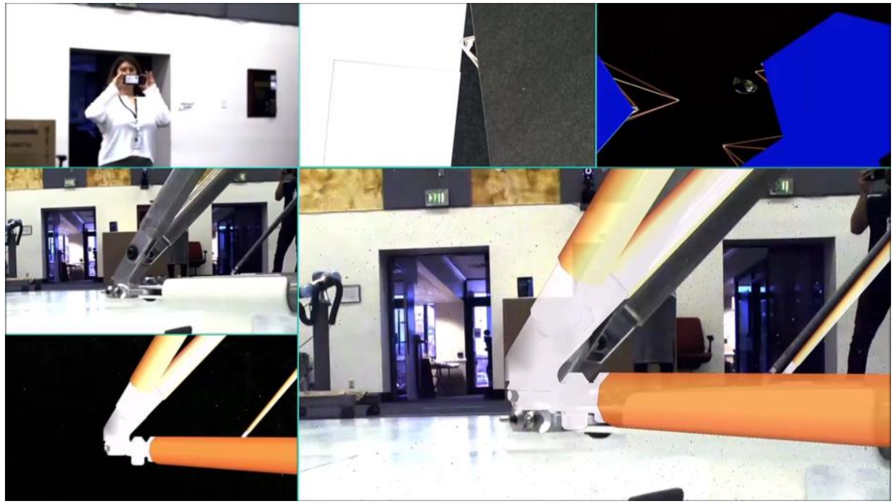


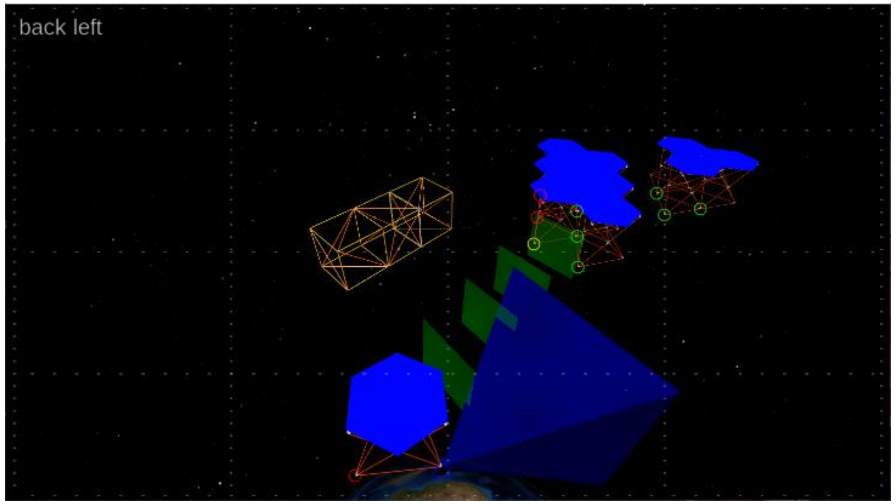


Robotic Assembly of Modular Space Exploration Systems (RAMSES)

- Visual Scene Simulation and Data visualization
  - Sensor/fiducial modeling and data visualization
  - Trajectory visualization
  - Visual sensor simulations
- Network communication with Autonomy
  - Multiple spacecraft component state data
  - Data Distribution Service (DDS)

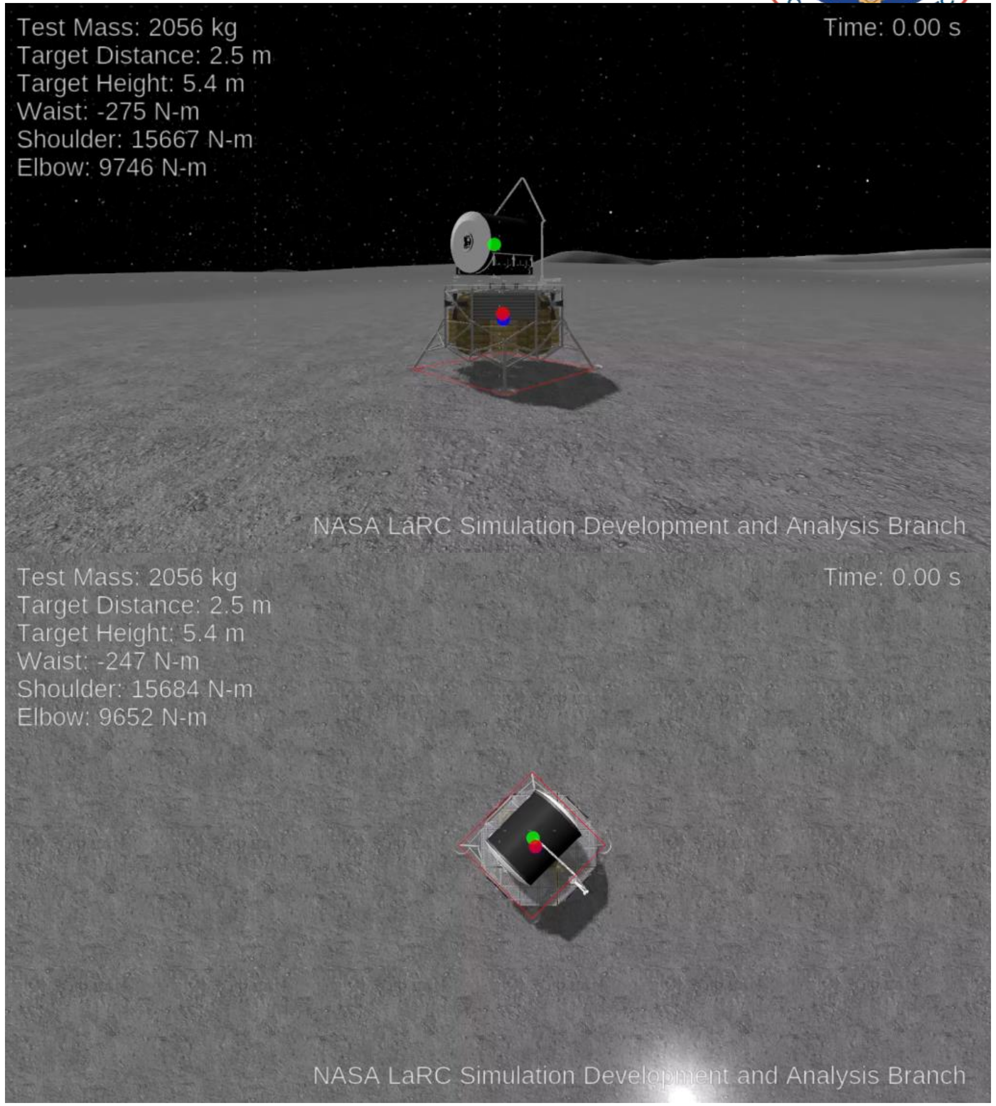






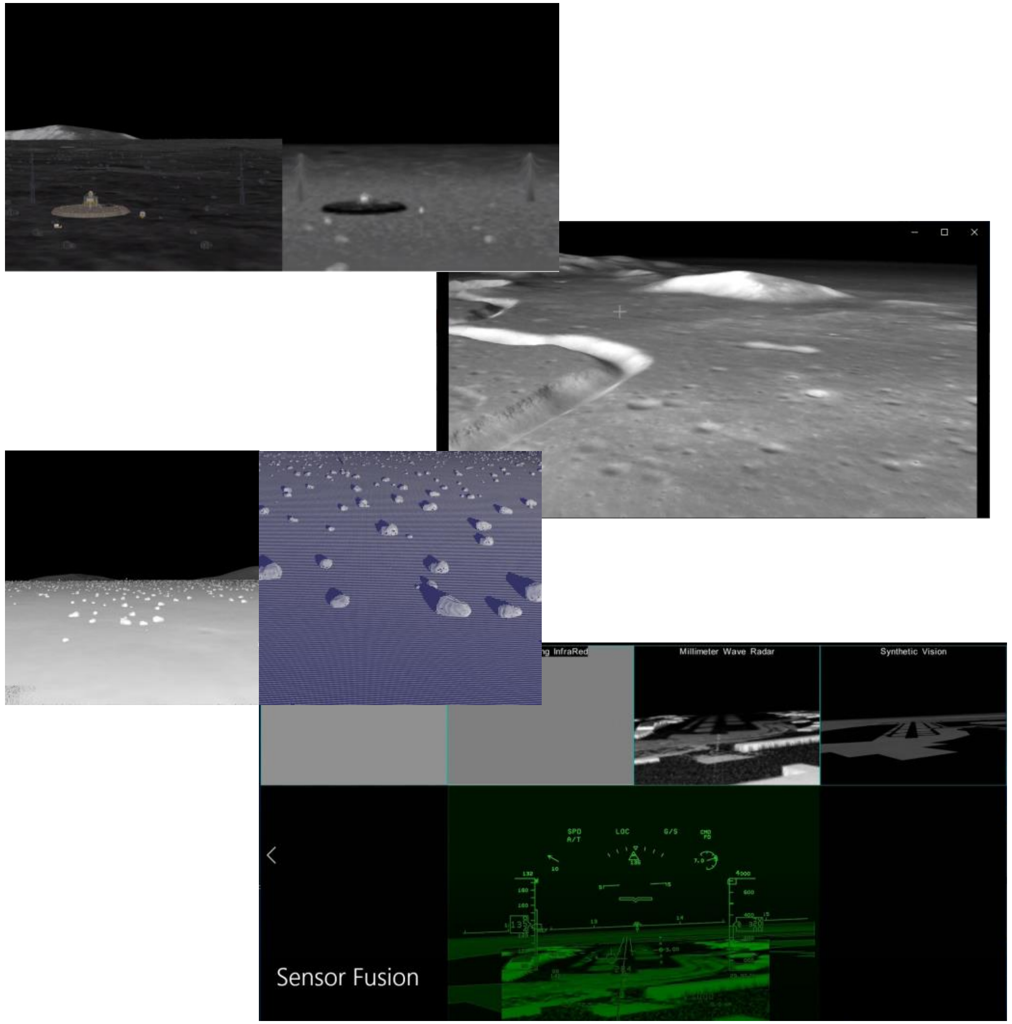
Lightweight Surface Manipulator System (LSMS)

- Rigid multi-body full dynamics EOM using
  - 5 body problem including lander
  - Simplified model of LSMS with moments applied at joints
    - Waist, shoulder, elbow joints
    - Translational DOF added to raise/lower test mass
  - Control law drives moments at joints to achieve desired test mass positions
- Visualization
  - Center of mass locations
  - Tip over hazards
  - Joint motor performance



LaRC Modeling and Simulation Future Work

- Verification and Validation
  - laboratory testing
    - Precision Assembled Space Structures (PASS)
  - Simulate autonomous assembly with autonomy hardware in the loop
- Modeling
  - Integration of software to model structural mechanics
- Visualization
  - Applications of virtual and/or augmented reality, e.g.:
    - Autonomous assembly supervision by humans
    - Spacecraft concept development
  - Ray traced scenes for more realistic sensor scene generation
  - Applications of existing LaSRS++ sensor simulations
    - Millimeter Wave Radar (MMWR)
    - Forward Looking Infrared (FLIR)
    - Light Detection and Ranging (LIDAR)
    - Sensor fusion



On-Orbit Servicing, Assembly, and Manufacturing (OSAM) Architecture Simulation System (OASiS)

NASA Project Lead
Jessica Friz
Principle Investigator and Simulation Software Developer
jessica.s.friz@nasa.gov
(757) 864-7357

NASA Core Team Members

IOK Wong – OSAM Hardware/Software Integration Lead
Benjamin Kelley – Autonomous Systems Engineer
Emily Judd – OSAM Architecture Analysis Engineer
Nathan Perreau –Simulation Software Developer
Timothy Dugan – Simulation Software Developer
Jonathan Harris – Equipment Specialist

NASA Mentors

P. Sean Kenney – Simulation Development and Analysis Branch (SDAB) Software Group Lead
Jason Neuhaus – SDAB Lead Simulation Software Architect and Developer
Dr. B. Danette Allen – NASA Senior Technologist for Intelligent Flight Systems
Dr. William Doggett – Chief Engineer for In-Space Assembly (iSA)
John Dorsey – PI for iSA and Persistent Assets

NASA Challenge Addressed

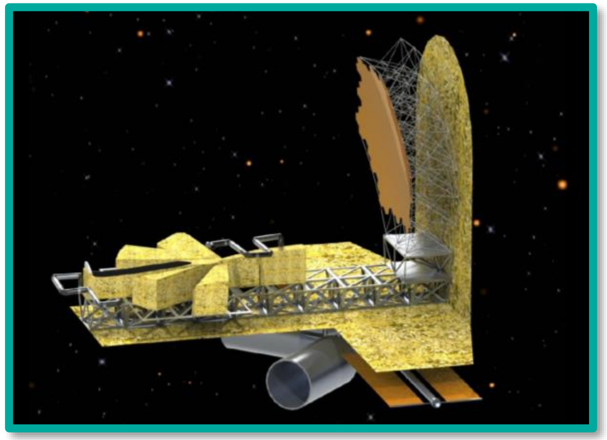
- Challenge:
  - Members of the NASA On-Orbit Servicing, Assembly, and Manufacturing (OSAM) National Initiative has identified a critical need for developing OSAM modeling and simulation capabilities
  - A high-fidelity simulation environment could be used to verify and validate complex, large-scale OSAM mission architectures that would otherwise require large and costly facilities and hardware
- Why:
  - The **OSAM Architecture Simulation System (OASiS)** will meet this critical need by providing OSAM mission developers with a modular, high-fidelity simulation environment in which to rapidly prototype and evaluate large-scaled OSAM technologies and operational concepts
  - OASiS will accelerate technology development, reduce mission costs and risks, and ultimately ensure the successful servicing, assembly, and manufacturing of vital structures that help us study and explore our universe, such as the In-space Assembled Telescope and the Lunar Gateway

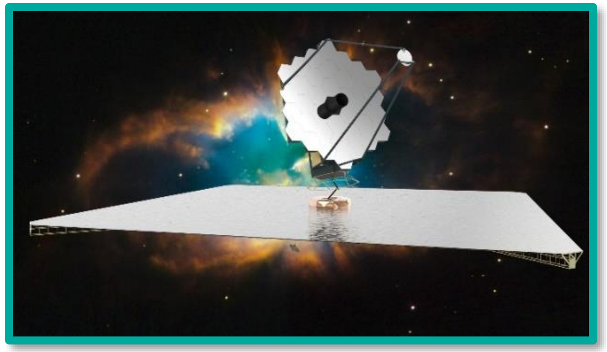
Product Lines	STIP Grand Challenges	STMD Capability Areas	
		Live: *Sustainable Living and Working Farther from Earth*	***Explore:*** *Transformative Missions and Discoveries*
Advanced Materials and Structural Systems	On-orbit Servicing, Assembly, and Manufacturing	Lunar Surface Technologies	Extreme Access
Intelligent Flight Systems		Intelligent/Resilient Systems & Advanced Robotics	Advanced Communications and Navigation
Measurement Systems	Operational Transformation	Advanced Materials and Structures	Servicing, Assembly, and Manufacturing
Systems Analysis and Concepts			

Technology Description: The Payoff

- Technical improvement:

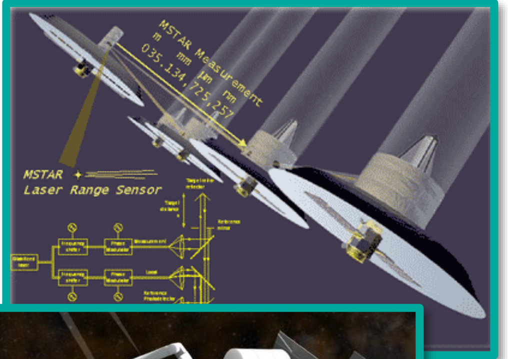
  OASiS will be a comprehensive OSAM simulation environment that:
  - Expands modular, high-fidelity modeling and simulation capabilities for large-scale OSAM architectures
  - Helps OSAM mission developers to explore using OSAM technologies for multiple operational concepts
  - Streamlines the process of modeling both existing and conceptual OSAM hardware
  - Provides the flexibility to model unlimited OSAM hardware models in any position or orientation
  - Incorporates advanced environmental and lighting effects to replicate the final mission environment
  - Provides metrology data feedback to ensure system accuracy and precision during operations
  - Supports autonomous control system designs through a DDS interface
  - Advances the state of the art in the real-time OSAM modeling and predictive simulation field
- Enabled missions:
  - Large-aperture orbital observatories: In-space Assembled Telescope (40-meter), High Definition Space Telescope (12-meter), and Large UV/Optical/IR Surveyor (15-meter)
  - Orbital research platforms: Lunar Gateway and the Persistent Platform Orbital Testbed

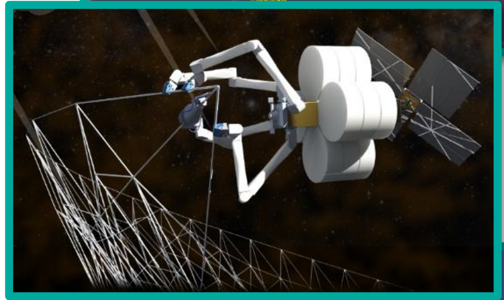


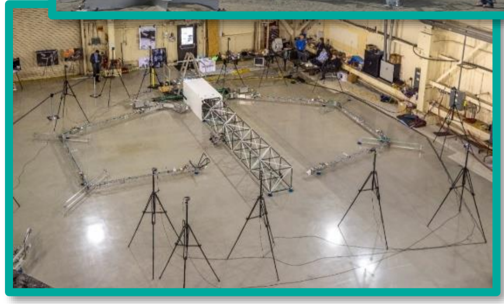


Current SOA and Limitations

- What is the current state-of-the-art (SOA) and what limits conventional solutions?
  - SOA
    - **In-Space Metrology Systems:** Modulation Sideband Technology for Absolute Ranging and Light Detection and Ranging Technology
    - **On-Orbit Fabrication:** SpiderFab
    - **Robotic Assembly Agents:** Tension Actuated Lightweight In-Space Manipulator and the Lunar Surface Manipulation System
    - **High-Fidelity Modeling and Simulation:** Trick (JSC), Marshall Vehicle Representation In C (MSFC), LaSRS++ (LaRC)
  - Limitations
    - Long-lead time for manufacturing of custom components, high operational costs, and limited access to full-scale, Earth-based testing facilities with appropriate environmental conditions
    - Currently no simulation environment, in its current form, that would meet the needs of OSAM mission developers looking to verify and validate complex, large-scale OSAM mission architectures
- How does the proposed approach overcome these limitations?
  - **OASiS will be a modular, high-fidelity simulation environment, helping OSAM mission developers to obtain the critical feedback needed to prototype and evaluate their large-scale OSAM operational concepts and technologies**





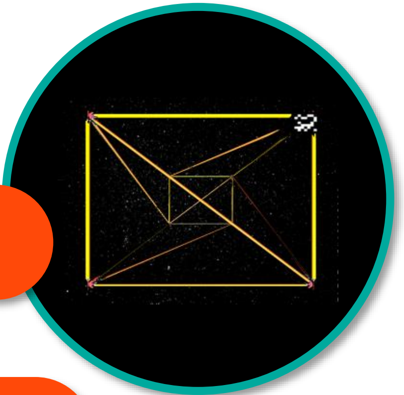


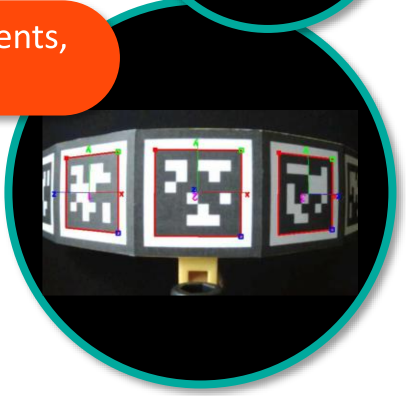
Development Approach

KEY OBJECTIVE

Develop OASiS capabilities to model, simulate, and evaluate a mission critical, large-scale OSAM operational concept, incorporating a variety of robotic agents, assembly structures, metrology system hardware, and environmental models

- Develop OASiS within an existing high-fidelity, modular simulation framework – the Langley Standard Real-time Simulation in C++ (LaSRS++)
- Create a library of characterized simulation models based on existing OSAM robotic agents, metrology system hardware, and assembly structures
- Further investigate and develop simulation lighting effects within LaSRS++ to enhance OASiS and support optical metrology system hardware models
- Design simple methods to incorporate new OSAM hardware, environmental models, and system functionality for OASiS users
- Develop a DDS interface for passing data among simulated metrology system hardware, robotic agents, and external autonomy frameworks to drive autonomous OSAM operations
- Validate accuracy of OASiS position-orientation (POSE) data between simulated OSAM operations and analog lab hardware setups





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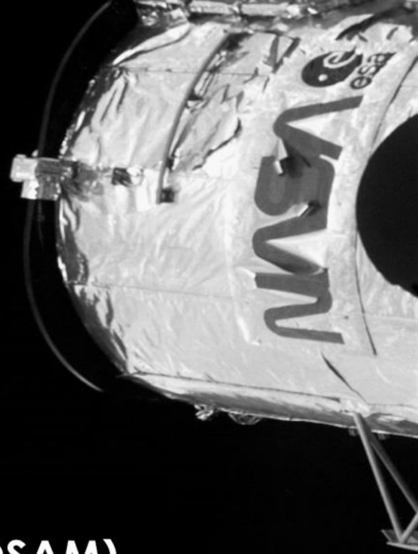

On-orbit Servicing Assembly and Manufacturing (OSAM)

Journeying Longer and Seeing Farther

Robots are poised to make what was once thought to be impossible in space a reality. From extending the lifespan of satellites, to assembling massive life-seeking telescopes in space, to refueling and repairing spacecraft on journeys to distant locations, the possibilities are endless. Key to these endeavors is demonstrating the foundational capabilities – servicing, assembly, and manufacturing.

To arrange further discussion of on-orbit servicing technologies contact
Patrick Cosgrove (Patrick.a.cosgrove@nasa.gov)

Background Graphic: OSAM technologies continue the legacy of the Hubble Space Telescope (HST) Servicing Missions, and will be implemented to assist astronauts span and expand orbiting stations like the International Space Station (ISS). OSAM technologies will also support lunar surface and orbiting operations.