



Space Technology Mission Directorate Game Changing Development Program

James Neilan – PM | Olive Stohlman - PI | FY22 PASS Annual Review Presentation | 09.14.22

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Project Overview



➤ Technology Product Capability

Closing a key in-space assembly technology gap, enabling efficient construction and long-term operations of large-scale persistent assets on-orbit.

➤ Technical Capabilities

Efficient modular architectures for in-space assembly. The focus is on hexagonal topologies using Tri-Truss modules and reversible interfaces

Modular assembly architecture and demonstration of operations with multi-agent coordination and planning compatible with an on-orbit environment.

Autonomous end-to-end precision assembly of 20-m-class path-to-flight mirror backbone structure

➤ Exploration and Science Applicability

Lunar surface infrastructure, including radiation and environmental protection, power generation, and communication hardware construction.

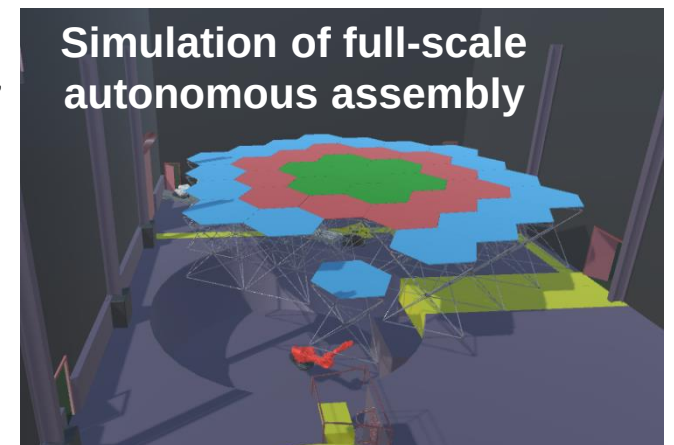
Astrophysics missions, in-Space Assembled Telescope (iSAT), the Large Ultraviolet Optical Infrared Surveyor (LUVOST) 15 meter, and the Origins Space Telescope (OST) 9.1 meter.

Persistent Platforms

**in-Space Assembled
Telescope (iSAT)**



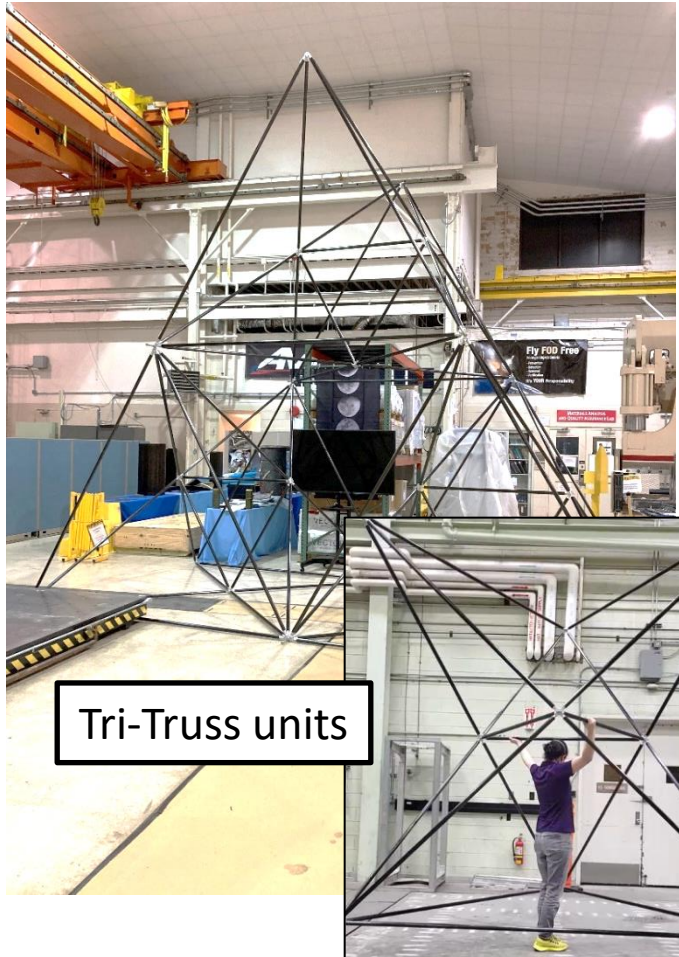
**Simulation of full-scale
autonomous assembly**



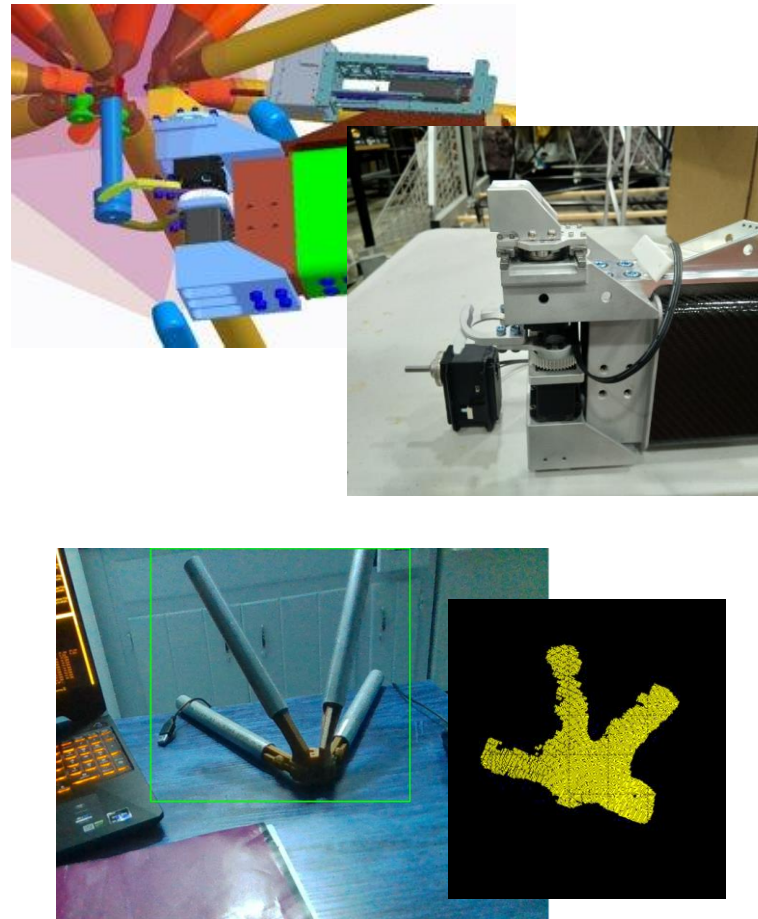
Project Overview



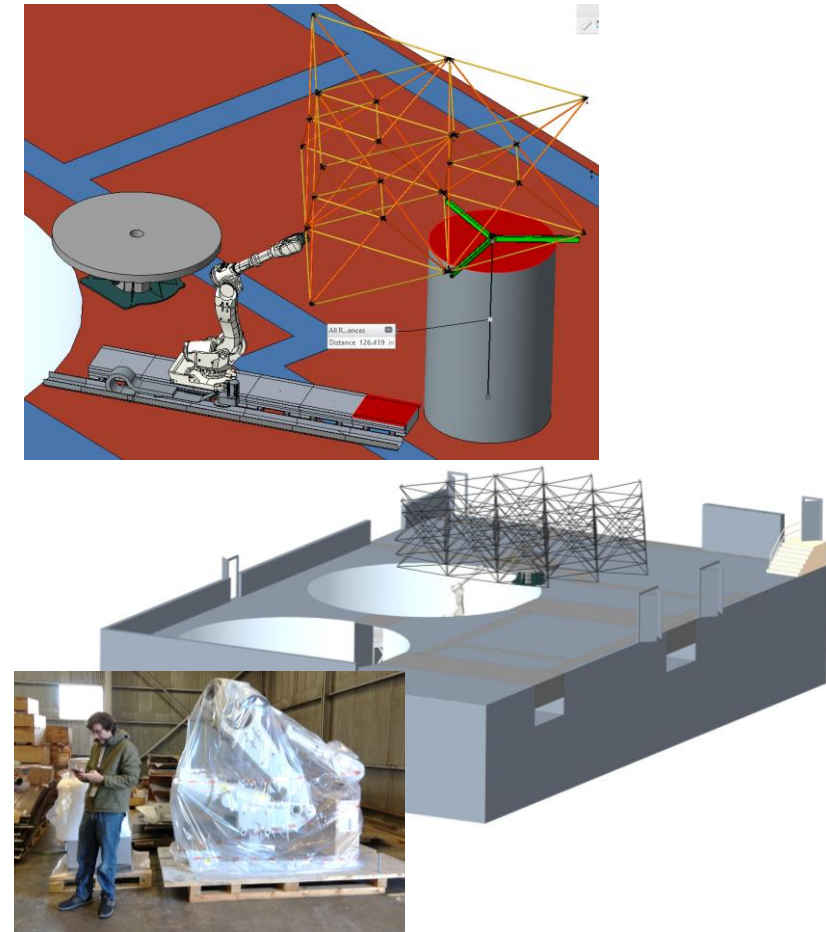
Structures and Analysis



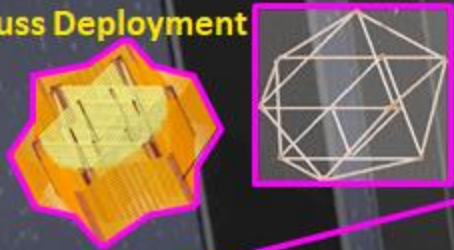
Autonomy and Robotics



Laboratory and Workforce Development



Truss Deployment



Asset identification and localization



Metrology



Fine Placement and assembly



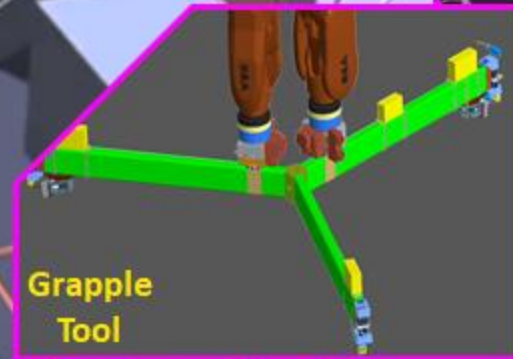
Coarse Placement



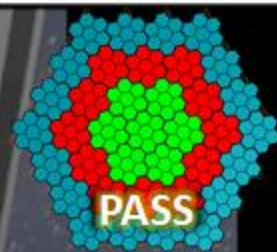
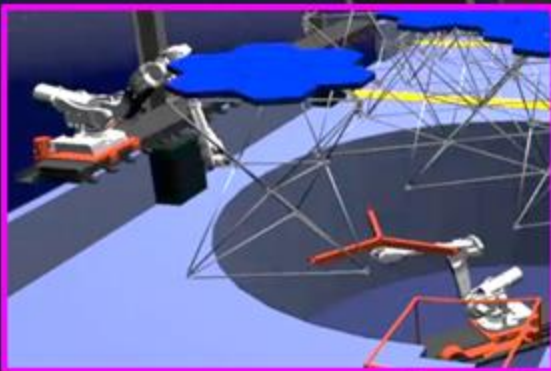
Quick Change



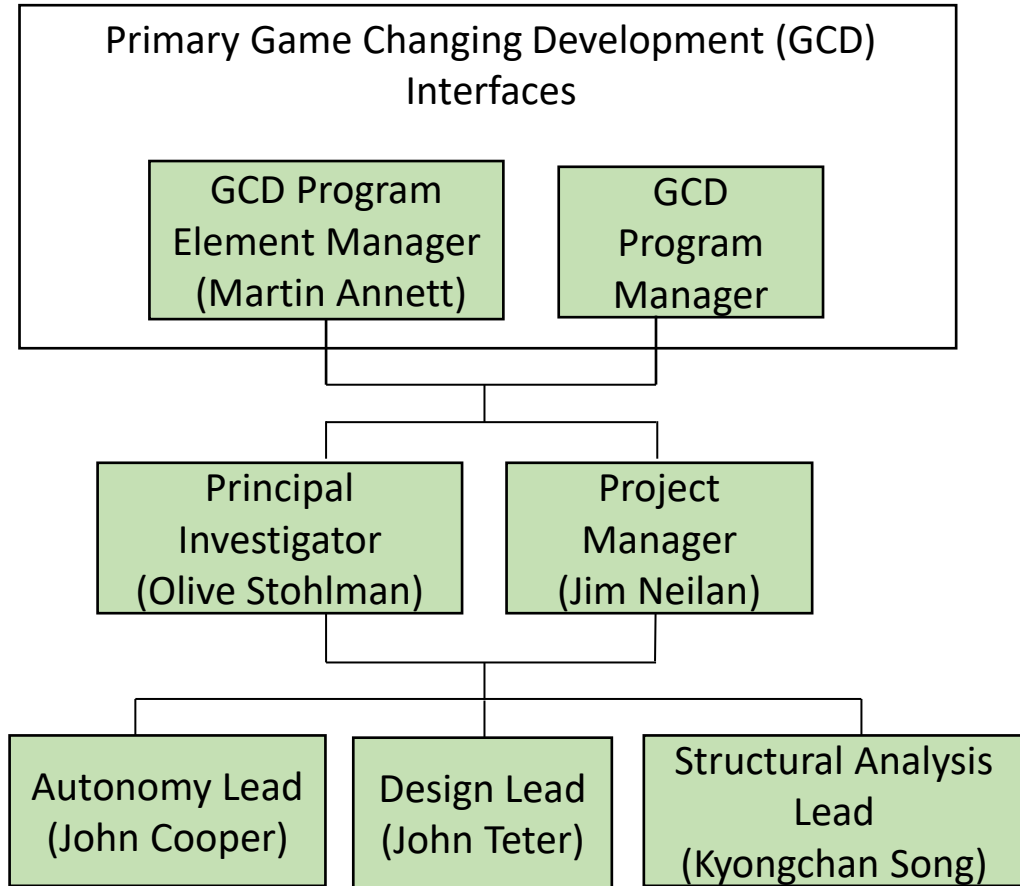
Grapple Tool



Collaborative handoff to Course Placement Agent



Team Members / Project Organization



Collaborations and Partnerships



➤ Contributing partners and/or stakeholders

➤ Government

- Other government agency (OGA) – In-space assembled structures
 - Collaborated with Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS) at NASA Ames and On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) at NASA Goddard
- Naval Research Lab – Tri-Truss assembly collaboration
- Kennedy Space Center – Lunar excavation and construction
- Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT)
- Tall Lunar Tower (TLT)
- Lightweight Surface Manipulation System AutoNomy capabilities Development for surface Operations and construction (LANDO)
- Part of three Tipping Point proposals

➤ Companies*

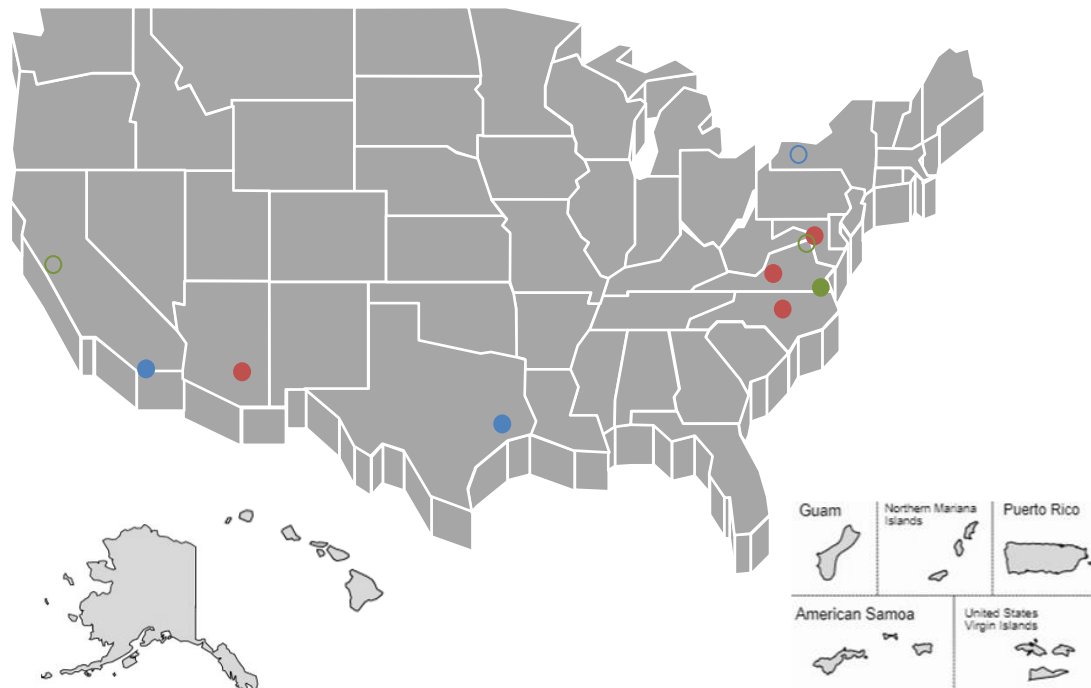
- Rock West Composites*
- ATSP Innovations, Small Business Innovation Research Phase 3
- Robot suppliers: Koike Aronson Ransome*, ABB*

➤ Universities

- University of Arizona (thin meniscus mirror)
- University of Maryland (path planning, Prof. Otte)
- North Carolina State University (high-velocity impact, damage modeling and prediction of composite structures, Prof. Pankow); (Shape memory alloys for multifunctional structural elements, Prof. Yuan)
- Virginia Tech – Autonomous assembly; Surface accuracy prediction and progressive adjustment in assembly

➤ Target applications

- Requirement-driving application: 20-m in-Space Assembled Telescope (iSat)-class telescope (potential)
- Technology can support tall towers, advanced radar/antennas/great shape flexibility/OGA applications, space nuclear propulsion, laser comms with ~2-meter mirrors, space solar power, habitats, persistent platforms (potential)



*Specific vendor and manufacturer names are explicitly mentioned only to accurately describe the test hardware. The use of vendor and manufacturer names does not imply an endorsement by the U.S. Government nor does it imply that the specified equipment is the best available

Technology Goals and Project Objectives



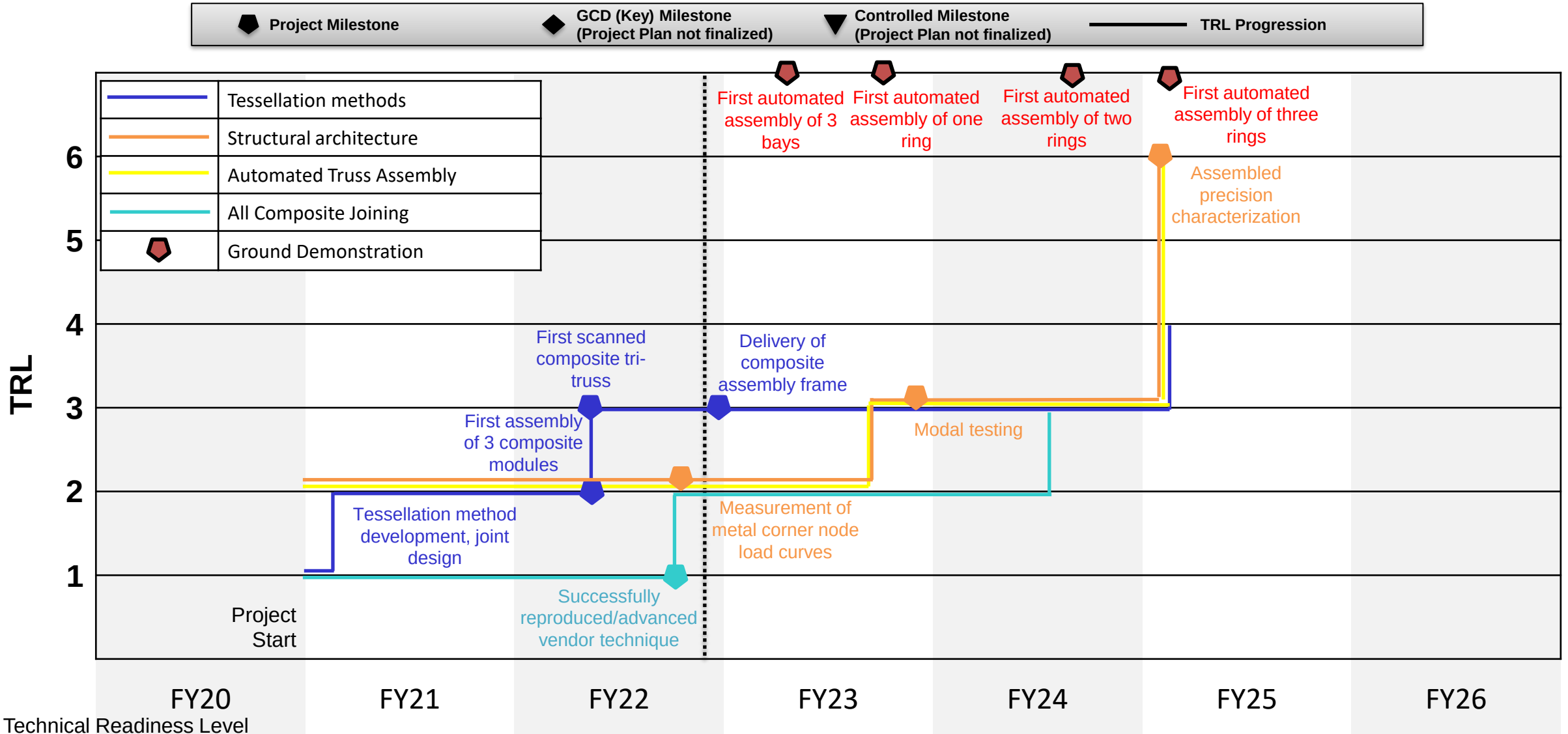
Technology Goals

Goal #1	Address the lack of confidence in on-orbit autonomous assembly capabilities by implementing a relevant autonomous precision assembly demonstration that is on the path to flight
Goal #2	Identify, develop and validate critical technologies (efficient high-stiffness Tri-Truss modules, predictive models, planners orchestrating the multi-agent assembly, precision joining for doubly curved topology) needed to achieve effective and efficient on-orbit assembly

Project Objectives

Objective #1	Develop efficient modular architectures for in-space assembly
Objective #2	Develop modular assembly architecture and demonstrate operations concepts that are executed with automated multi-agent coordination and planning that are compatible with an on-orbit environment
Objective #3	Perform autonomous end-to-end precision assembly of 20m-class path-to-flight mirror backbone structure in LaRC OSAM laboratory to demonstrate maturity of technologies needed for in-space assembly

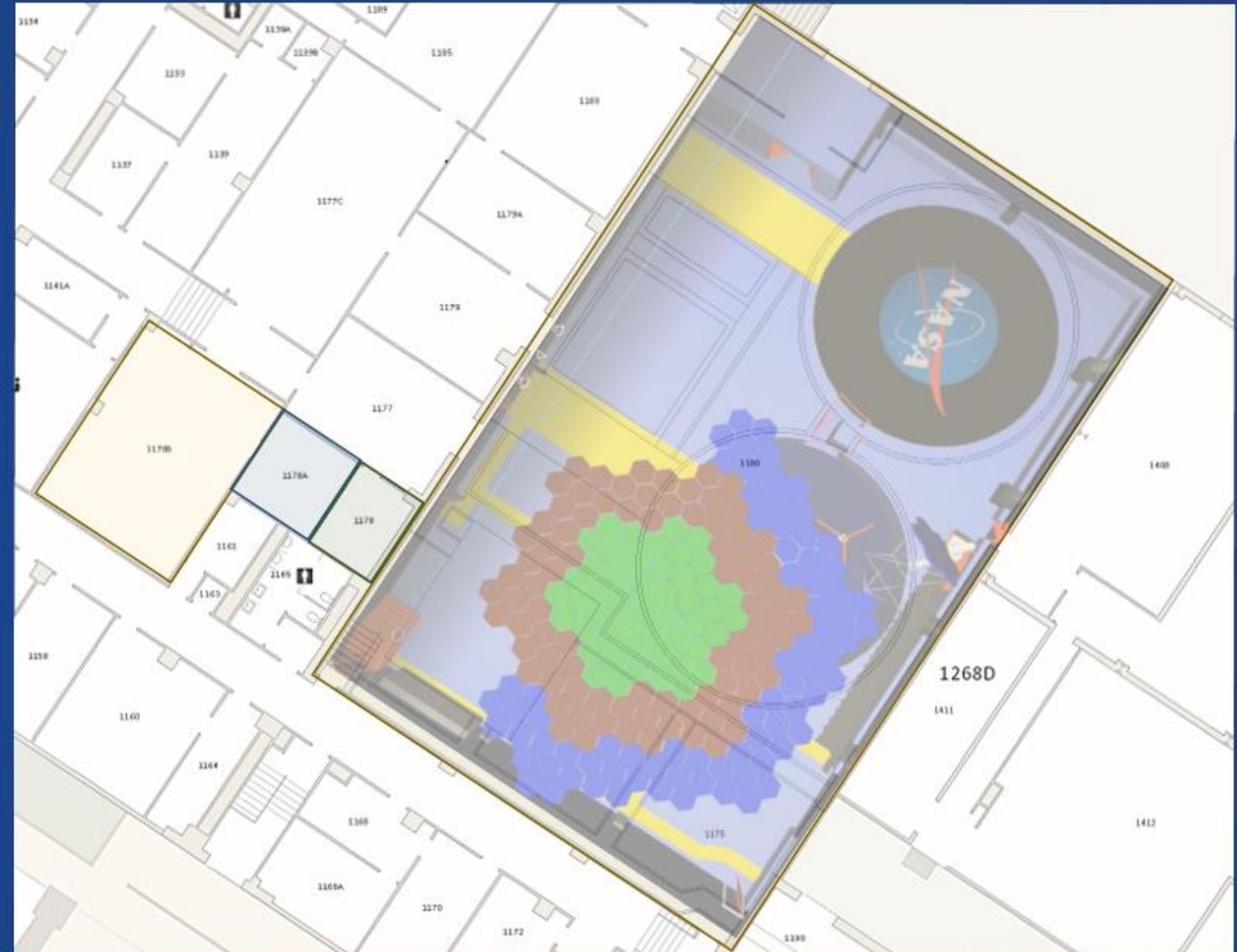
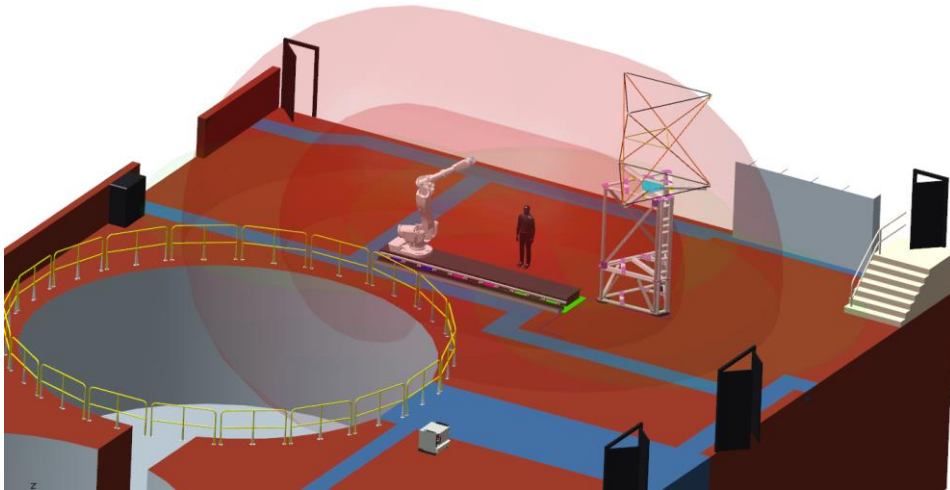
TRL Assessment



Building 1268 ISAM Facility Layout

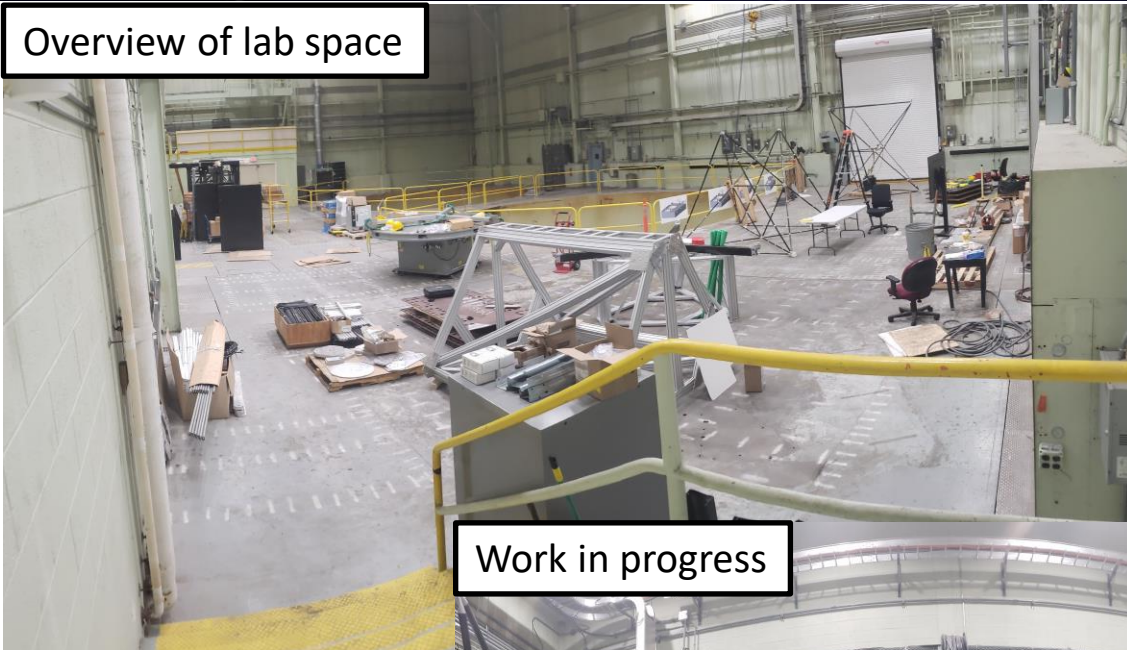
Phase I Status

- Initial robot and track mounting review complete
- Standard Operation Procedures under development
- Access control system design
- Robot controller mounting requirements analyzed final review pending
- Robot stand partially assembled



Laboratory Status

Overview of lab space



Work in progress

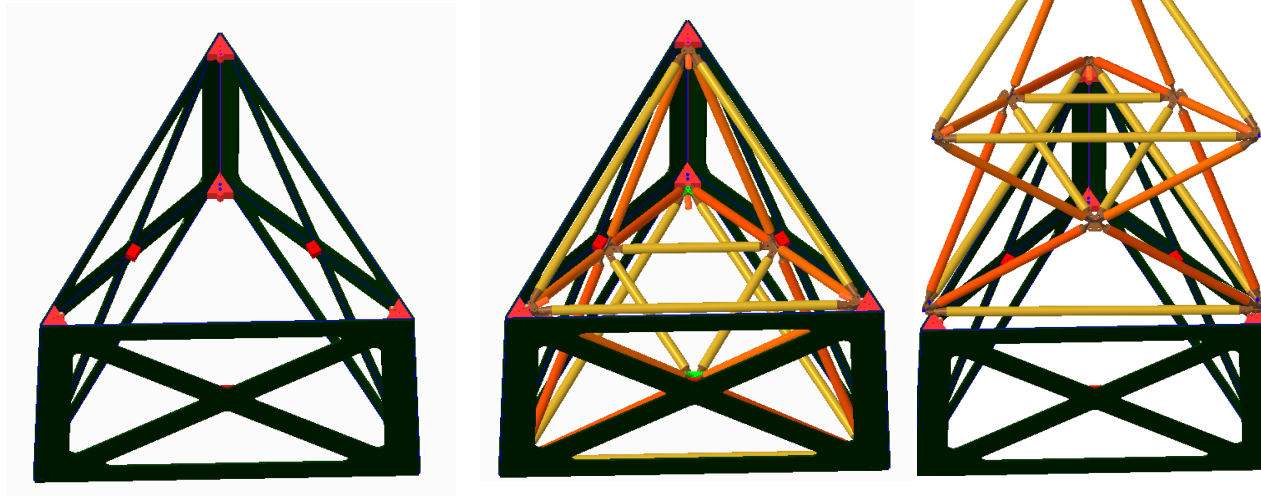


Foundry turntable

Truss Fabrication

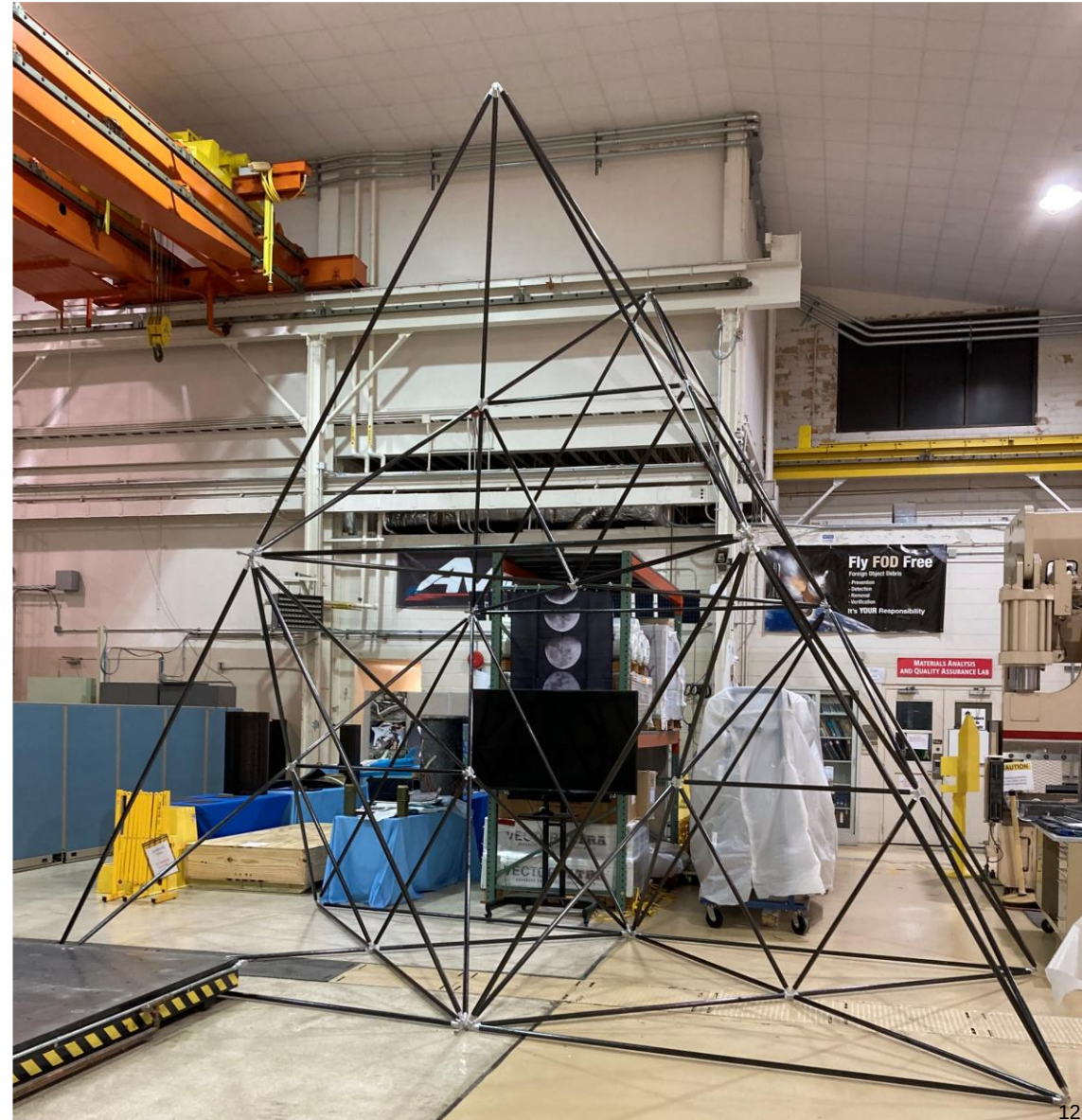


- Tri-truss fabrication fixture
 - Holds nodes the correct locations while composite struts are bonded in place
 - Prototype fixture is aluminum, final version will be composite to minimize thermal expansion issues
 - Trusses laser scanned, corner nodes (critical dimension) accuracy 0.5 mm



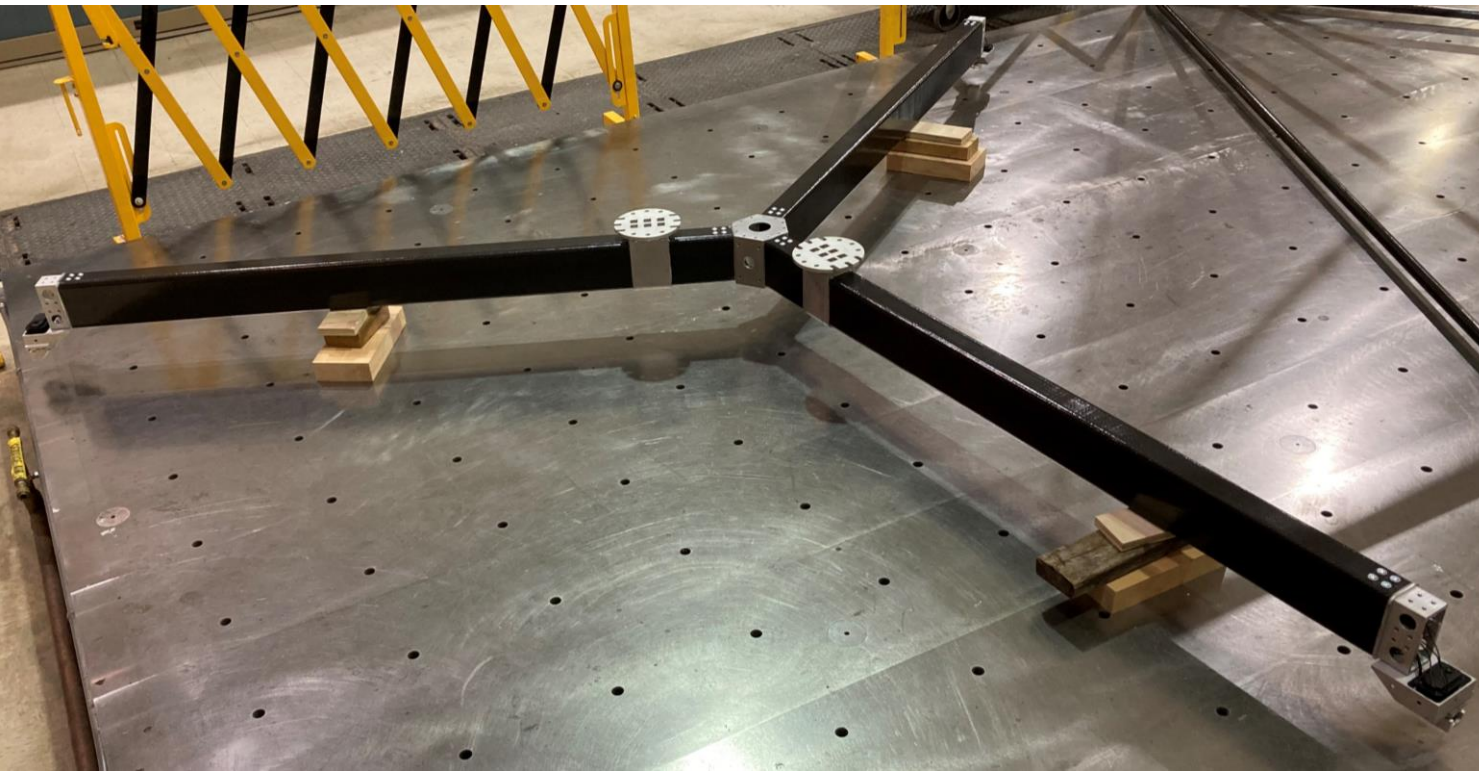
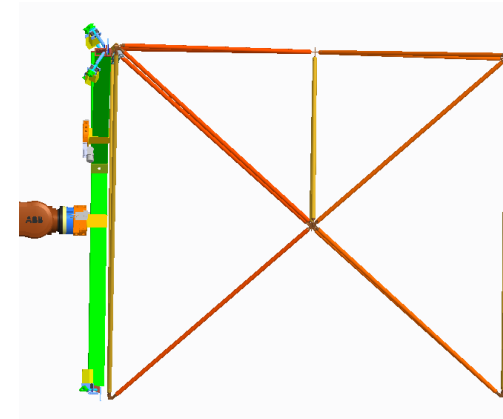
Node and Truss

- Design and fabrication of four 2.8 m x 2.8 m Tri-Trusses
 - Three bays mated with multi-nuts



Grapple Tool

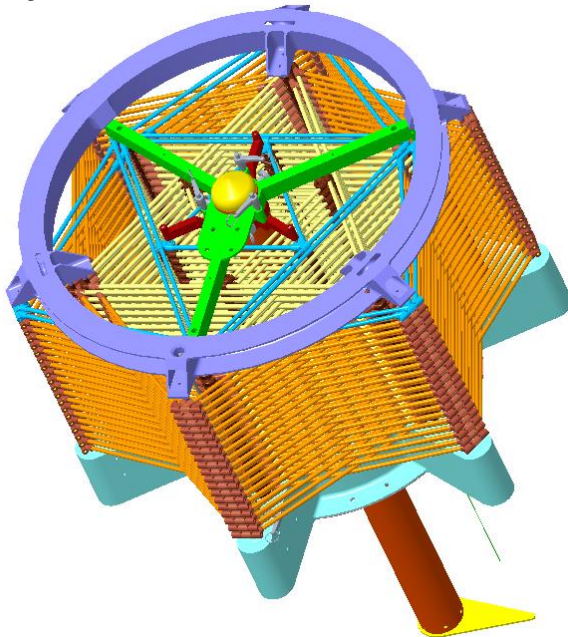
- Design and structural fabrication of a grapple fixture
 - Allows 3.9-m ABB robot to hold and manipulate a Tri-Truss
 - Each end fixture includes grappling, metrology, and attachment actuators



Stowable Design



- Design and fabrication of prototype 420 mm x 420 mm deployable Tri-Truss with launch fixture
 - Launch stack of 37 Tri-Trusses fits within a standard ESPA class payload



Stowed



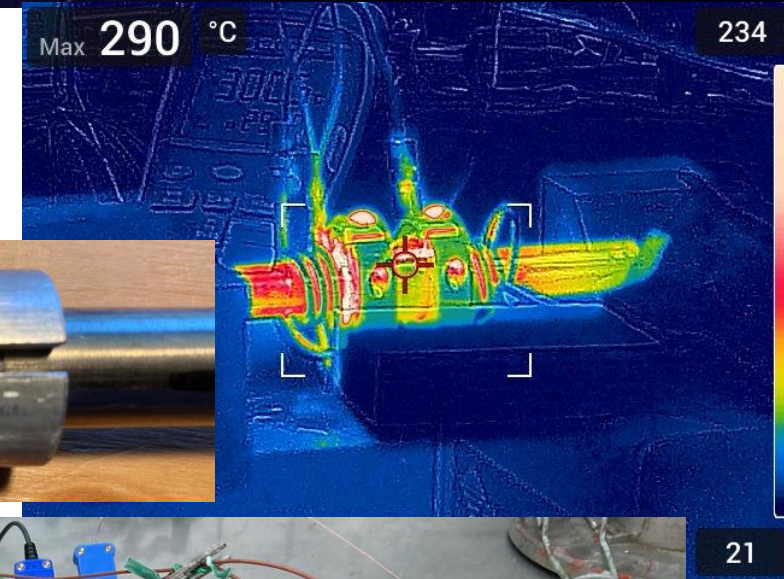
Deployed



Inductive Adhesive Bonding



- Developing methods to use thermal adhesive to bond structures together
 - Induction heating could be used in space to bond structural components together:
 - Preliminary induction heating tests on rods and collars
 - Preliminary induction heating tests on two-part nodes
 - Working with SBIR project on process



Bond Proof Test



Bottom pull condition
600 kg (total)



Middle triangle compression
300 kg

- Tri-Truss bond proof loading tests were conducted with two different loading conditions, for the bond proof of the aluminum nodes and composite tubes of Tri-Truss
- No structural or bonding failures were observed
- Strains gages at 21 locations indicated the modulus of composite tube is about 70% of the reported manufacturer's value

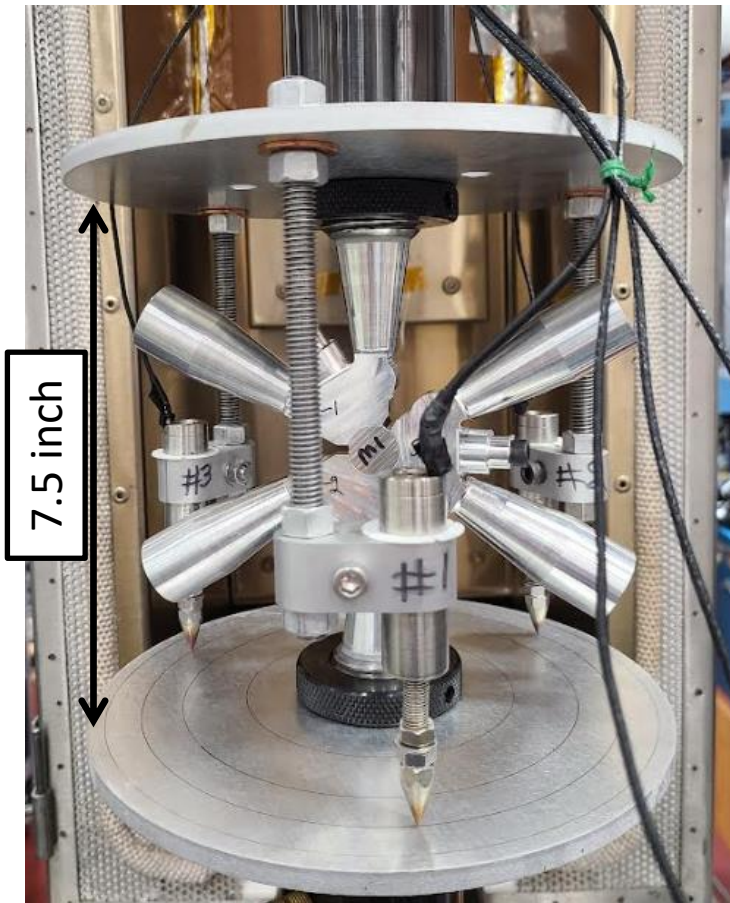
Modal Test of Single Tri-Truss Module



Modal test setup of a single Tri-Truss module

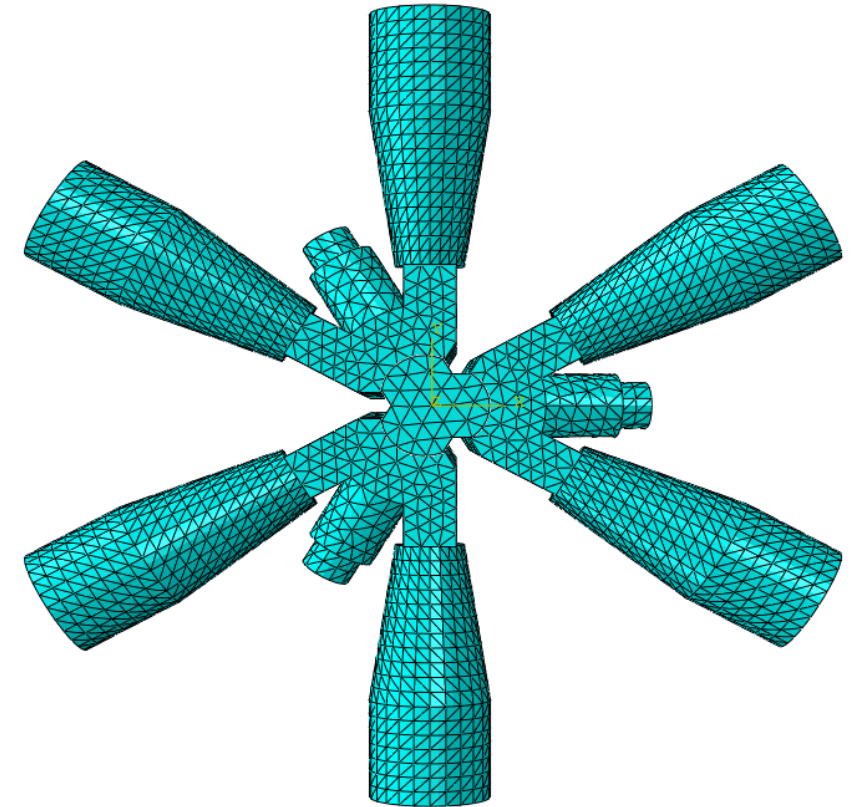
- Modal test of single Tri-Truss module was conducted by UM student Ray Garatsa
- From the modal test, mode shapes of free suspended Tri-Truss module were measured and compared with the predicted mode shaped of finite element model
- Results indicated the modulus of composite tube is about 70% of the reported manufacturer's value

Multi-Nut Test and Finite Element Model



Multi-Nut Test Setup

- Maximum tension and compression load 500 lb
- Varying bolt torque levels (15, 30, and 60 in-lbs) to investigate assembly requirements
- Results now near-linear behavior for high torques, increased hysteresis at low torques

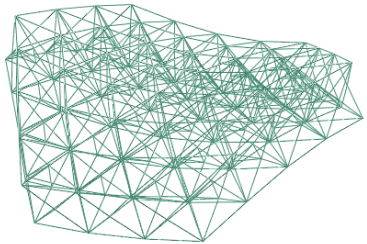


Development continues on both complete and simplified finite element models

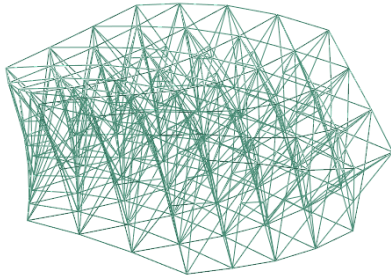
Future-Facing Design Principles



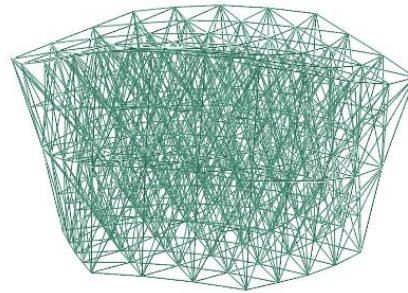
- Establishing design principles for future applications
- Designing to raise the first natural frequency
- Finite element models of three-ring Tri-Truss structure explored
 - Number of layers
 - Strut length
 - Size of Tri-Truss modules



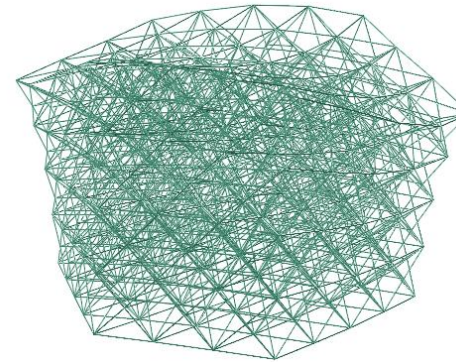
$f = 9.36 \text{ Hz}$



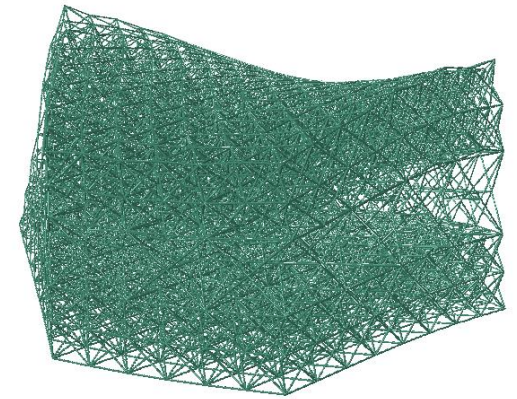
$f = 12.6 \text{ Hz}$



$f = 37.7 \text{ Hz}$

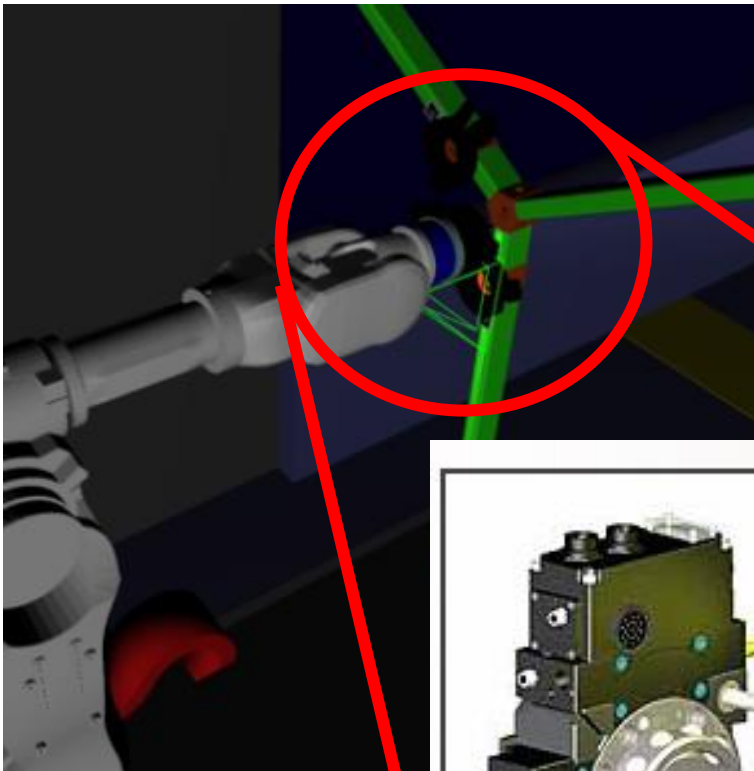


$f = 42.8 \text{ Hz}$



$f = 55.5 \text{ Hz}$

Selected Grapple Tool Interface



QC-210 with Pneumatic module and Control module

Figure 3.1—Offset Definitions

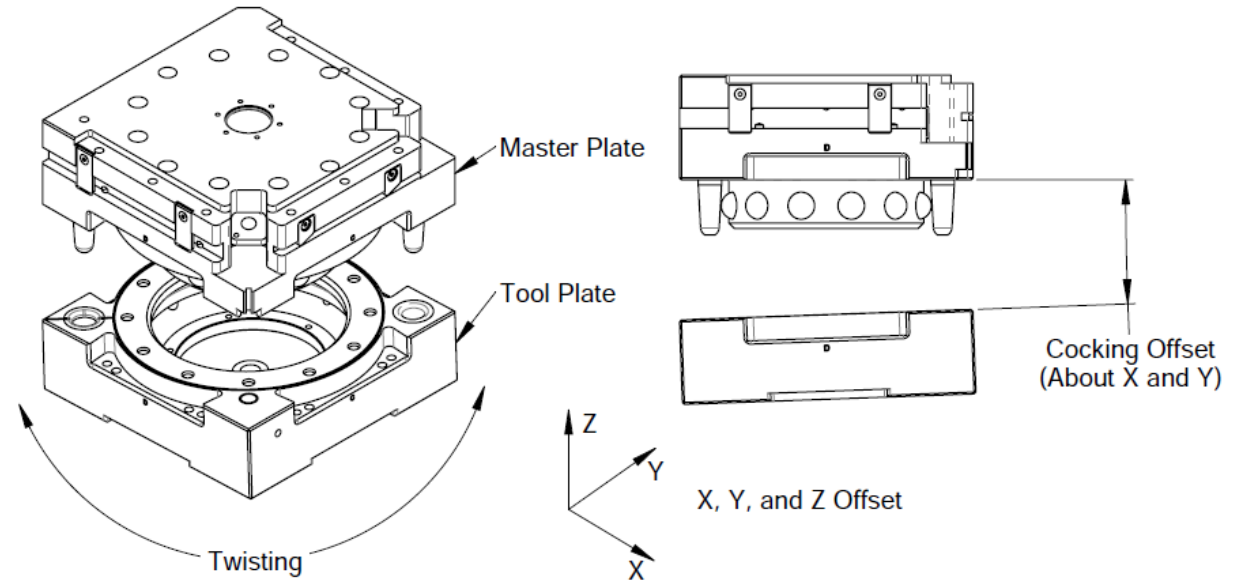


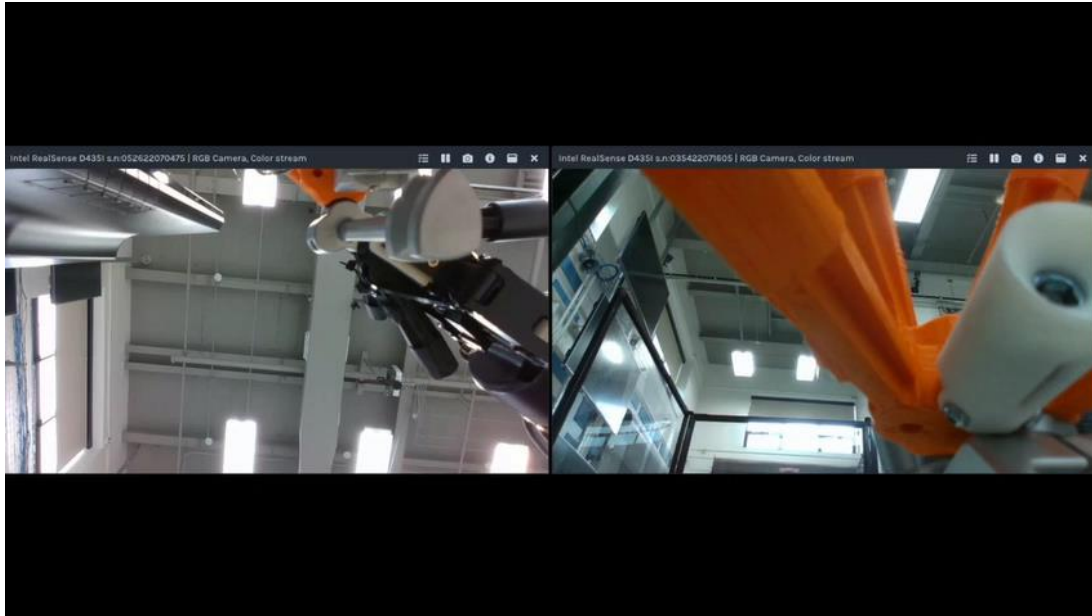
Table 3.1—Maximum Recommended Offsets Prior to Coupling

Model	No-Touch Zone Z Offset (Max) ¹	X and Y Offset (Max) ²	Cocking Offset (Max)	Twisting Offset (Max)
QC-210	0.08" (2 mm)	±0.08" (2 mm)	±0.7°	±1°

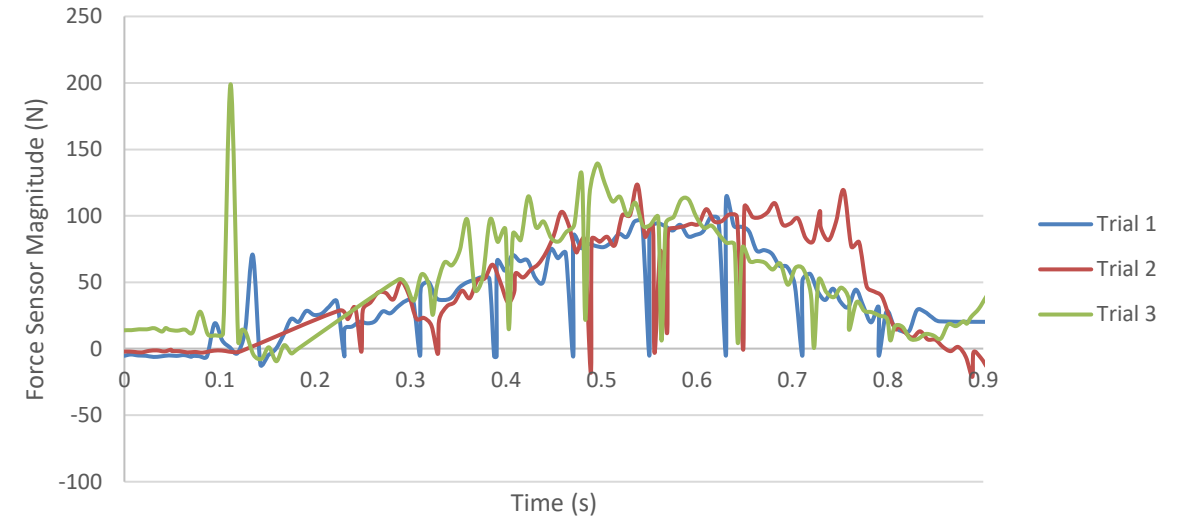
Notes:

1. Maximum values shown. Decreasing actual values will minimize wear during coupling/uncoupling.
2. Actual allowable values may be higher in some cases but higher offsets will increase wear during coupling.

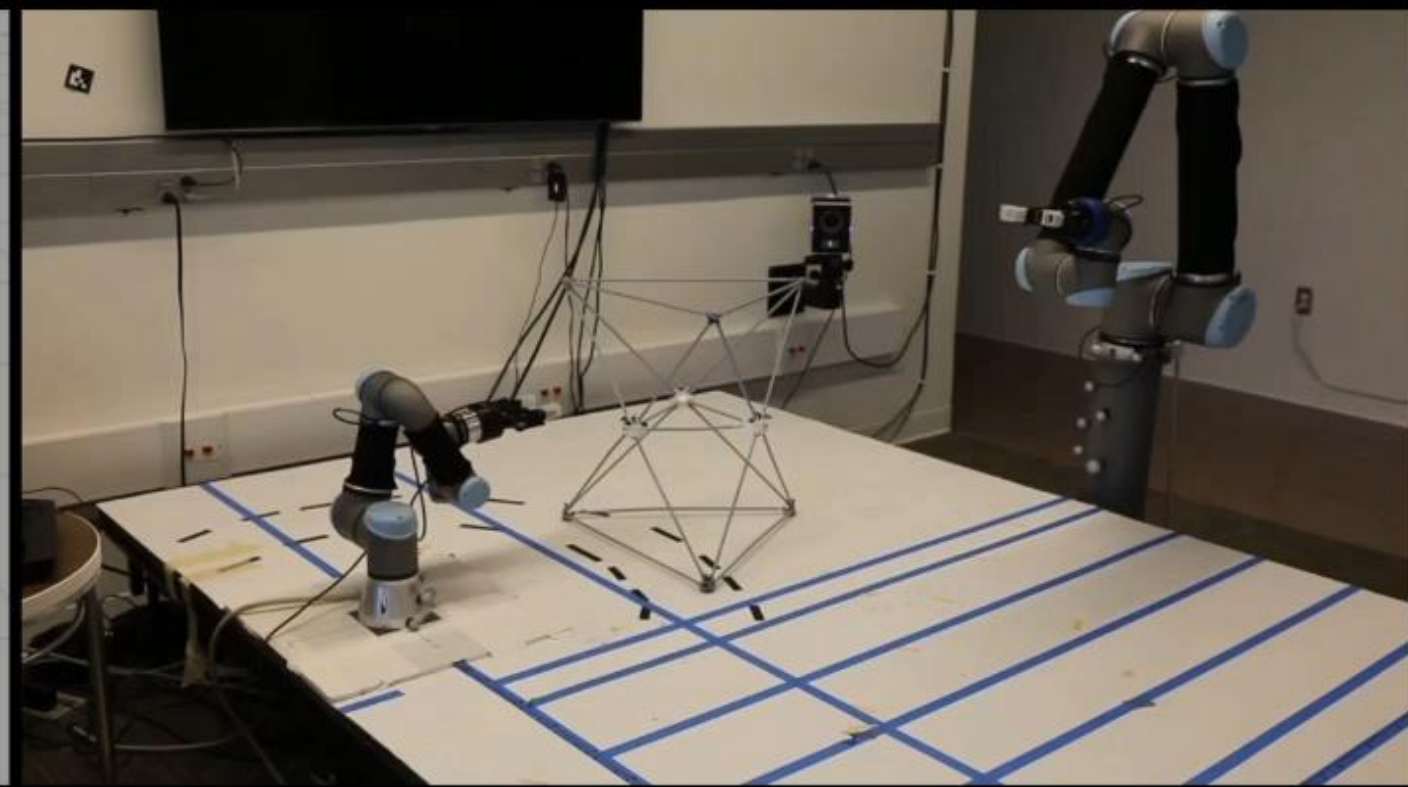
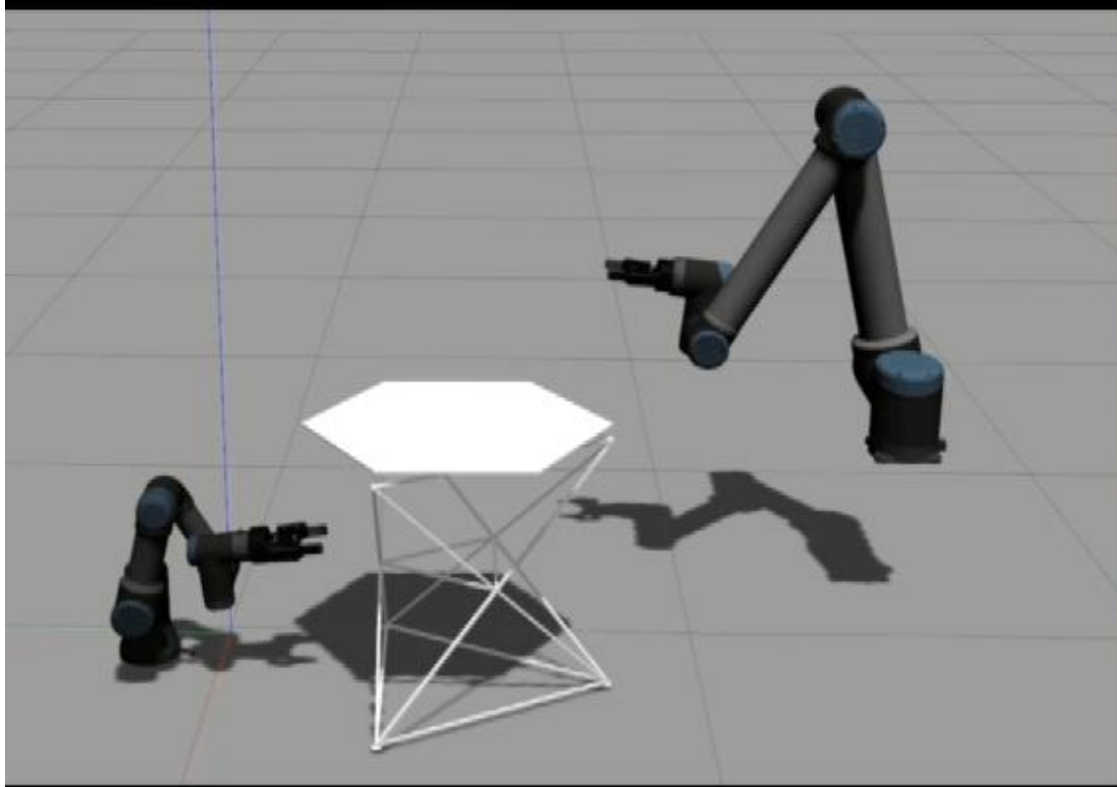
Grapple Tool Integration Test



Test Load Measurement



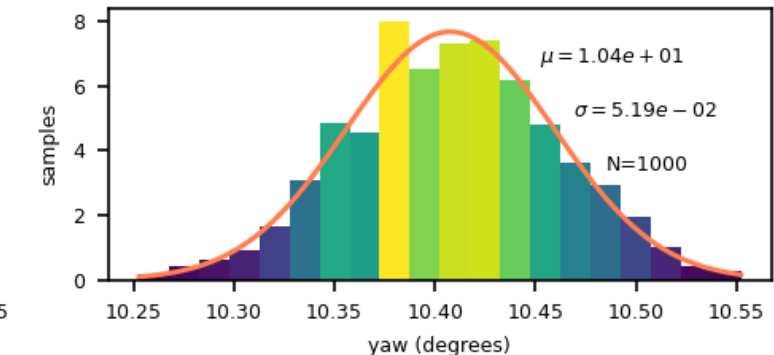
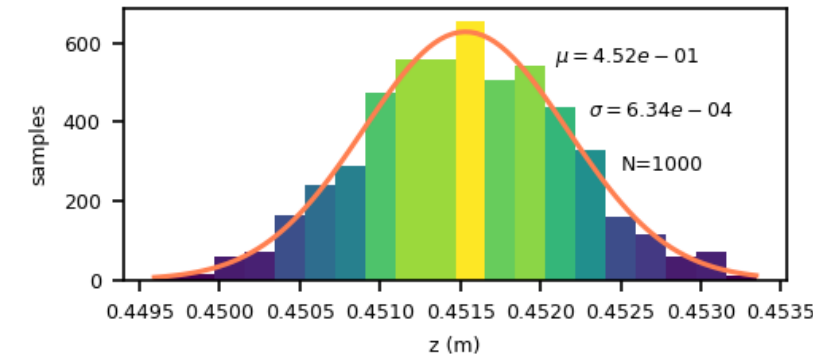
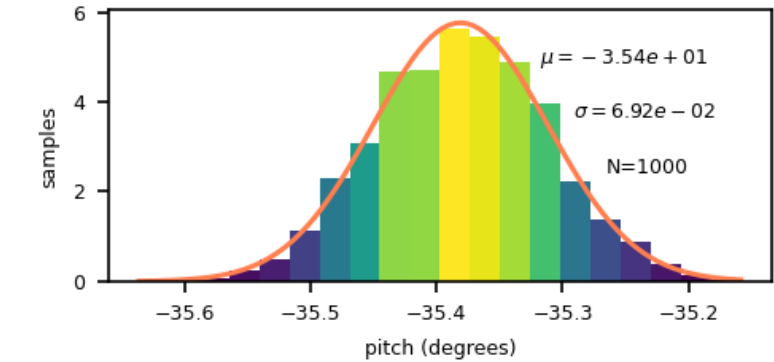
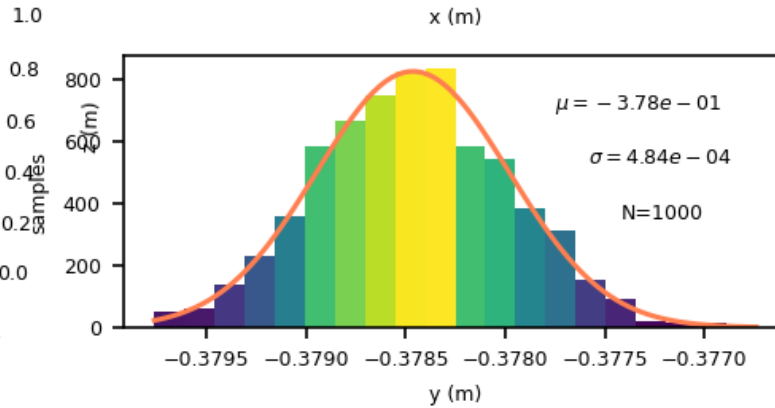
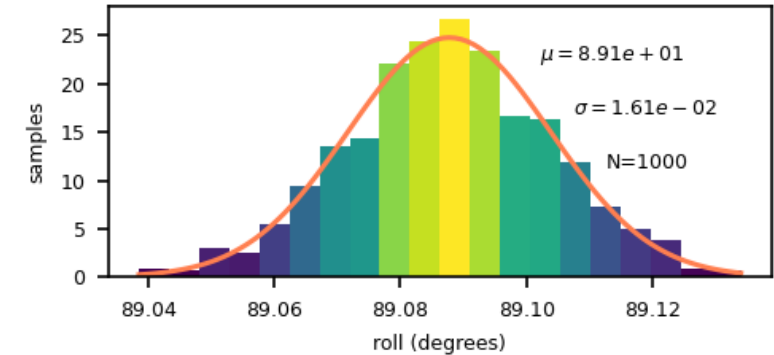
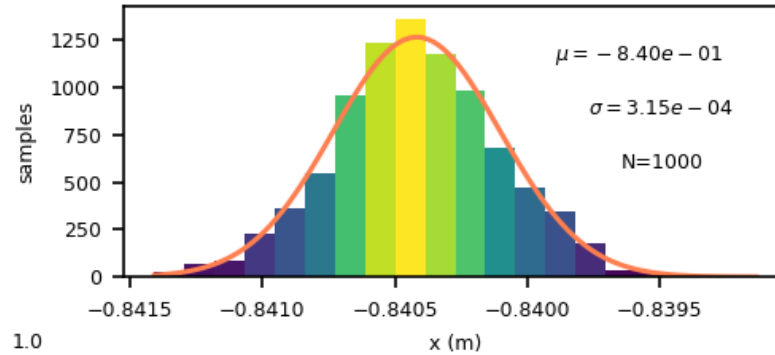
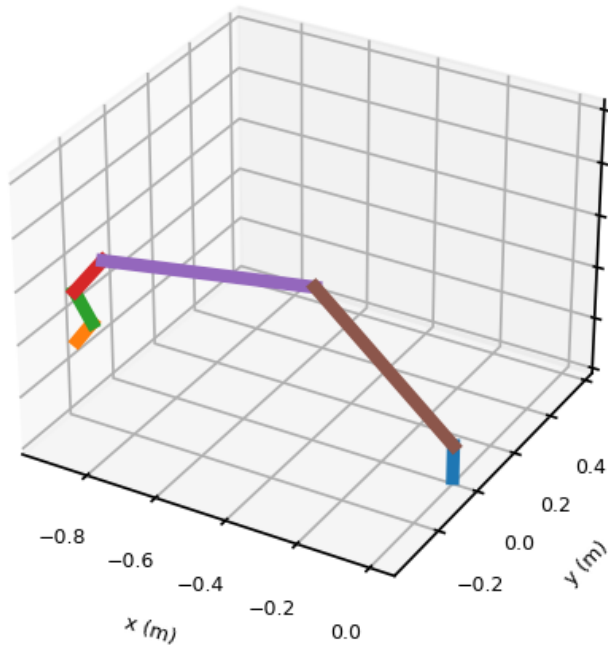
Adopted Gazebo as Simulation/Digital Twin Environment



Uncertainty Quantification for Robot End-Effector Pose



Pose Visualization



Sensor Selection and Object Pose Estimation Algorithm



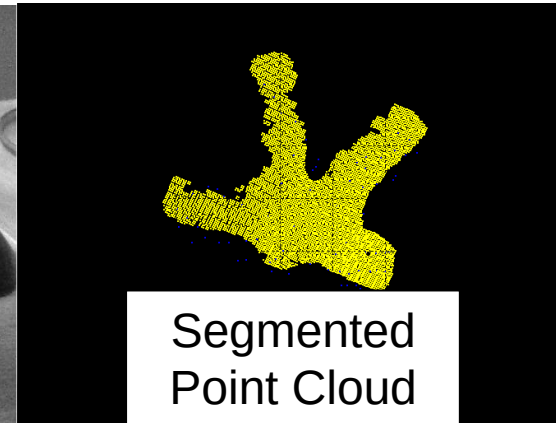
Intel Realsense d435i depth camera



Bouding Box

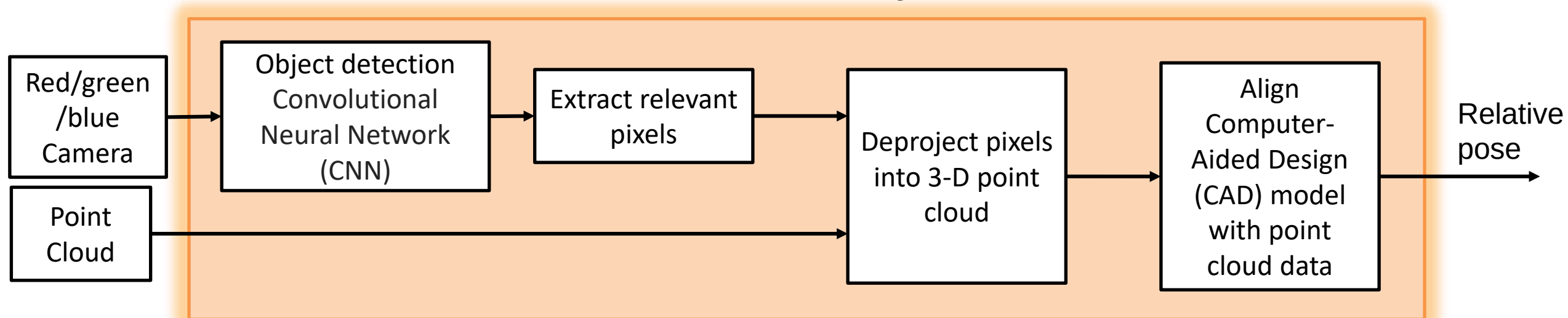


Mask



Segmented
Point Cloud

Pose Estimation Block Diagram



Subscale Grapple Tool for Rapid Iteration



Project Assessment Summary



Project Name	Performance				Comments
	C	S	T	P	
Mid Year					(C) Cost – Green (S) Schedule – Fire alarm and roll-up door refurbishment completed significantly behind schedule, expecting to make up time (T) Technical – Four full-sized Tri-Trusses built and hand-assembled, grapple tool parts in hand, autonomy and structures research progressing (P) Programmatic – Transitions to new principal investigator (PI) (Olive Stohlman) and new program element manager (PEM) (QuynhGiao Nguyen)
Annual					(C) Cost – Green (S) Schedule – Facing delays in finalizing robot installation construction plan, contract in works with Jacobs for construction drawing assistance (T) Technical – First measurements of structural deformation under load, Tri-Truss normal modes, joint behavior; autonomy and structures research progressing (P) Programmatic – Onboarded new project manager (PjM) (Jim Neilan), transitioned to new PEM (Martin Annett), project plan fully drafted

Plans Forward – Phase 1

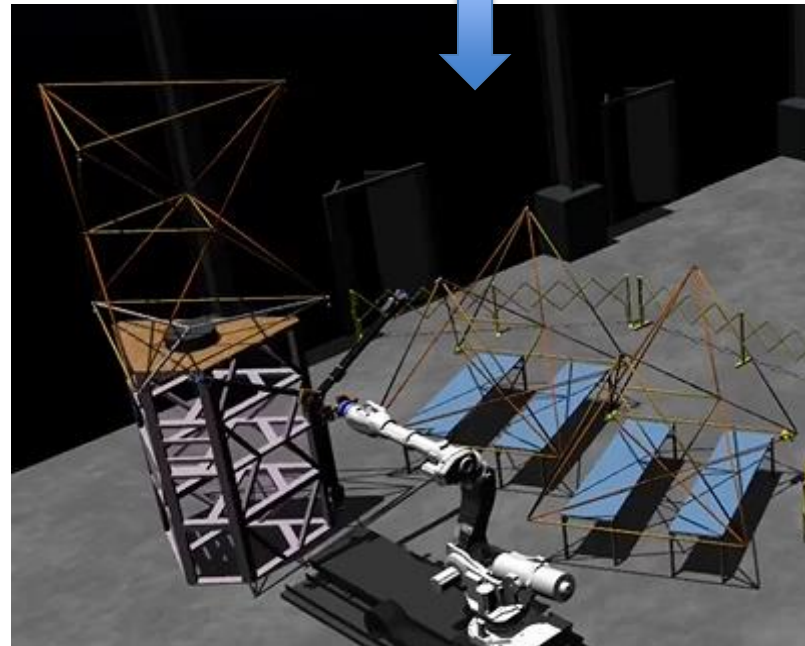


NASA Langley Research Center
Project Manager: Jim Neilan
Principle Investigator: Olive Stohlman

Game Changing Development Program Percision Assembled Space Structure (PASS)

Space Technology & Exploration Directorate
Status Date: 6/30/2022
Prepared by: Linda Campbell

	FY21				FY22				FY23				FY24				FY25			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2		
Game Changing Development Program Key Milestones	★	Authority to Proceed				Three Module Assembly (Triangle)			★	First Ring Assembly (w/Harness) ★				Second Ring Assembly (% w/Harness) ★			Third Ring Assembly (% w/Harness) ★			★
														★	Module Exchange ★					



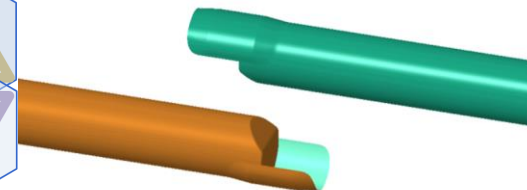
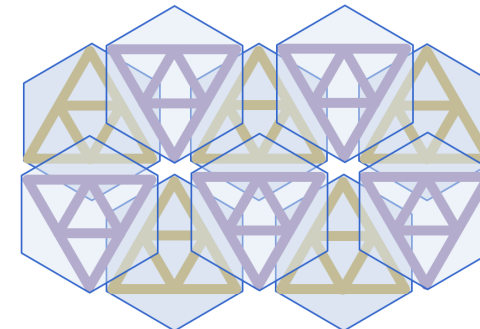
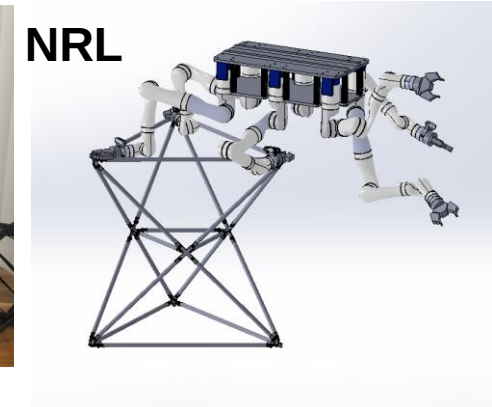
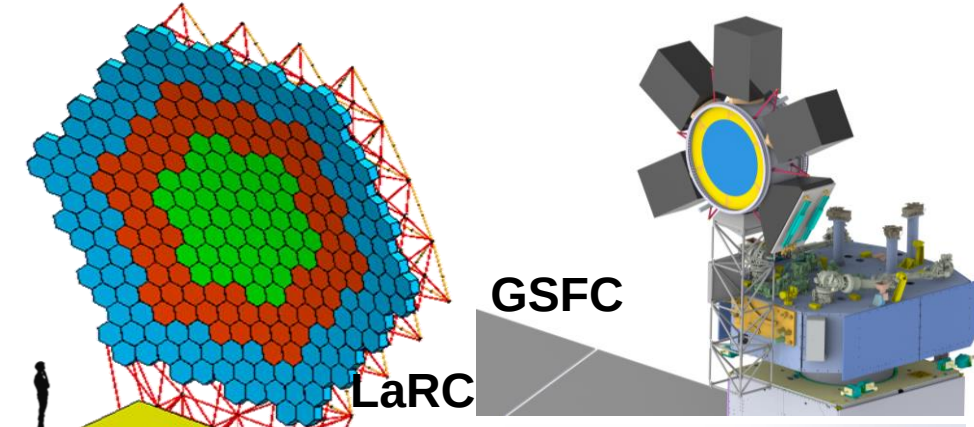
Mission Infusion and Partnerships



➤ **PASS: NASA and Other Gov't Agency Partnership**

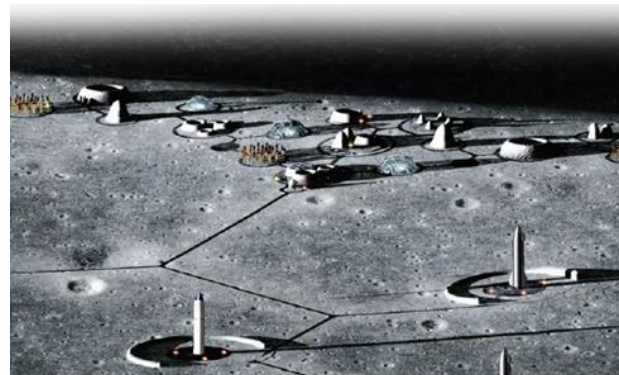
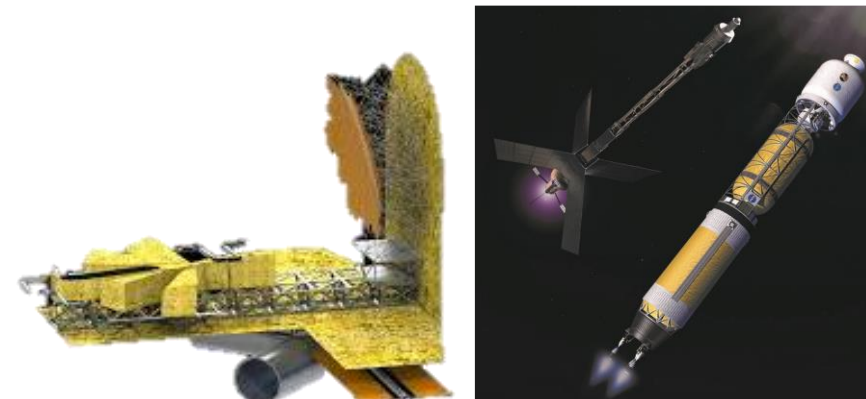
- NASA: Langley Research Center (LaRC), Goddard Space Flight Center (GSFC), Ames Research Center (ARC)
- Naval Research Laboratory (NRL)
- Small Business: Electrodynamics Technologies Inc. (ED Tech), ATSP Innovations
- University: Virginia Tech, Univ. of Maryland, North Carolina State

➤ **Infusion/transition plan**



ED Tech

ATSP



Education / Public Outreach (EPO)



EPO Involvement

- Scitech (January 2022) papers:
 - Supervised Autonomous Assembly to Create and Evolve Persistent Assets (AIAA-2022-2076)
 - Designing a Software Architecture for the Precision Assembly of Space Structures (AIAA-2022-2077)
 - TriTruss Strut-to-Joint Bond Test: Analysis and Setup (AIAA-2022-0843)
 - Modeling Effort of TriTruss Modular Structure for In-Space Assembled Telescope Foundational Structure (AIAA-2022-0844)
- Other conferences and papers:
 - ASCEND (November 2021)
 - Society for Experimental Mechanics (June 2022) – Hodges and Pankow, "Modeling Micrometeoroid and Orbital Debris Impact on Composite Truss Tubes"
- University collaborations and students:
 - University of West Virginia, Clemson University
 - University of Iowa, North Carolina State University, U. of Central AR
- Visits and visitors:
 - Fir Force Research Lab technical interchange meeting, 10/14/21
 - In Space Developmental Test (iSDT) collaboration meeting, 1/22

- PI visit to VA Tech, 4/29/22
- OGA research group visit 8/9/22
- VA Tech, UMD, and co-op student visit, 8/18/22
- Top 3 Newsworthy Events:
 - Tri-Truss proof test (to be presented at Scitech 2023)
 - Surprisingly STEM Soft Robotics feature (to be released by Office of Science, Technology, Engineering, and Mathematics Engagement)
 - First robotic drive node assembly



EPO Calendar Outlook (High Priorities):

6 Month Look-Ahead	
ASCEND 2022	October 24- 26
AIAA Scitech 2023	January 23-27

Summary



➤ Accomplishments September 2021 - August 2022:

- Lab improvements
 - Roll-up door installation
 - Side room refurbishment
 - Turntable delivery
 - Test stand assembly
- Structural design:
 - Manufactured four Tri-Trusses
 - First assembly of a 3-bay unit
 - First proof test of a Tri-Truss
 - First robotic drive of a multi-nut joint
- Structural analysis:
 - Joint stiffness testing
 - One-bay modal test data
 - Proof test strain gage data

- Autonomy and robotics:
 - Object detection algorithm
 - Uncertainty quantification for subscale robots, ready to scale
 - Industrial robot arm training
- TechMat deliverables are test reports for autonomous assembly demonstrations (Project plan under review)

Technology	Start TRL	End TRL
Tessellation Methods	1	4
Structural Architecture	2	6
Automated Truss Assembly	2	6
All Composite Joining	1	3