In-Space Assembly Concepts Research and Development

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Acknowledgement

Project Enabling Programs:

The NASA's Early Career Initiative
The NASA's POLARIS Program
The NSAS's Game Changing Program

Project Teams:

The CIRAS Team
The ASSEMBLERS Team
The LSMS Team
The LANDO Team
The Lunar Safe Haven - Blue Team
The PASS Team
The TLT Team

Supporting Communities:

The Greater In-Space Assembly and Manufacture Community at NASA – LaRC
The Greater Research and Development Supporting Community at NASA - LaRC

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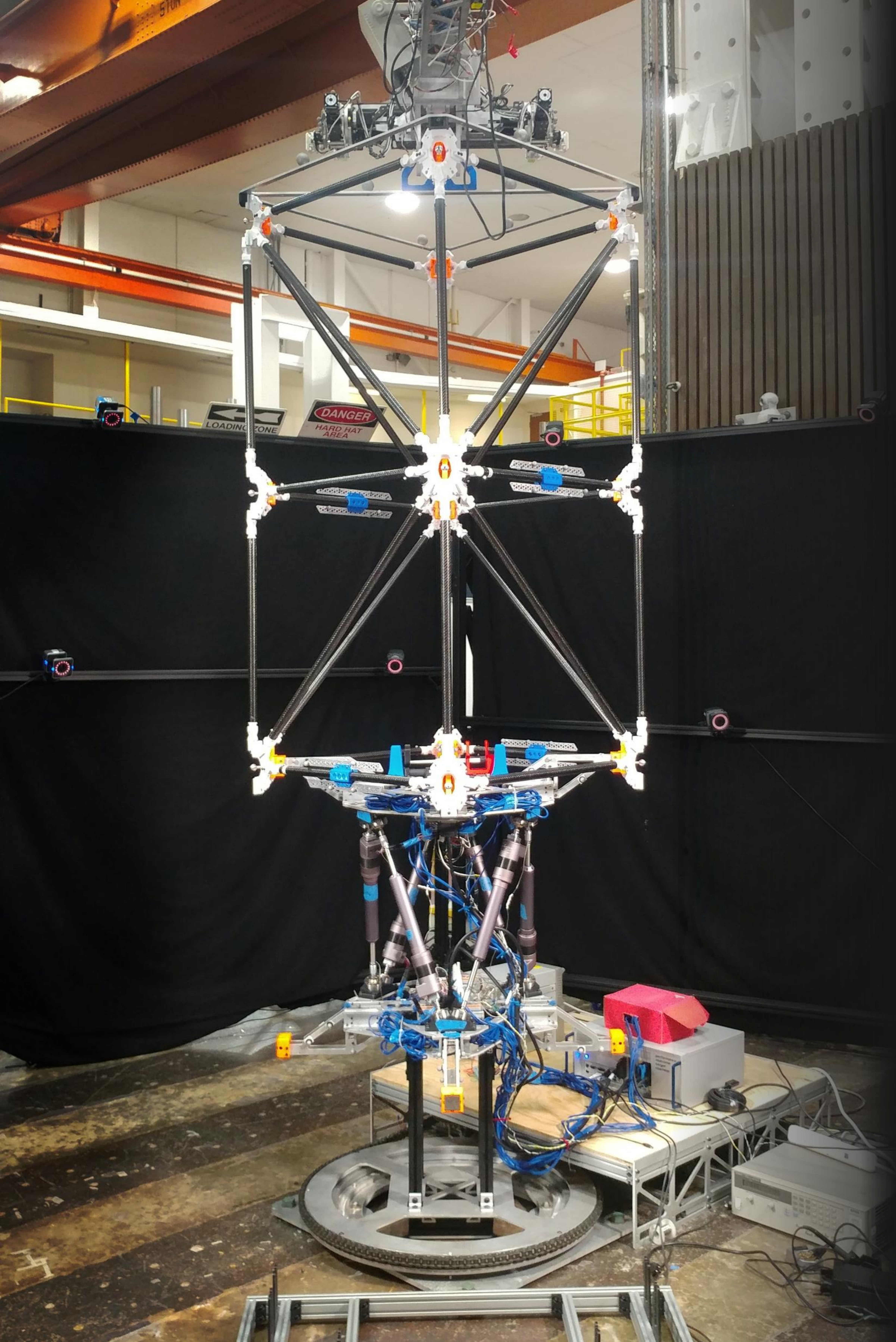
Closing Slide with Project Patches.



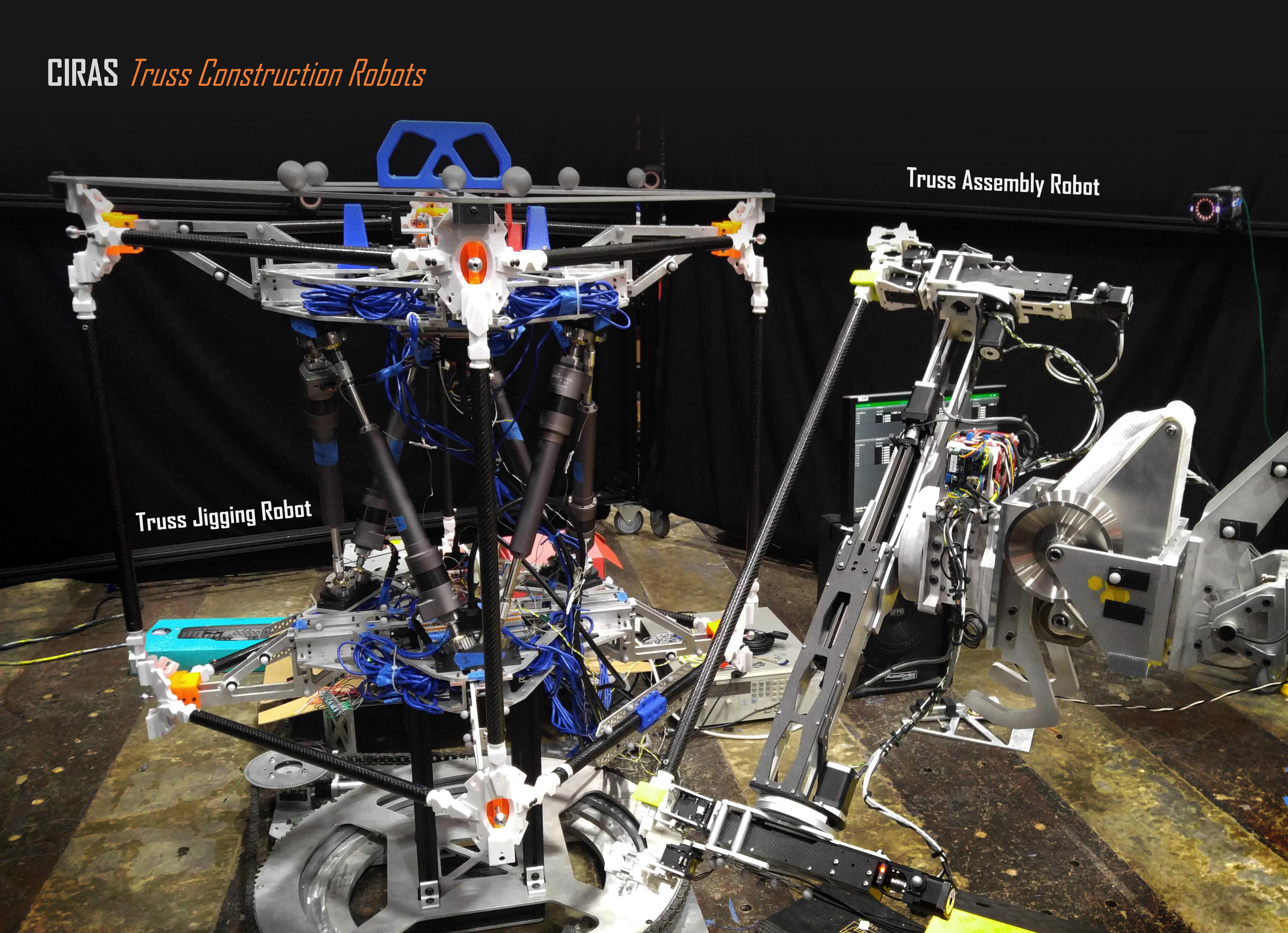
CIRAS

Commercial Infrastructure for Robotic Assembly and Services

Commercial Infrastructure for Robotic Assembly and Services (CIRAS) aims to investigate technologies needed to build a 15+ m linear truss boom on orbit utilizing long-reach manipulators in conjunction with energy beam welding technologies.

Two key robotic agents were developed to build the truss boom in addition to the given long-reach manipulator and energy beam welding tool. A jigging robot was developed to hold the parts in place before the parts are permanently welded together. A truss assembly robot was developed to handle all the truss components and assemble the truss.

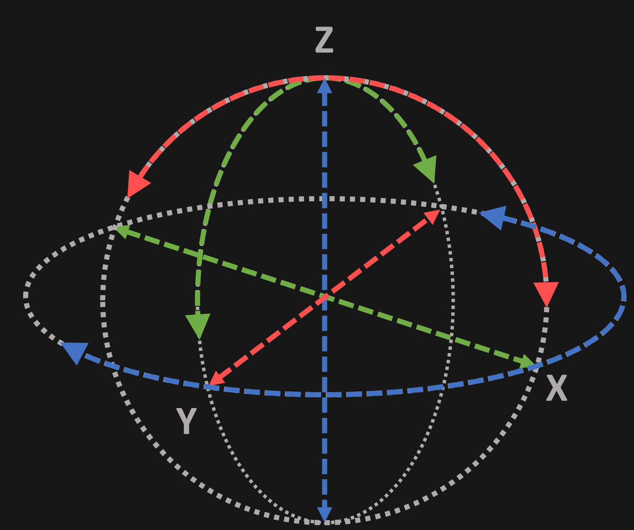
A truss test article was developed based on joints designed specifically for 3D-printing Titanium manufacturing that can be welded using the energy beam tool. Each truss component is also outfitted with visual tracking markers to track the components' position and record the truss assembly demonstration.



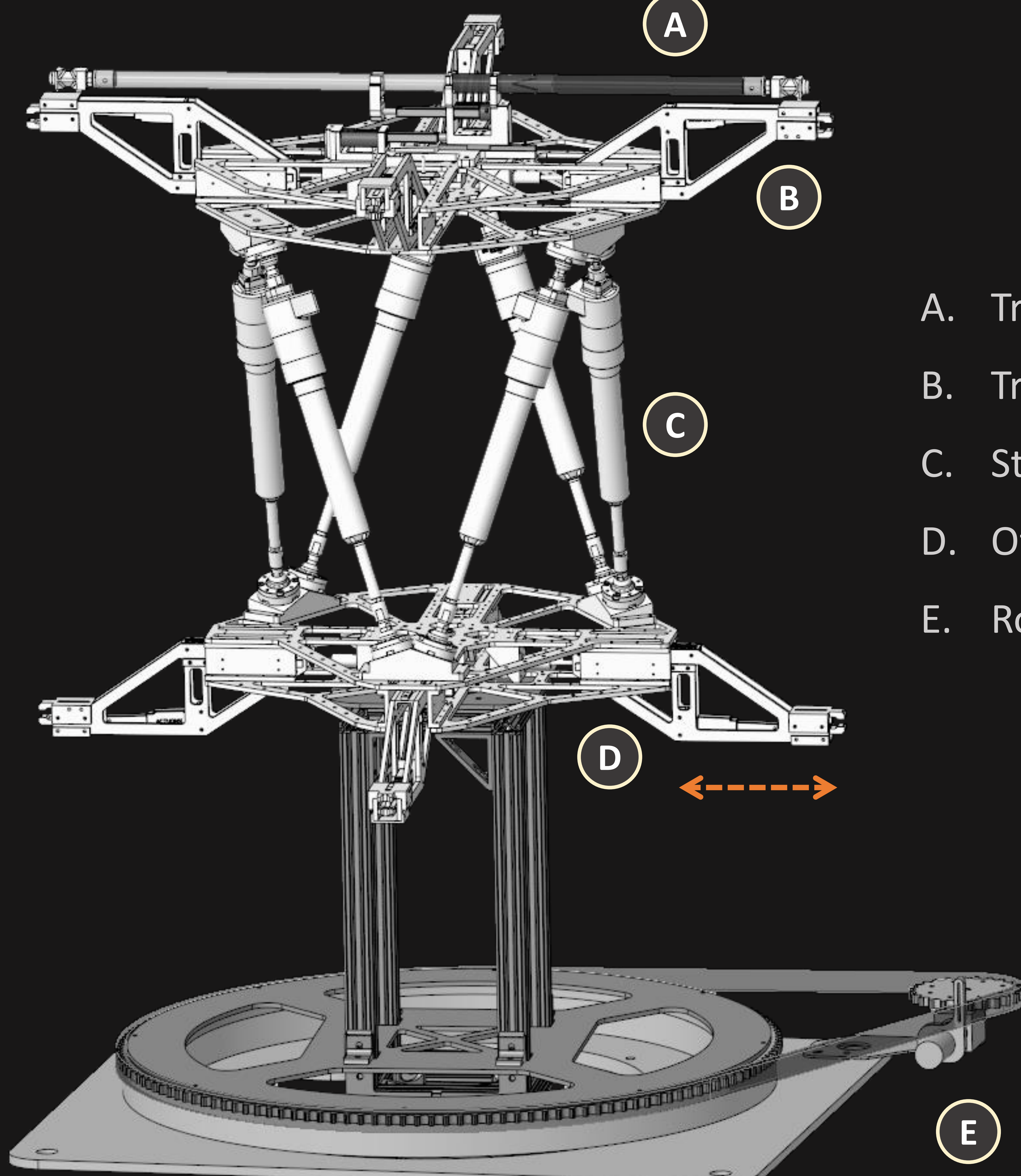
CIRAS

Commercial Infrastructure for Robotic Assembly and Services

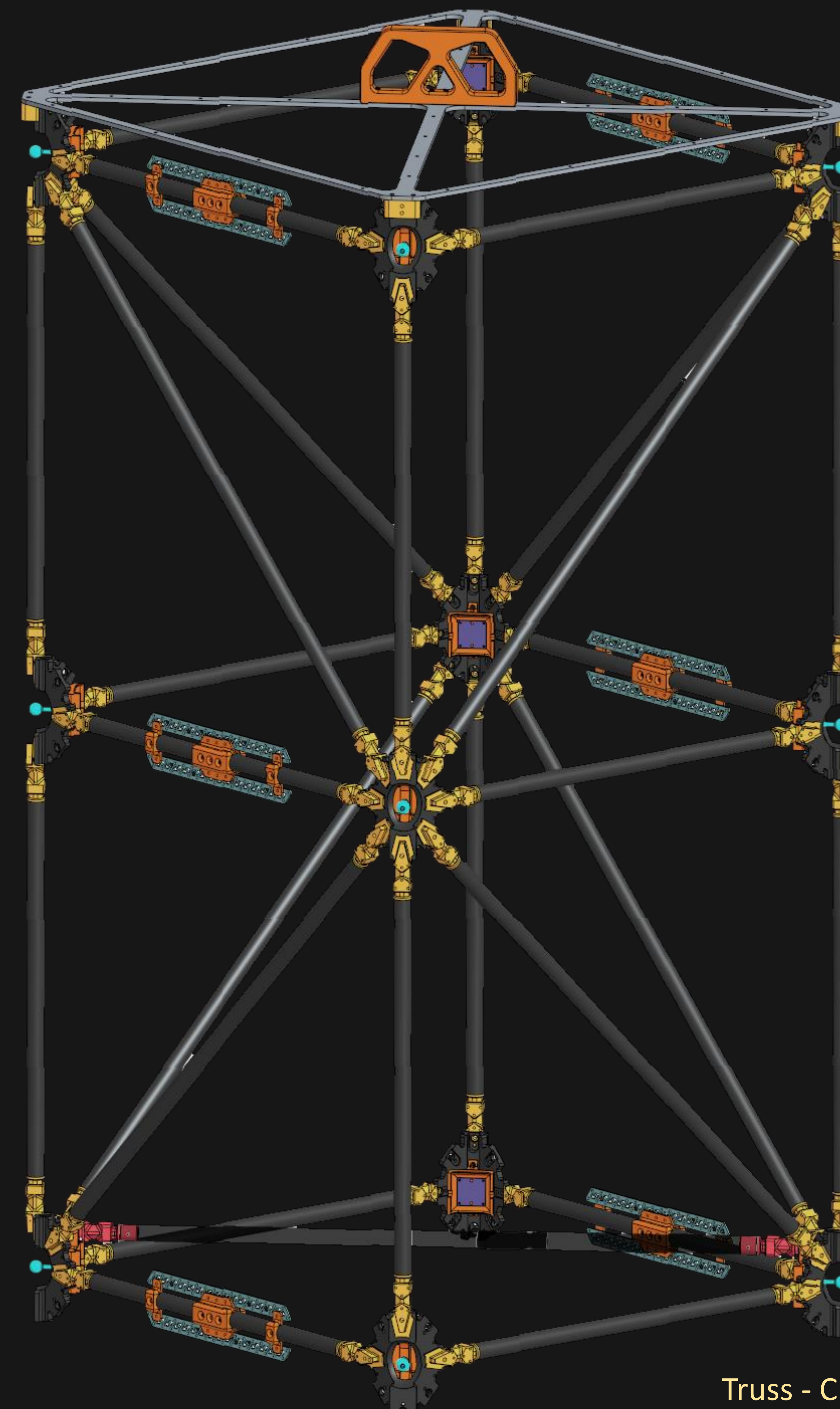
CIRAS *Truss Jigging Robot*



Truss Jigging Robot System with six degrees of freedom (DOF) helps adjust and holds all the parts together before the parts are welded together



A. Truss Closing Strut
B. Truss Gripper (x8)
C. Stewart Platform
D. Off-set Structure
E. Robotic Turn Table

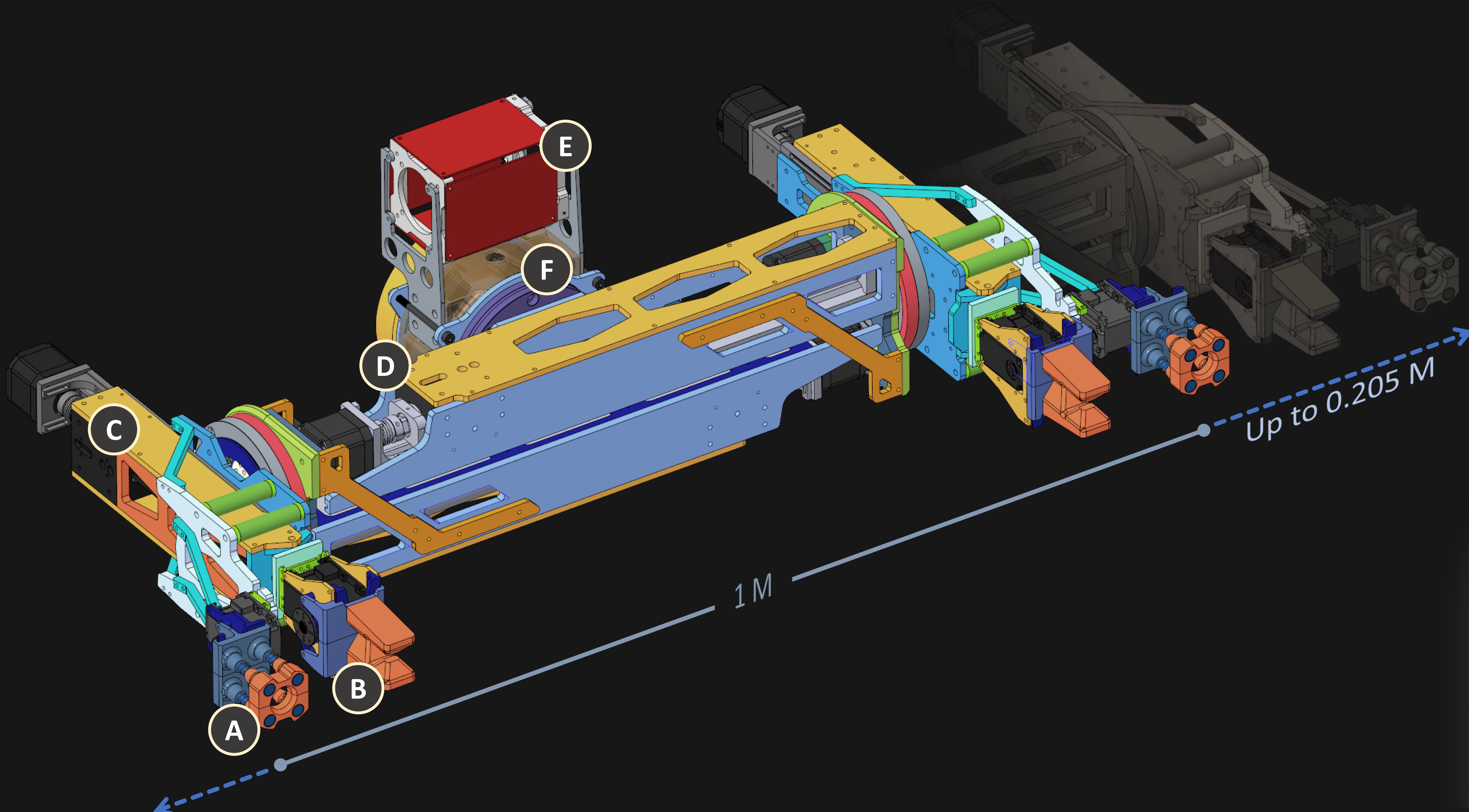


Truss - C
Structure Test Article

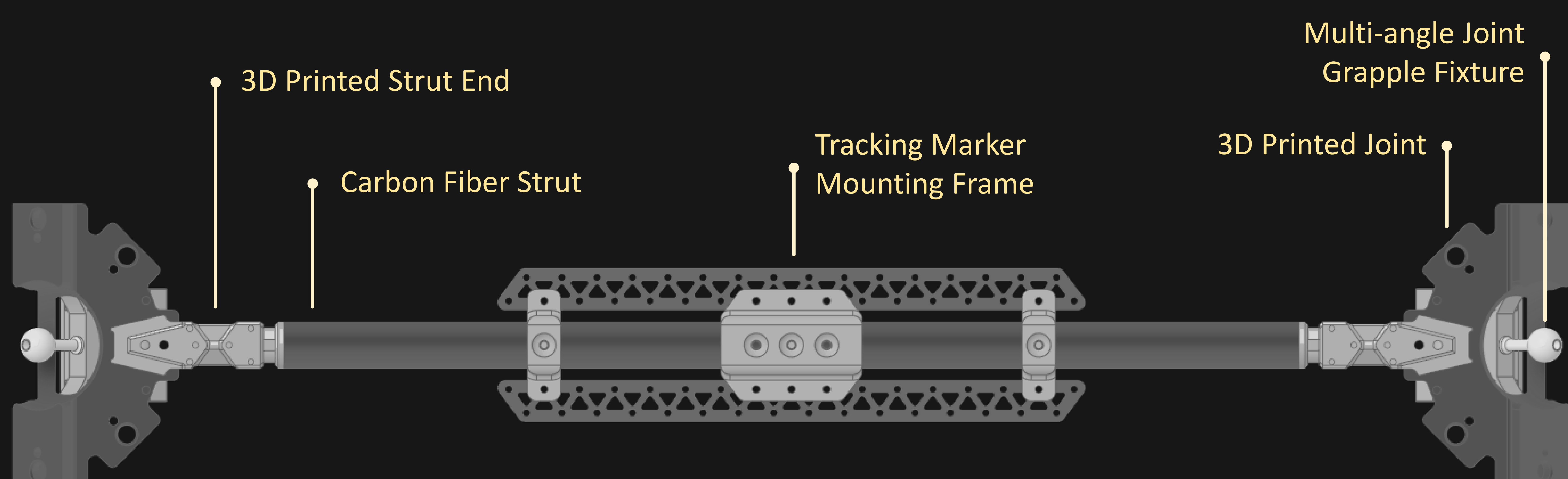
CIRAS

Commercial Infrastructure for Robotic Assembly and Services

CIRAS *Truss Assembly Robot*



A. Joint Gripper (x2)
B. Strut Gripper (x2)
C. Extendable Arm (x2)
D. Extendable Frame (x2)
E. End Effector Turn Table
F. End Effector Controller



Joint Pre – attached Strut

3D printed Titanium
Energy Beam Welded Joint

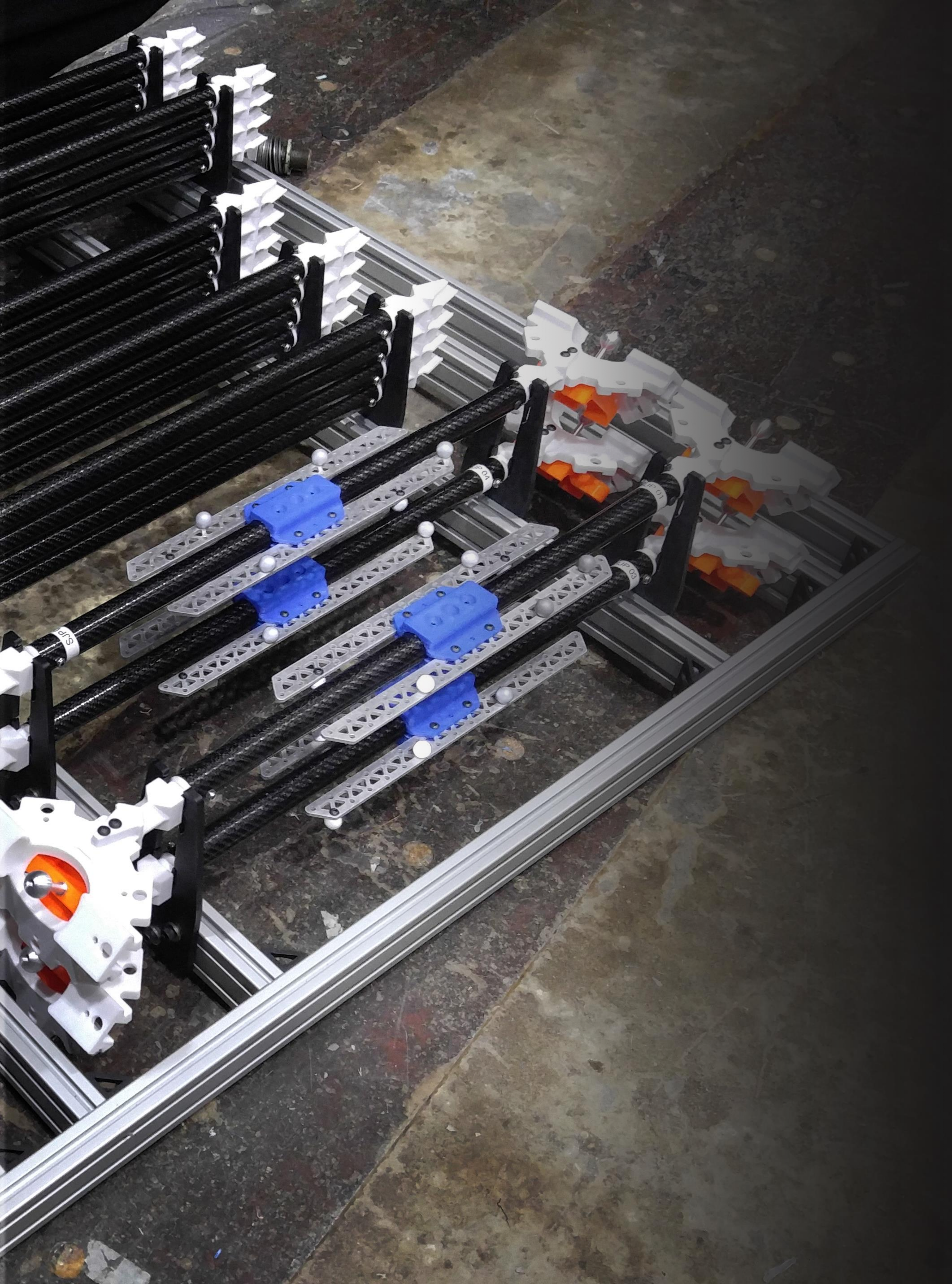
CIRAS

Commercial Infrastructure for Robotic Assembly and Services

CIRAS *Truss Assembly Robot*

CIRAS

Commercial Infrastructure for Robotic Assembly and Services



R-BEES

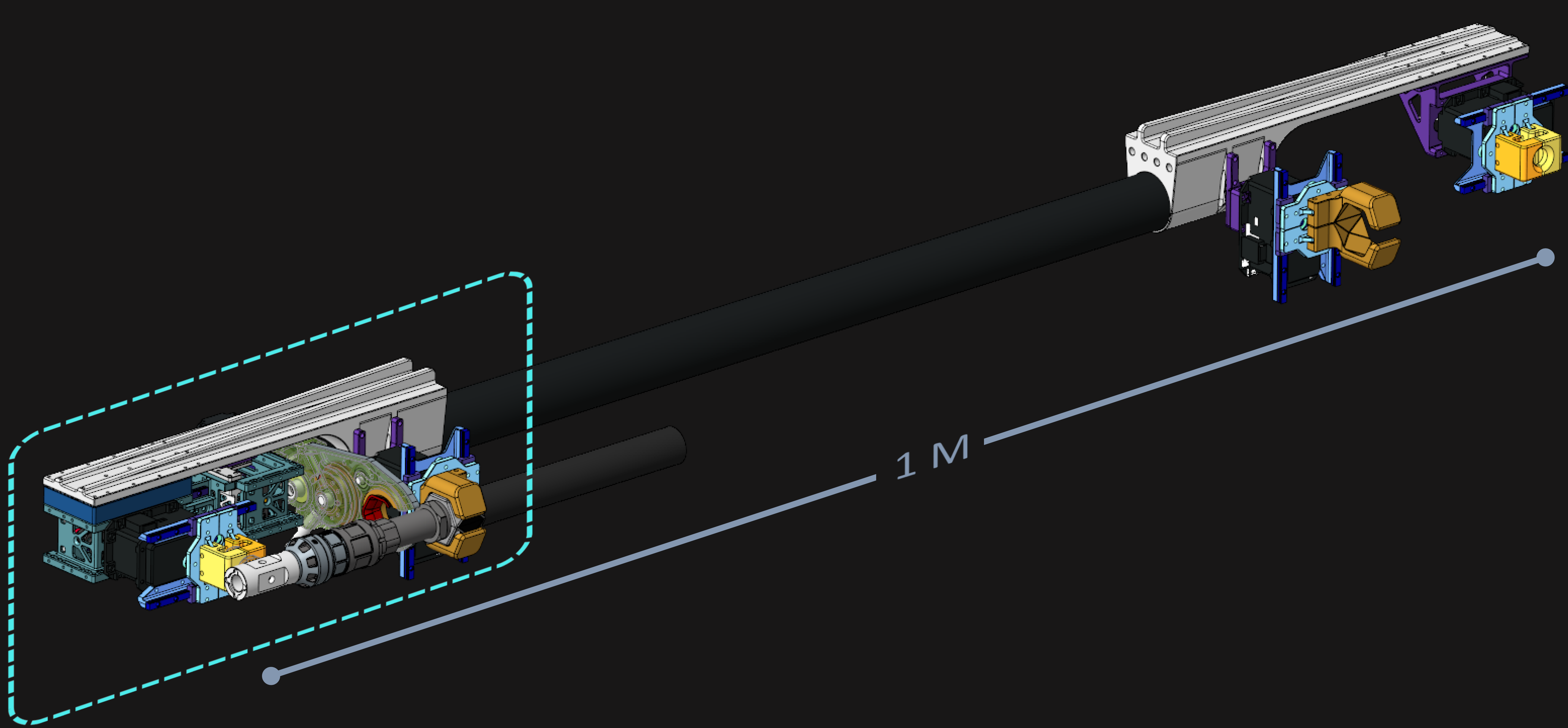
Robotic Building End Effectors

Robotic End Effectors serve as the hands, fingers, and tools of the robotic manipulator to perform complex tasks. Without the appropriate end effector, the manipulator is limited to basic movements and can only execute most basic operations.

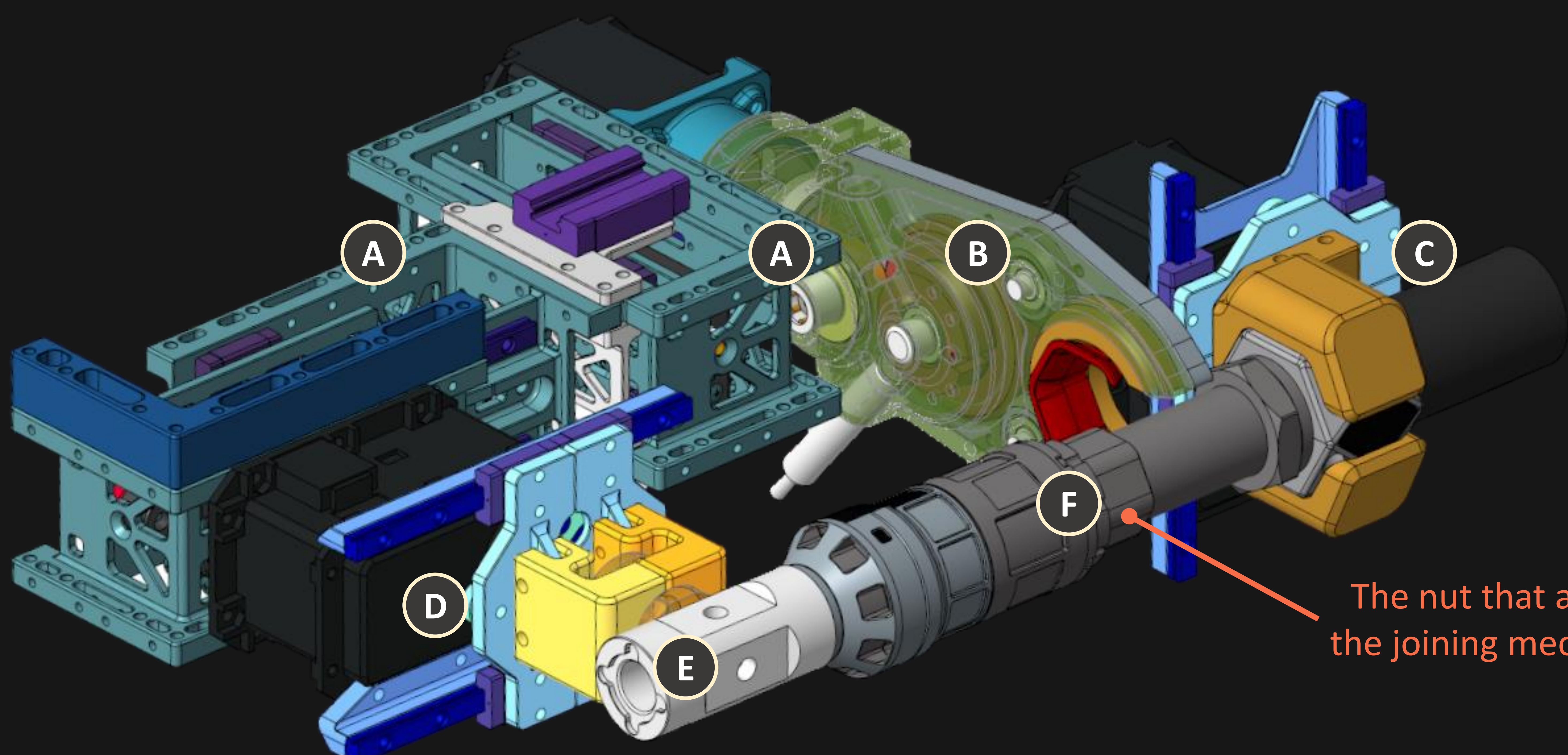
Having proper end effectors are essential for robotic assembly operations. The end effectors, however, can often be more complex than the robotic manipulator, and operated under more operational constraints. Parameters such as manipulator payload capacity, workspace limitation, and assembly complexity can make the design of the effector very challenging.

Over complicated design of the robotic assembly end effectors, and the associate joining system can make the assembly system infeasible for the intended mission. A co-design approach between the end effectors and the joint ensures a simple yet effective assembly system making the robotic assembled structure possible.

Strut Attachment System *Joining End Effector*



Strut Attachment System (SAS) developed by Honeybee Robotics, LLC



A. Linear Stage Module (x2)
B. Nut Runner
C. Strut Gripper
D. Node Gripper
E. Node Receptacle
F. SAS joining Interface

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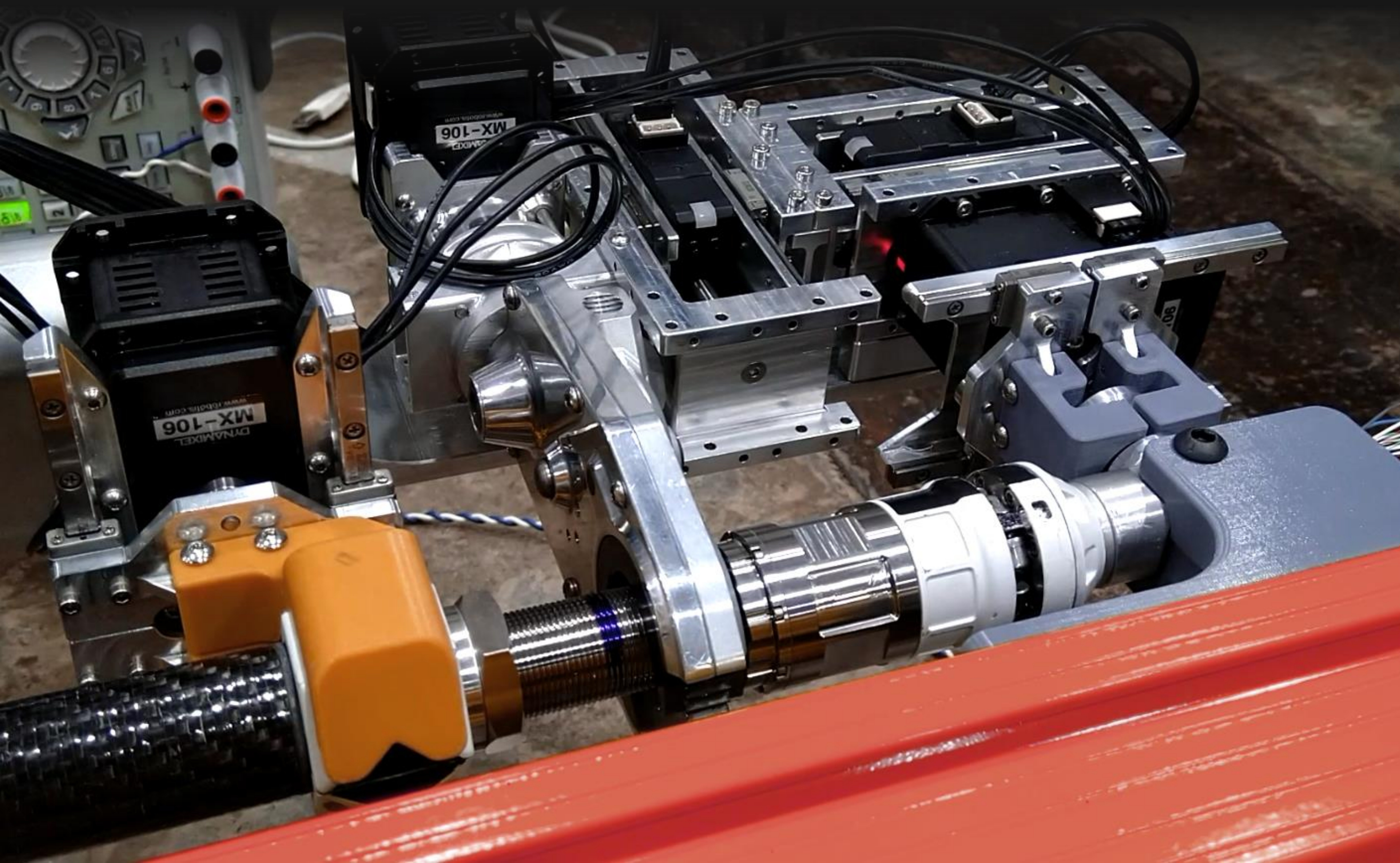
R-BEES

Robotic Building End Effectors

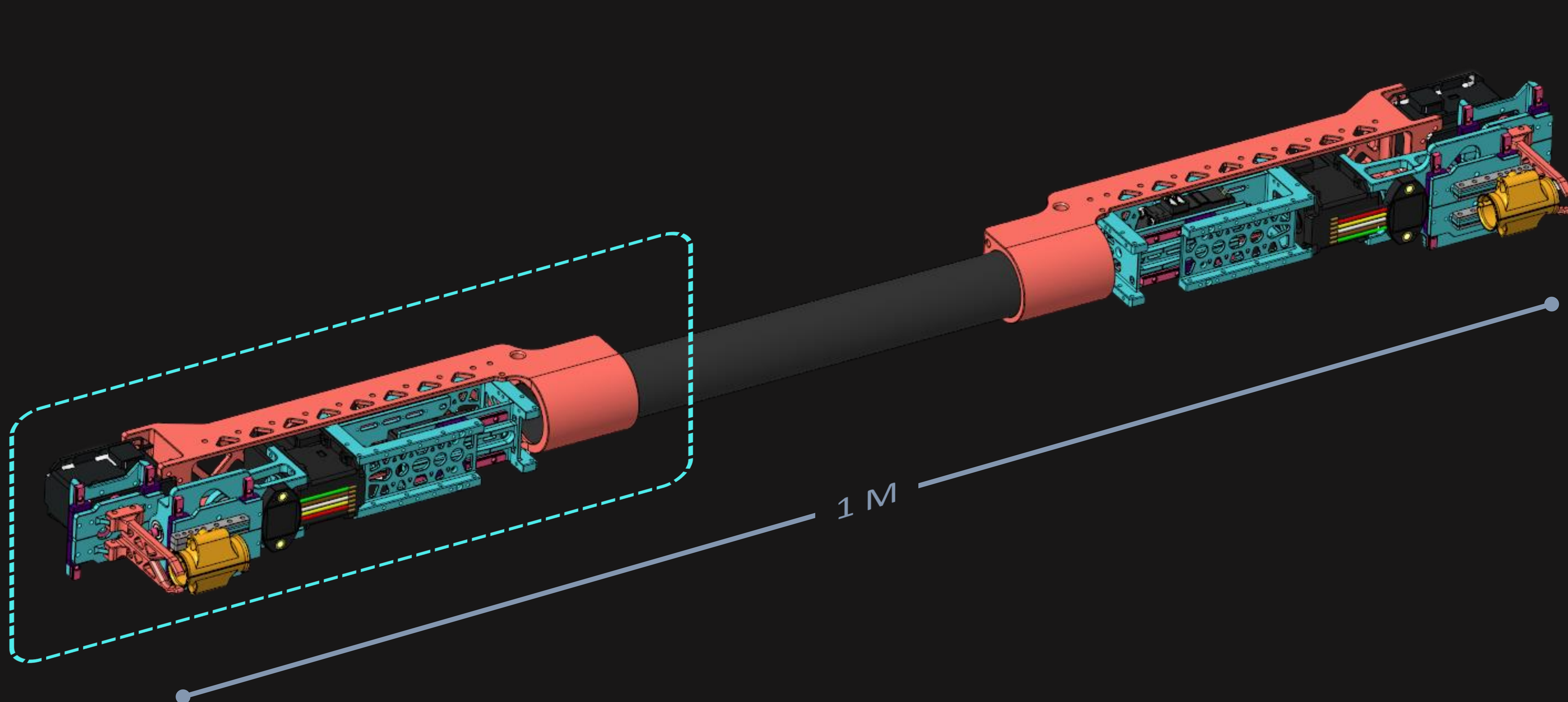
Strut Attachment System *End Effector Test Article*

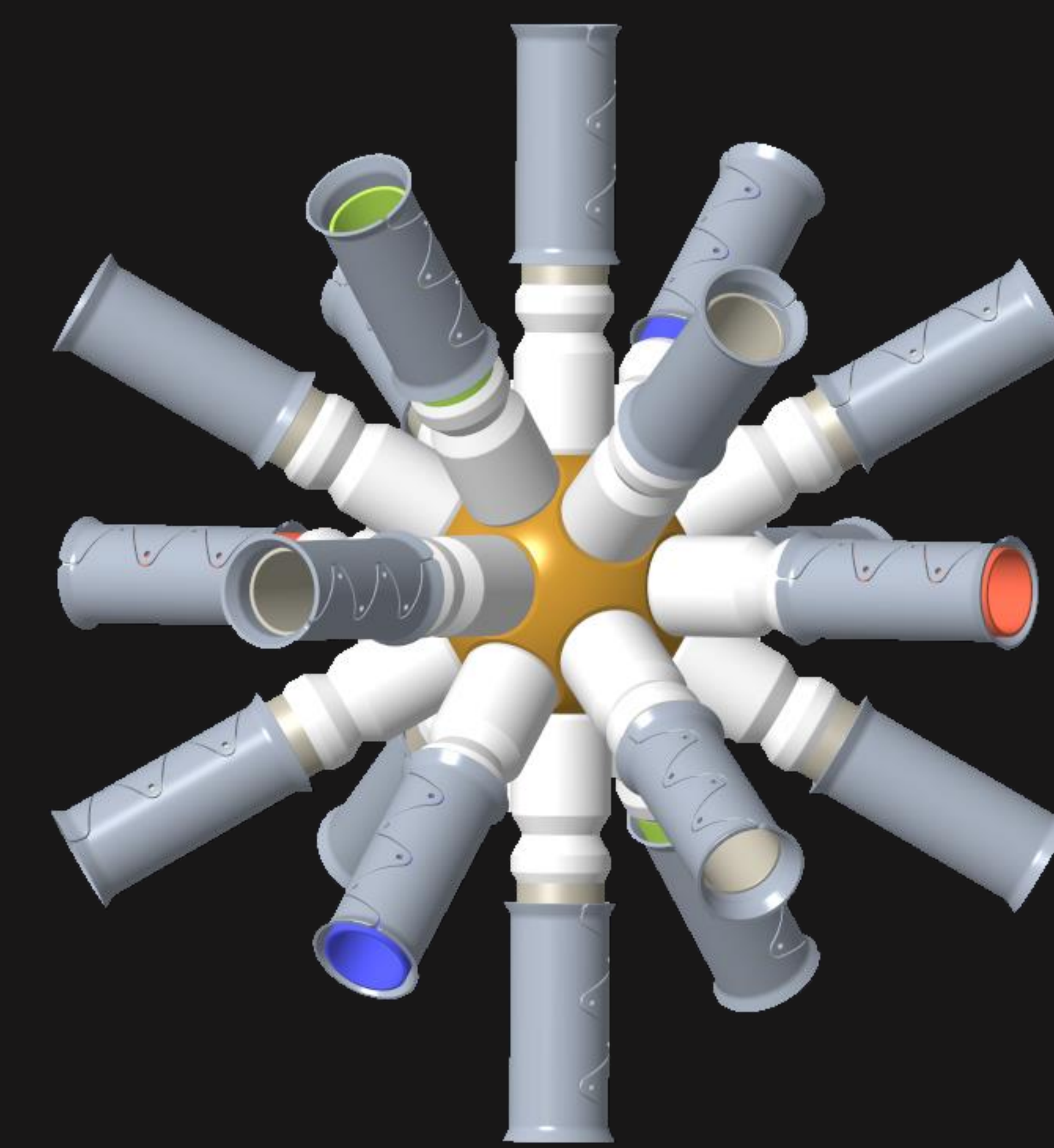


R-BEES

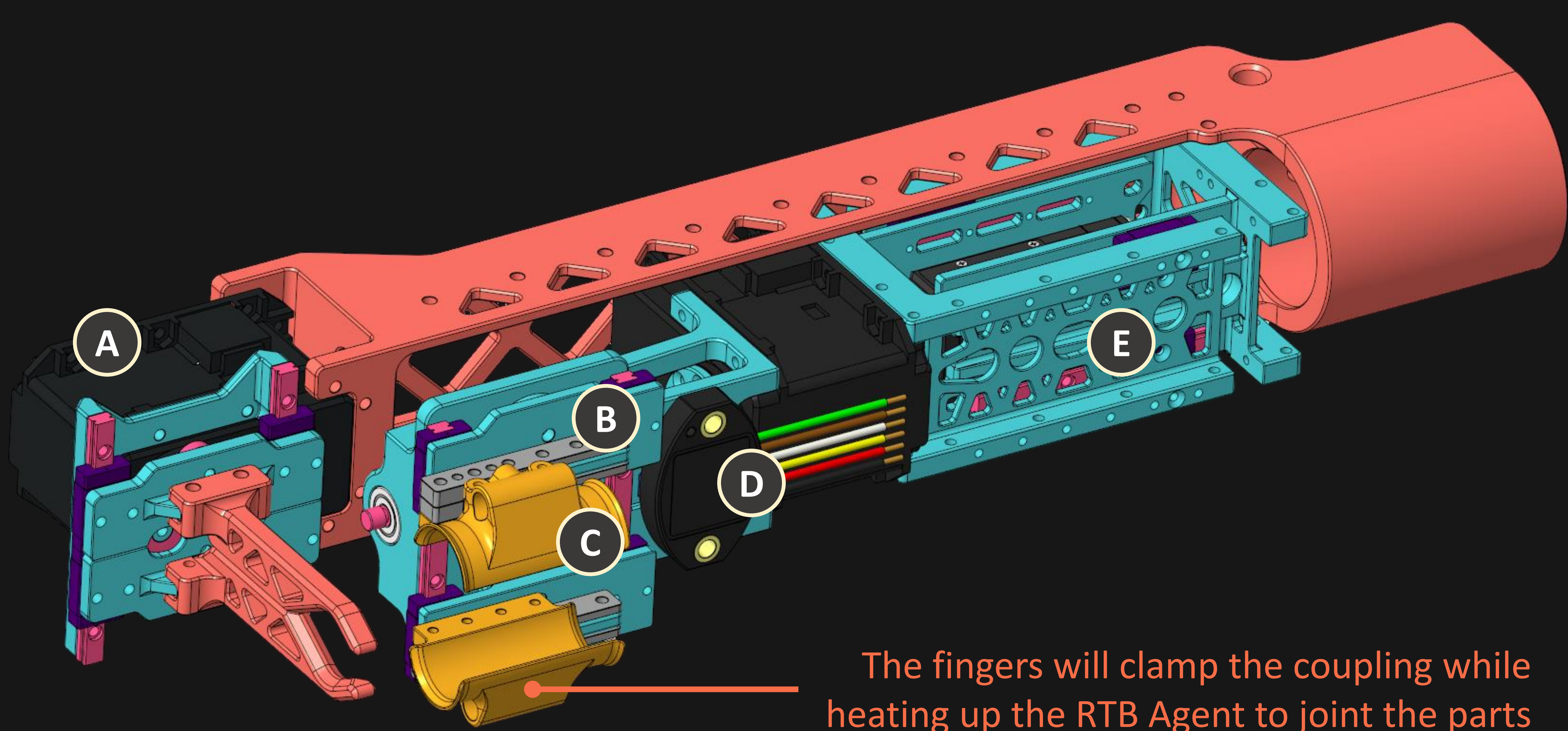
Robotic Building End Effectors

Reversible Thermal Bonding *Joining End Effector*





Joint design to work with Reversible Thermal Bonding (RTB) struts



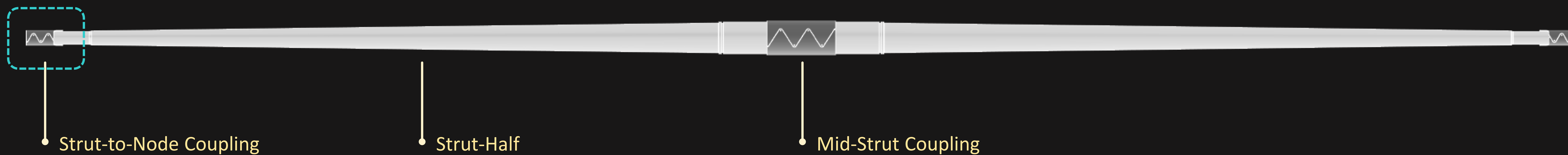
The fingers will clamp the coupling while heating up the RTB Agent to joint the parts

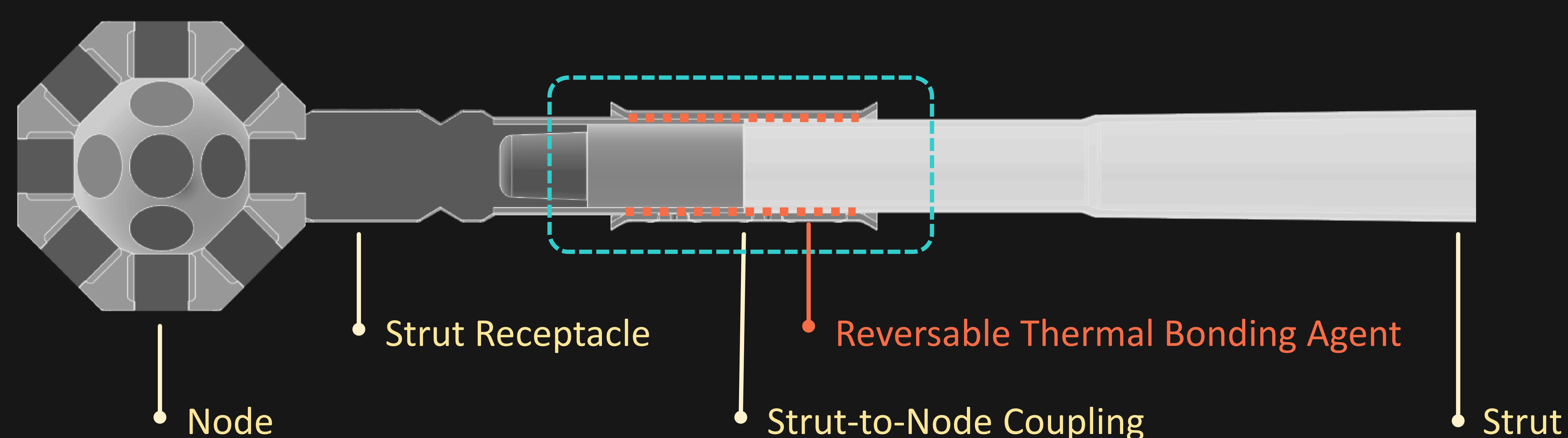
A. Node Gripper
B. Bonding Coupling Gripper
C. RTB Agent Activation Fingers
D. Actuation Sensor
E. Linear Stage Module

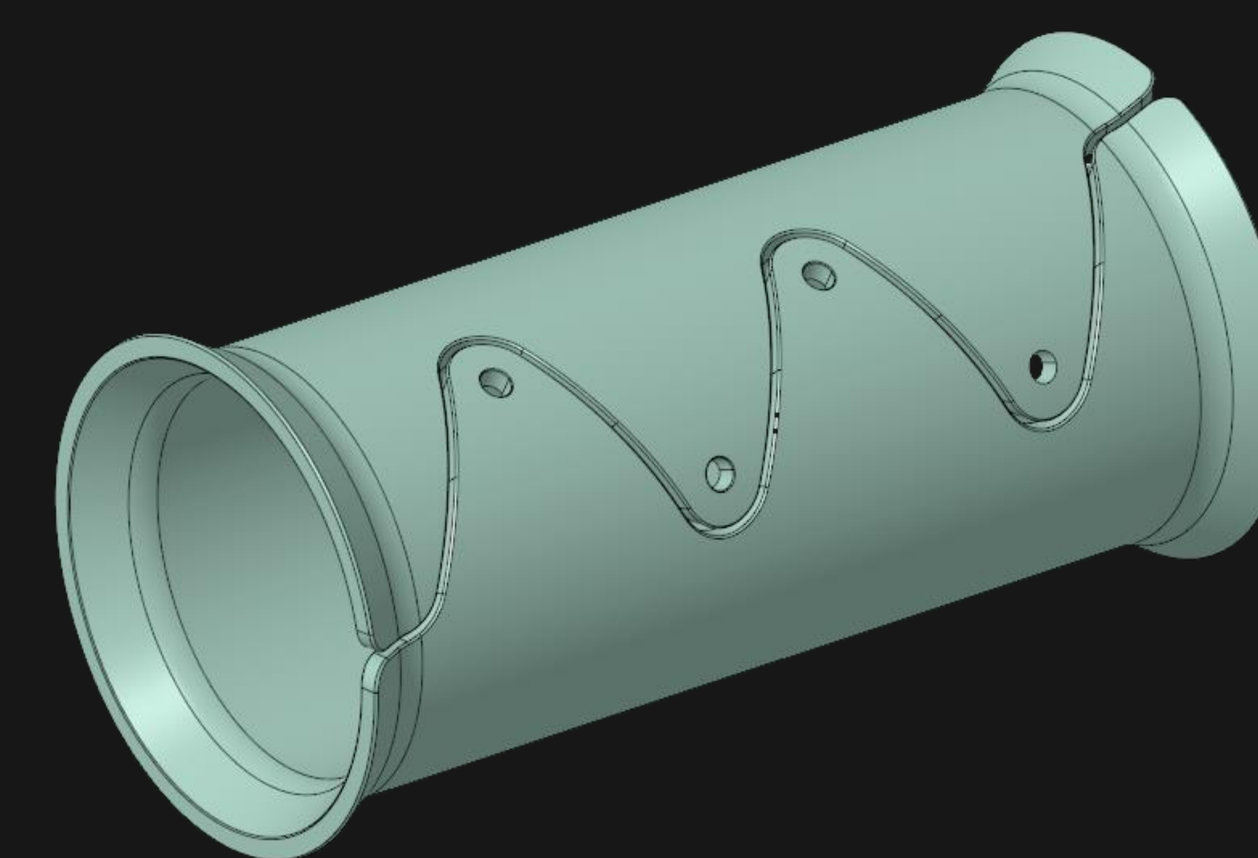
R-BEES

Robotic Building End Effectors

Reversible Thermal Bonding *Joining Coupling Design*

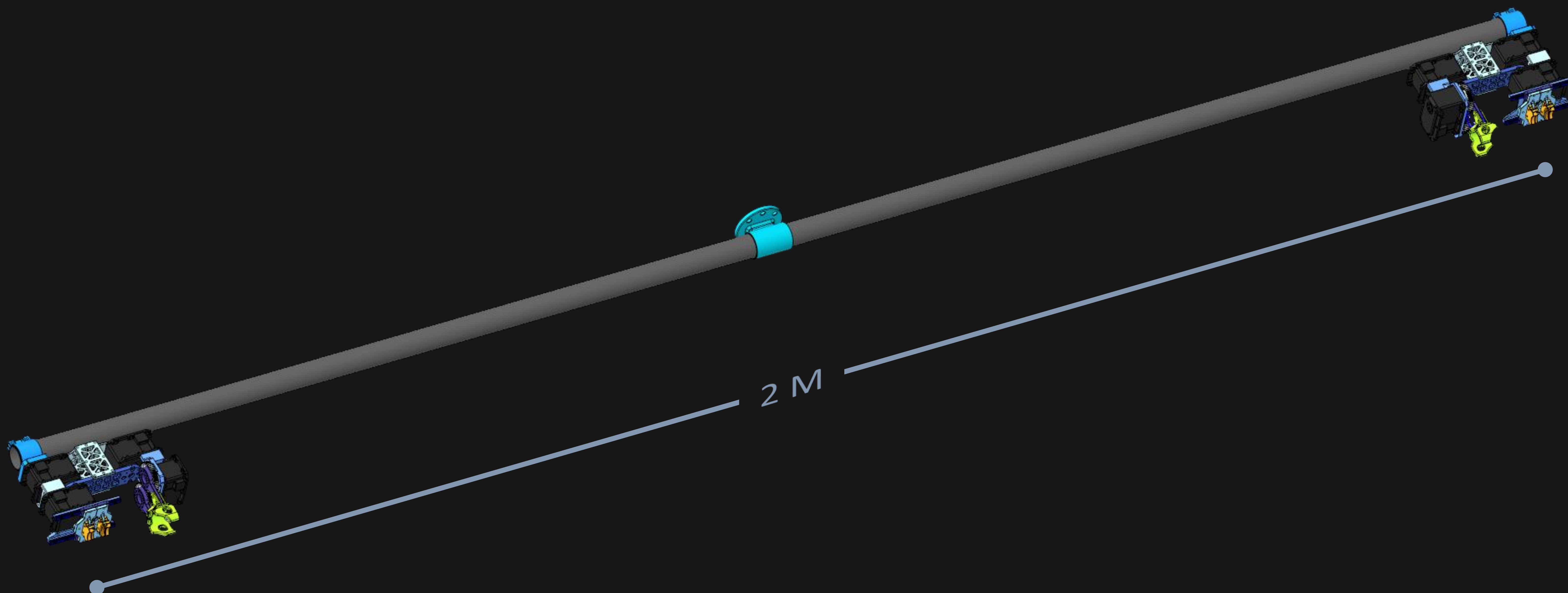


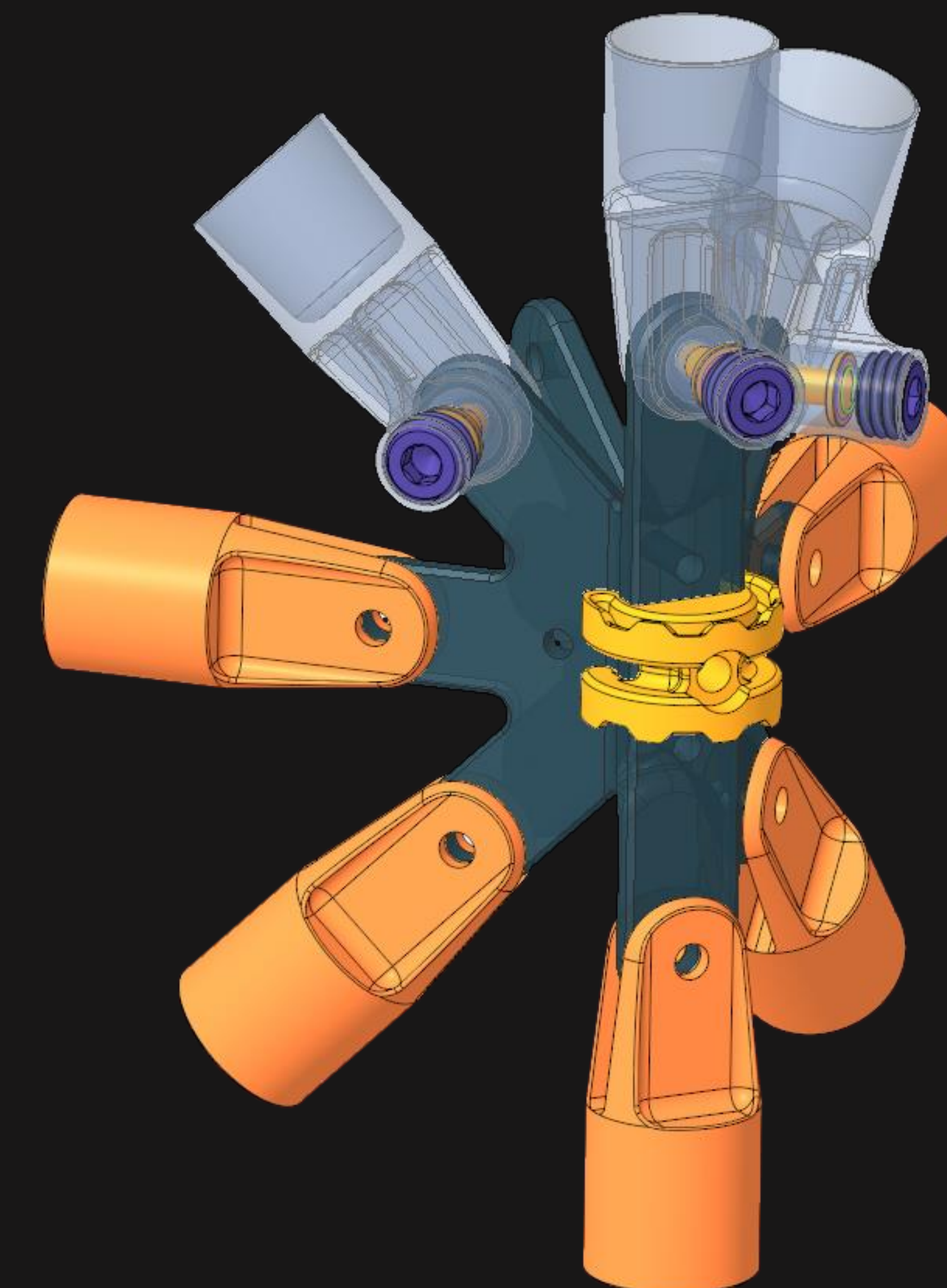




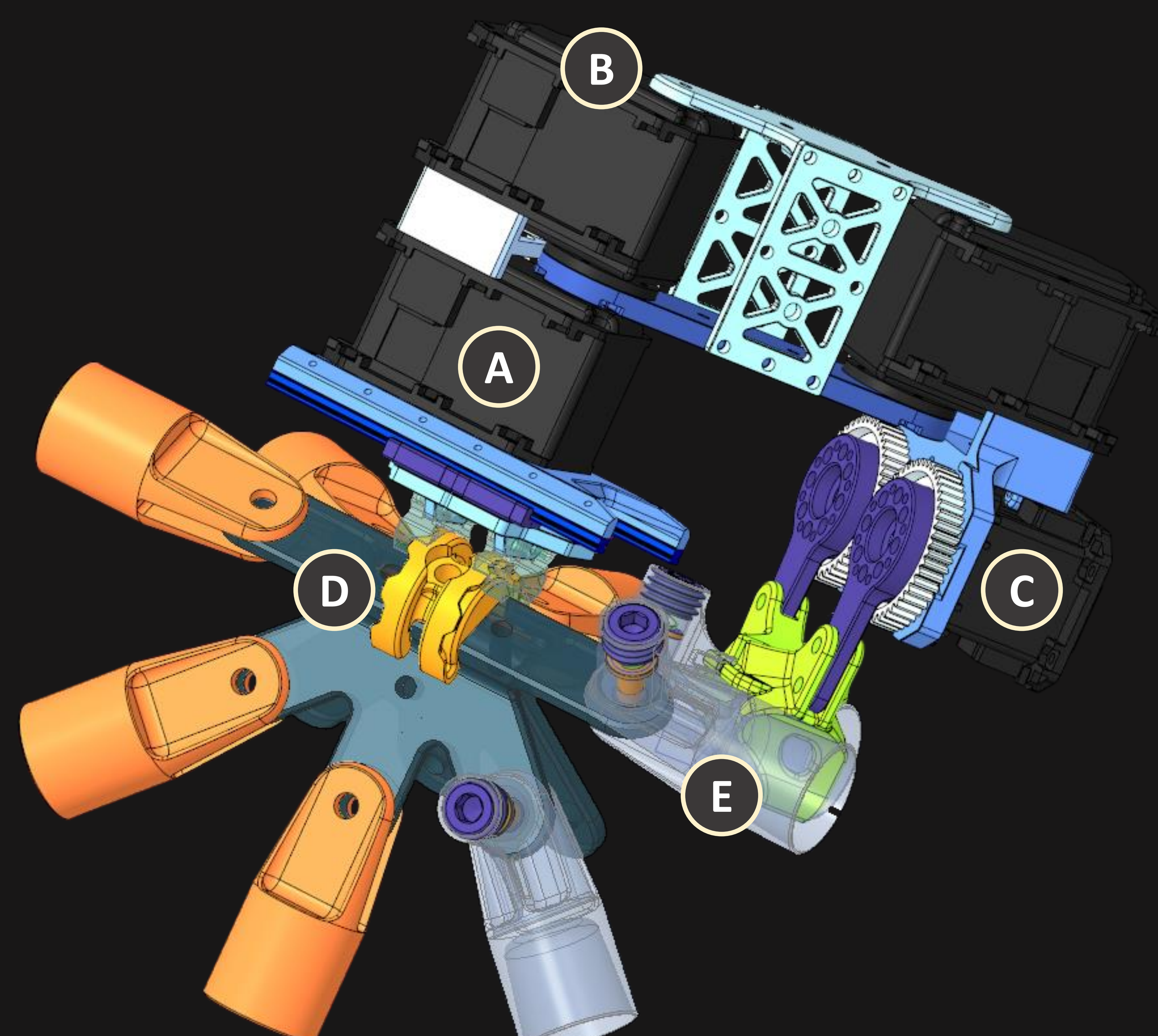
The Reversible Thermal Bonding (RTB) process involves three components with surface coated with the RTB agent, the strut end, the strut receptacle, and the joining coupling. When the strut end is aligned with the strut receptacle, the joining coupling will slide into position, covering the two components. Specific heat and pressure are then applied to activate the RTB agent, which bonds with all the parts and forms the connection. The described process can be reversed to separate the connection.

Multi-angle Side-insertion Strut Joint *Joining End Effector*





Joint with Multi-angle gripping fixture for struts to be installed from different angles

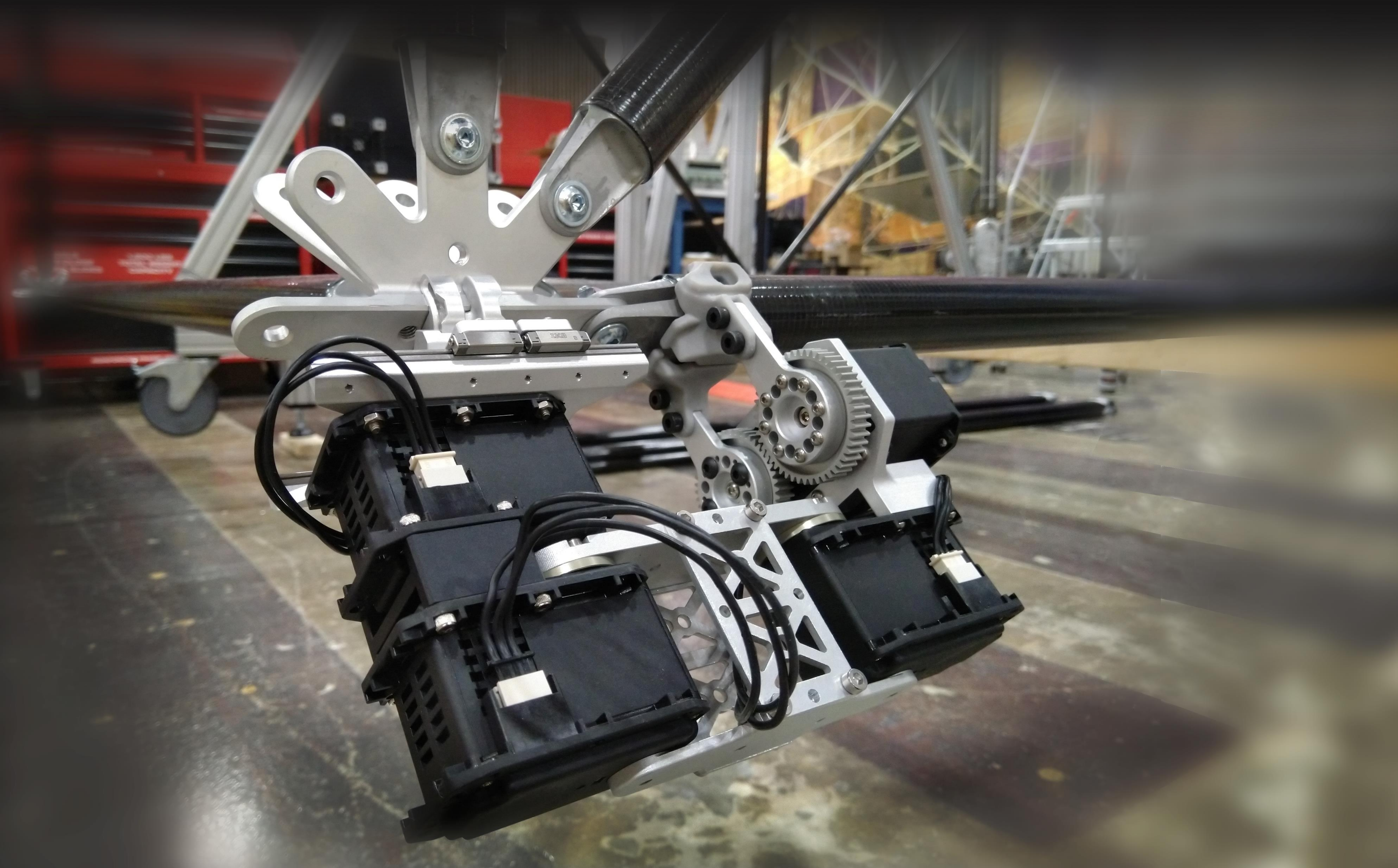


A. Node Gripper
B. Angle-Adjust Link
C. Strut Gripper
D. Multi-angle gripping fixture
E. Self-Locking Strut End

R-BEES

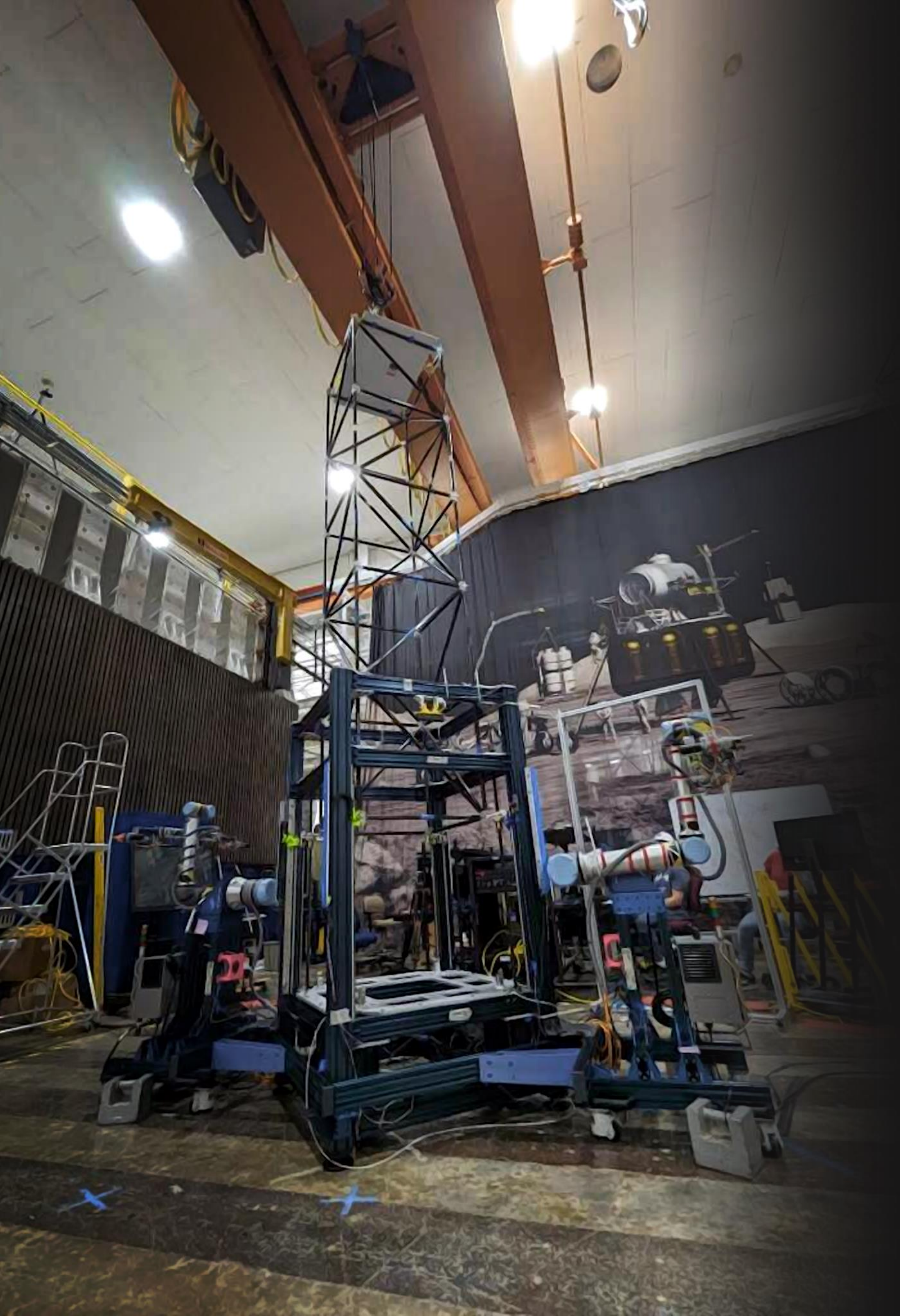
Robotic Building End Effectors

Multi-angle Side-insertion Joint Strut *End Effector Prototype*



R-BEES

Robotic Building End Effectors



TLT

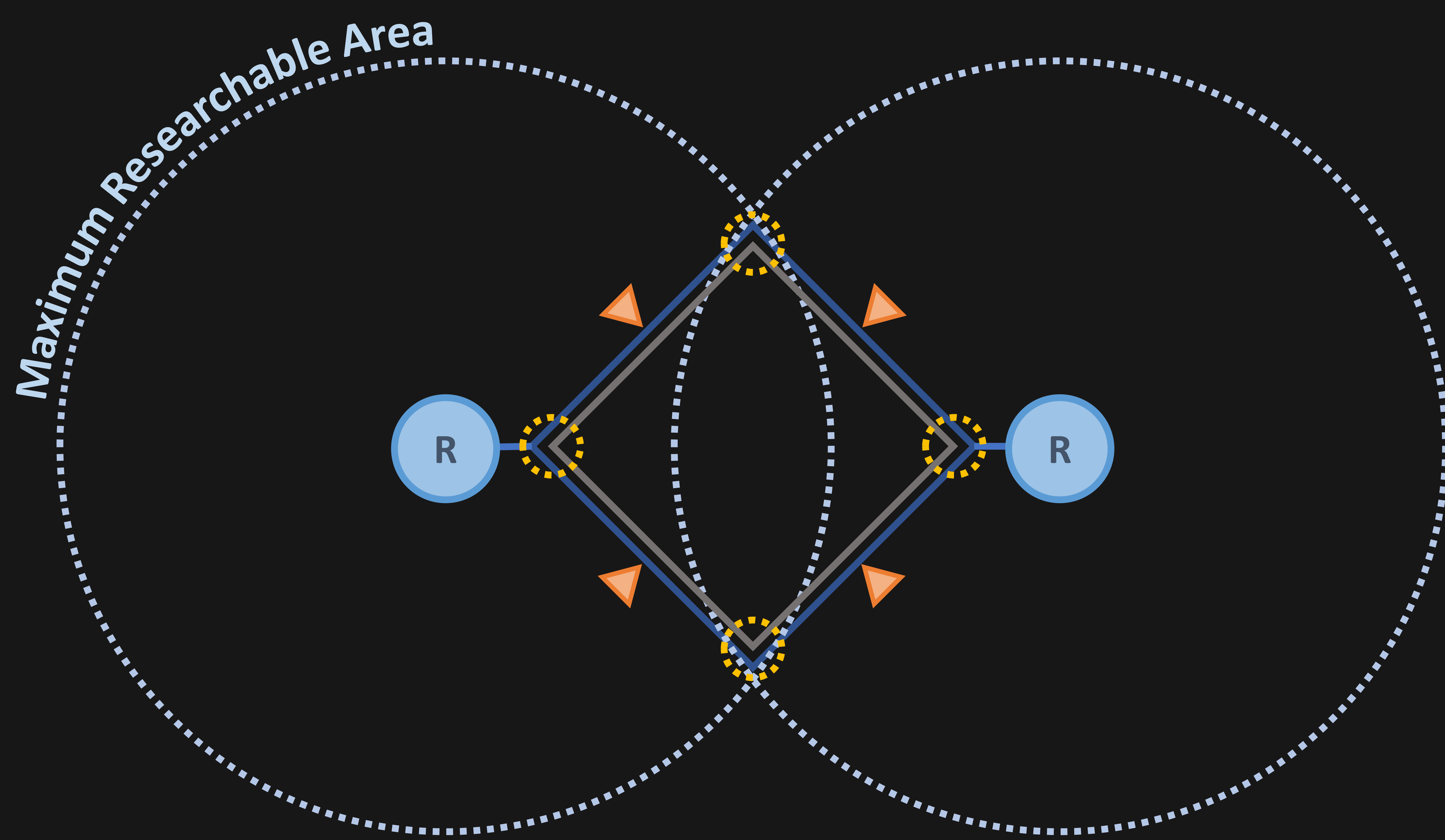
Tall Lunar Tower

The Tall Lunar Tower (TLT) project aims to investigate technologies needed to build 50+ m towers on the lunar south pole area. The additional elevation allows the solar power generation systems to be landed on a wider range of locations with minimum effective-lunar-night, the period when sunlight is not available at the given location.

A robotic construction system was developed to build the truss structure, incrementally adding one truss bay at a time as the tower rises from the base until completion. Truss components are joined together inside the assembly area, then lifted to make room for the subsequent truss bay. Optionally, additional payloads or utilities can be attached to the completed truss segment at the outfitting area above the truss assembly area.

Two mobile stations with telescopic pedestal-mounted robotic arms were used to operate the truss assembly end effectors integrated with joining tools. Once the tower is completed, the mobile robotic arm station can then be removed from the robotic construction system and be redeployed for building another tower or other structures.

Tall Lunar Tower *Robotic Construction System – Mk-ZERO*



Top View Diagram

A. Truss Lifting Drive (x2)

B. Robotic Arm (x2)

C. Telescopic Robotic Pedestals (x2)

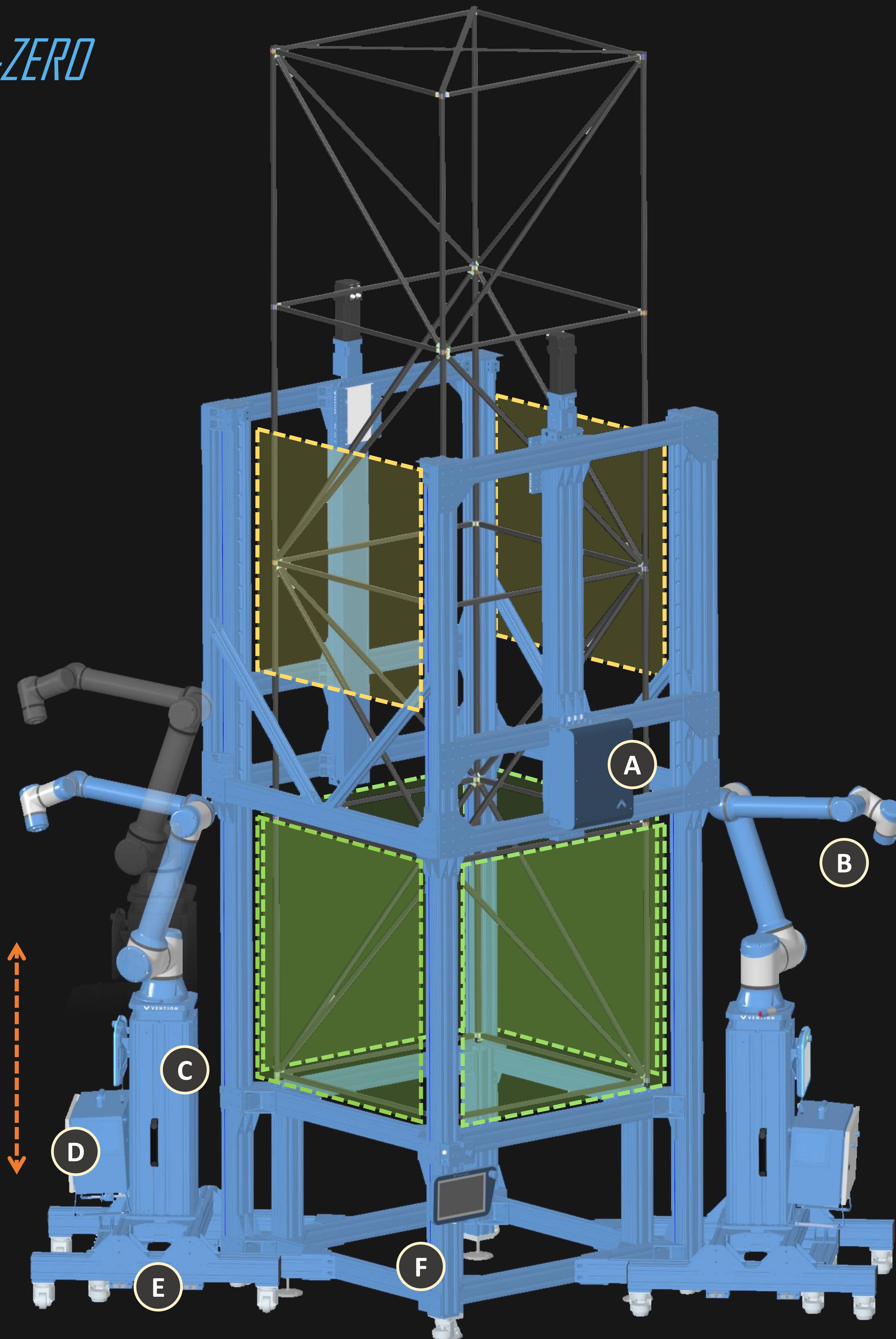
D. Robotic Arm Controller (x2)

E. Robotic Arm Mobile Stand (x2)

F. Jigging Frame

Truss Outfitting Area

Truss Assembly Area



TLT

Tall Lunar Tower

Tall Lunar Tower *Robotic Construction System Mk-One*

A. Stationary Grippers (x4)

B. Vision Cameras (x2)

C. Foundation Footings (x4)

D. Lead Screw Bearings +
Manual Drive Interface (x4)

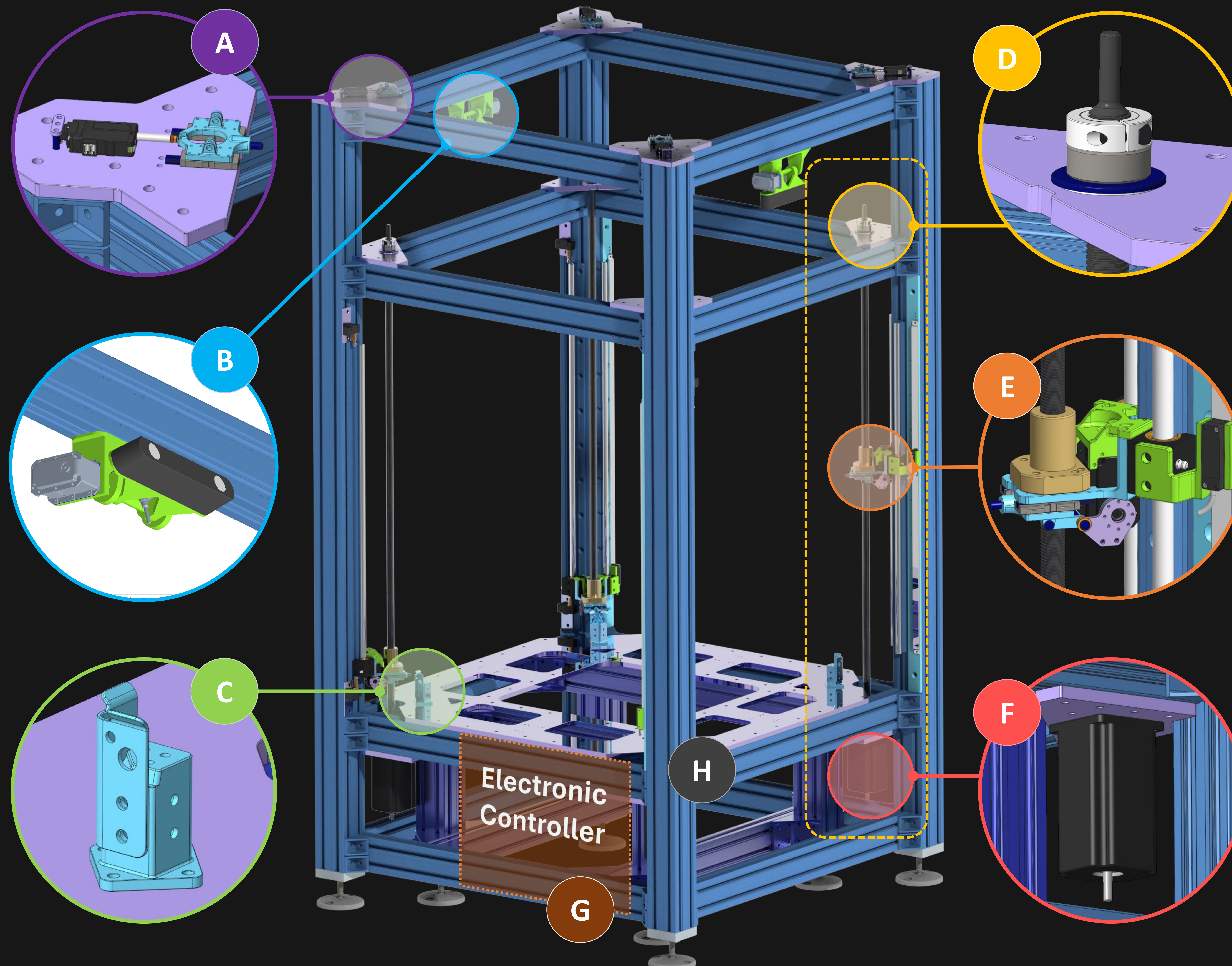
E. Mobile Grippers (x4)

F. Lead Screw Motor (x4)

G. Electronic Controller

H. Jigging Frame

Truss Lifting Unit



TLT
Tall Lunar Tower

SSS-Joint

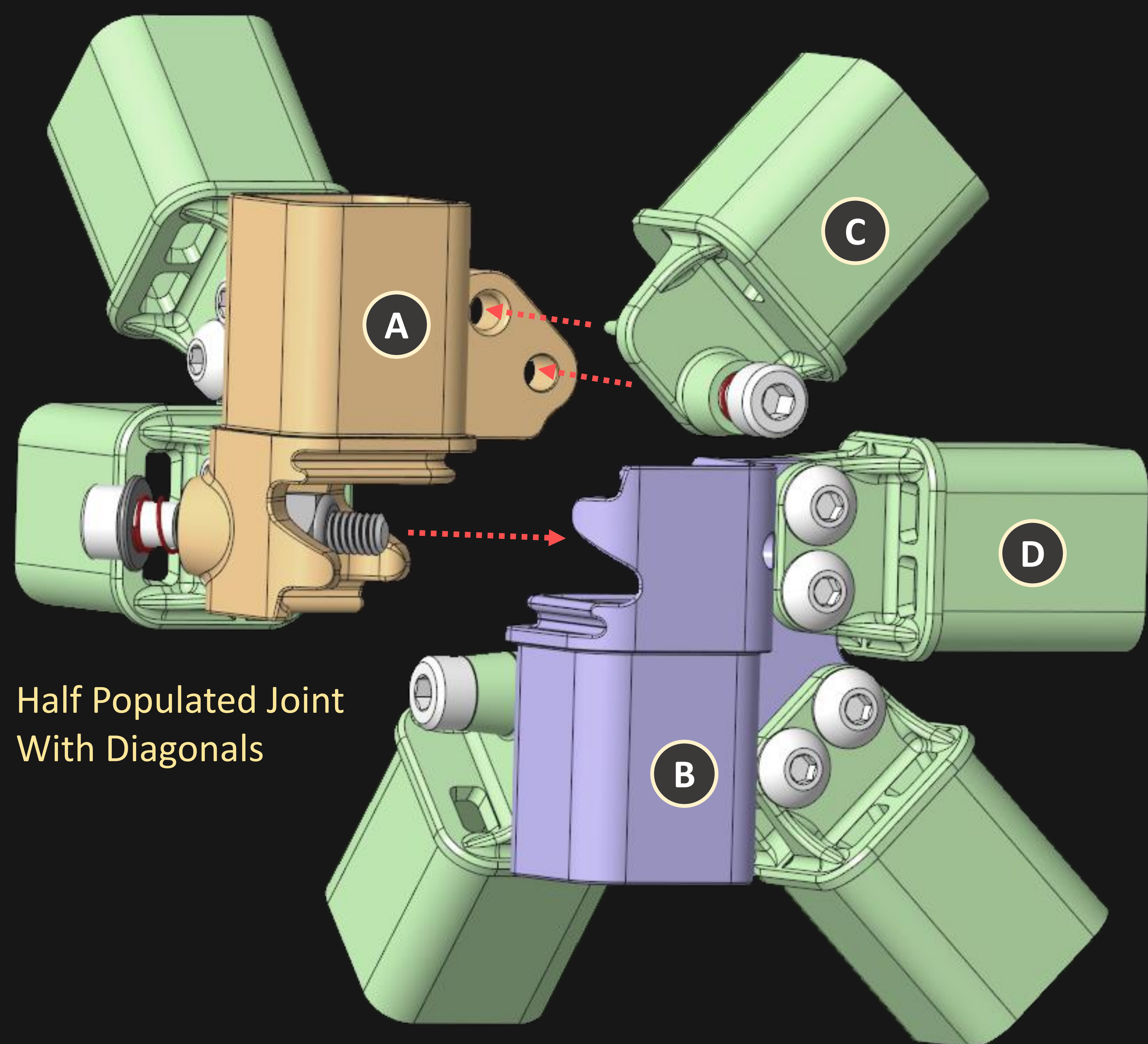
Single-action-lock Structural Space Joint

The Single-action-lock Structural Space Joint (SSS-Joint) was developed to support the Tall Lunar Tower (TLT) project, serving as the joining system for the 50 m truss test article. The SSS-joint variants are well mass optimized with subtractive form gripping features that facilitate easy and secure handling. The SSS-joint's joining interface is designed to deliver exceptional structural performance, and only require a torque-limiting screwdriver to assemble

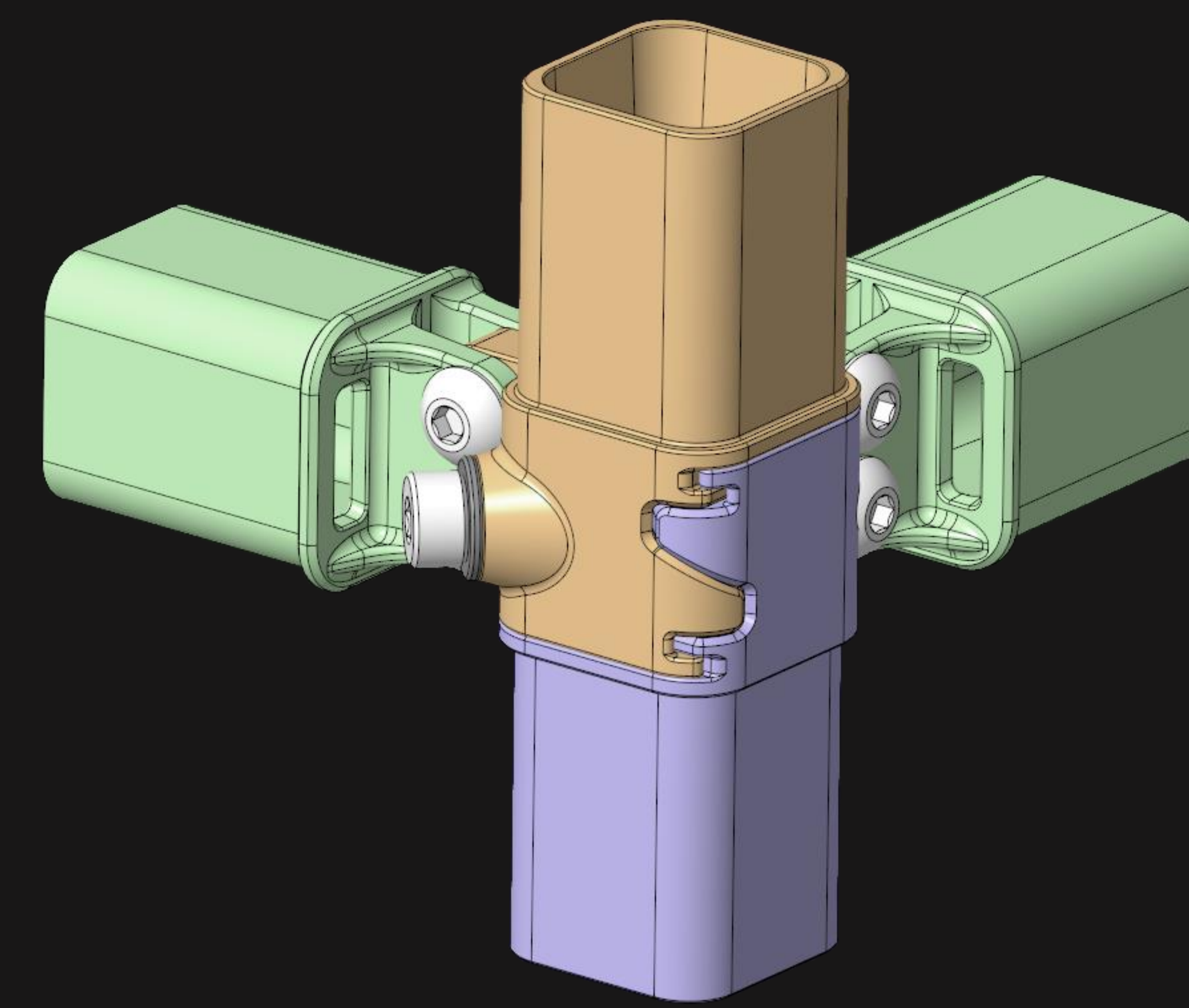
The SSS-joint joining interface has interlocking features, which double as self-alignment guides, ensuring simple yet effective robotic assembly. The different variants of the SSS-joint help provide joining interfaces needed for a wide range of joining locations, where the truss will be connected to other systems.

The unique half-node design found on the SSS-joint also enables diverse truss tessellation options, some of which significantly can enhance truss assembly efficiency by reducing the part counts and steps needed to build the truss on-site.

SSS-Joint *Key Components and Variants*

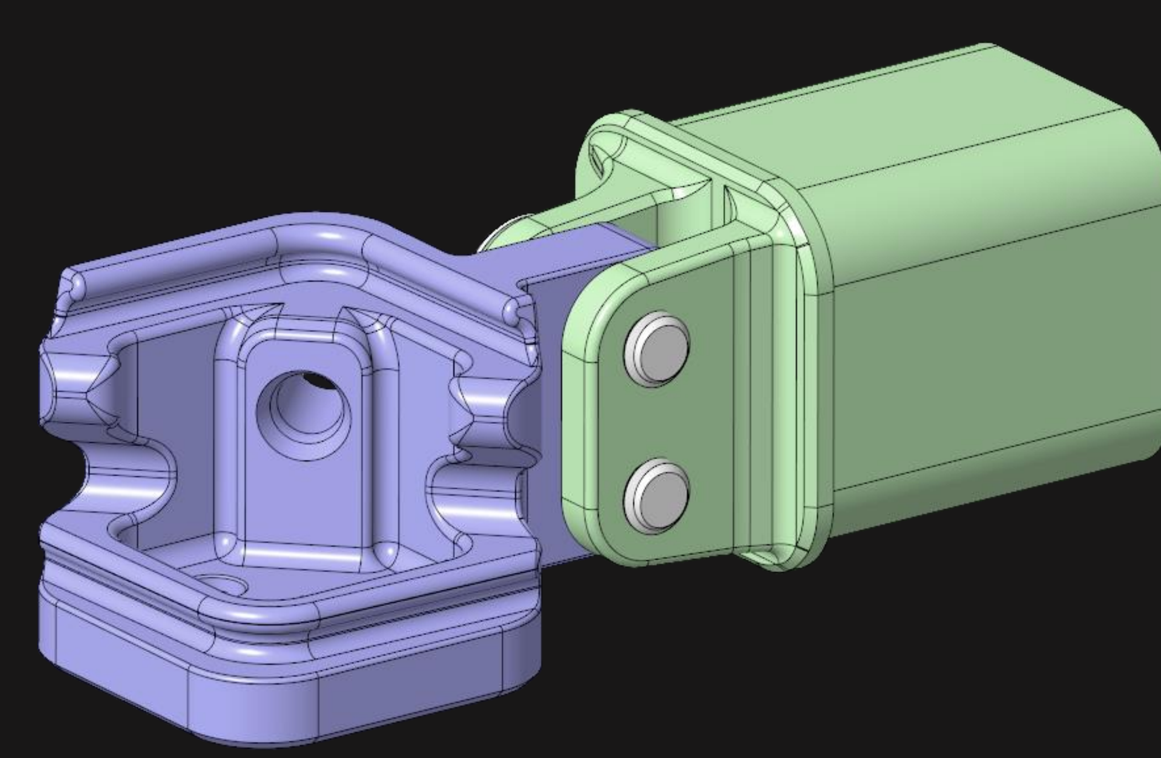


Half Populated Joint
With Diagonals

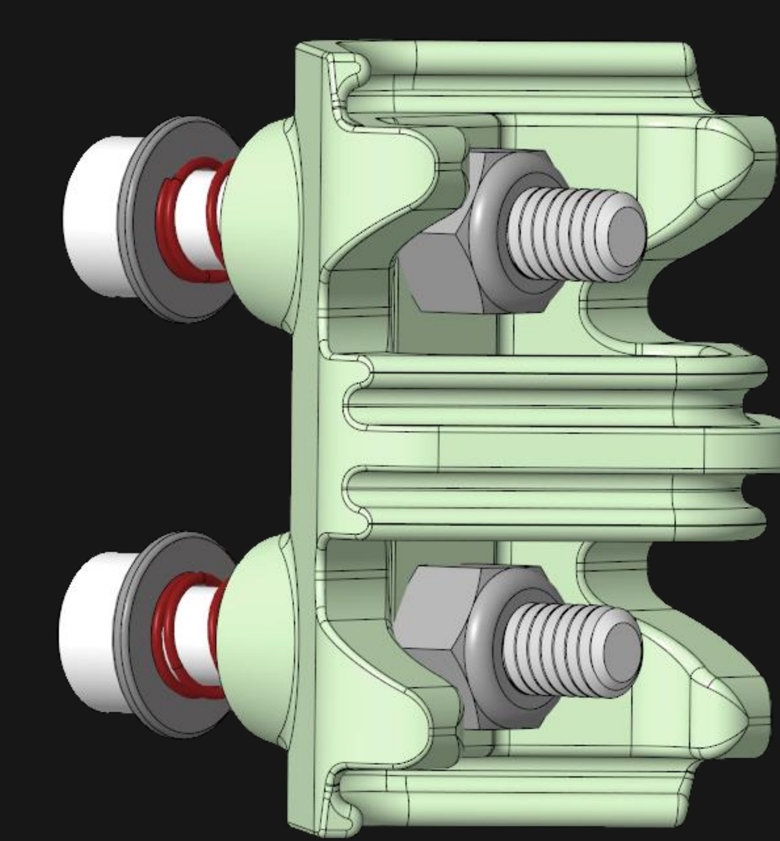


Half Populated Joint without Diagonals

A. Half-Node with Spring-loaded Captive Screw
B. Half-Node with Locknut Thread
C. Single Strut Attachment Strut End (x2)
D. Pre-attached Strut End (x4)



Half-Node for Truss Ends

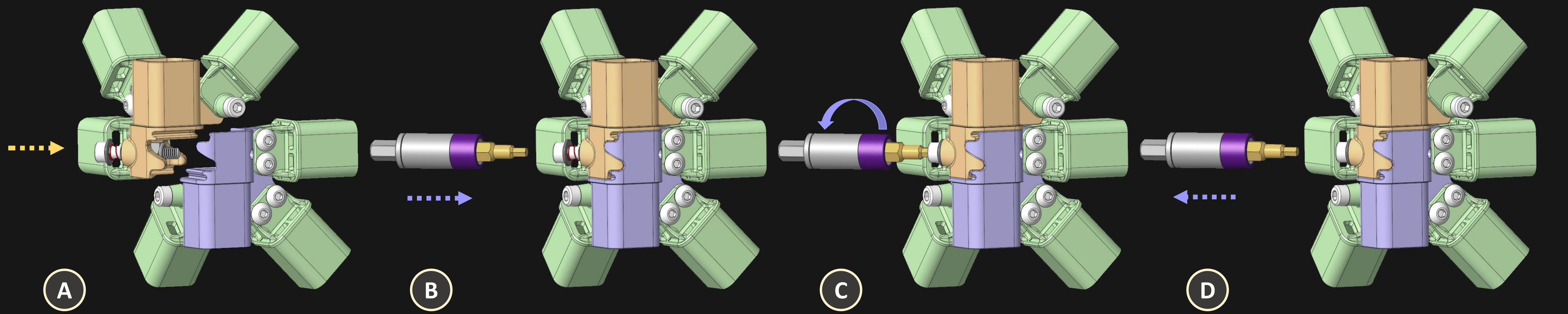


Half-Node with Double Joining Interfaces

SSS-Joint

Single-action-lock Structural Space Joint

SSS-Joint *Joining Process and Connection Load Paths*

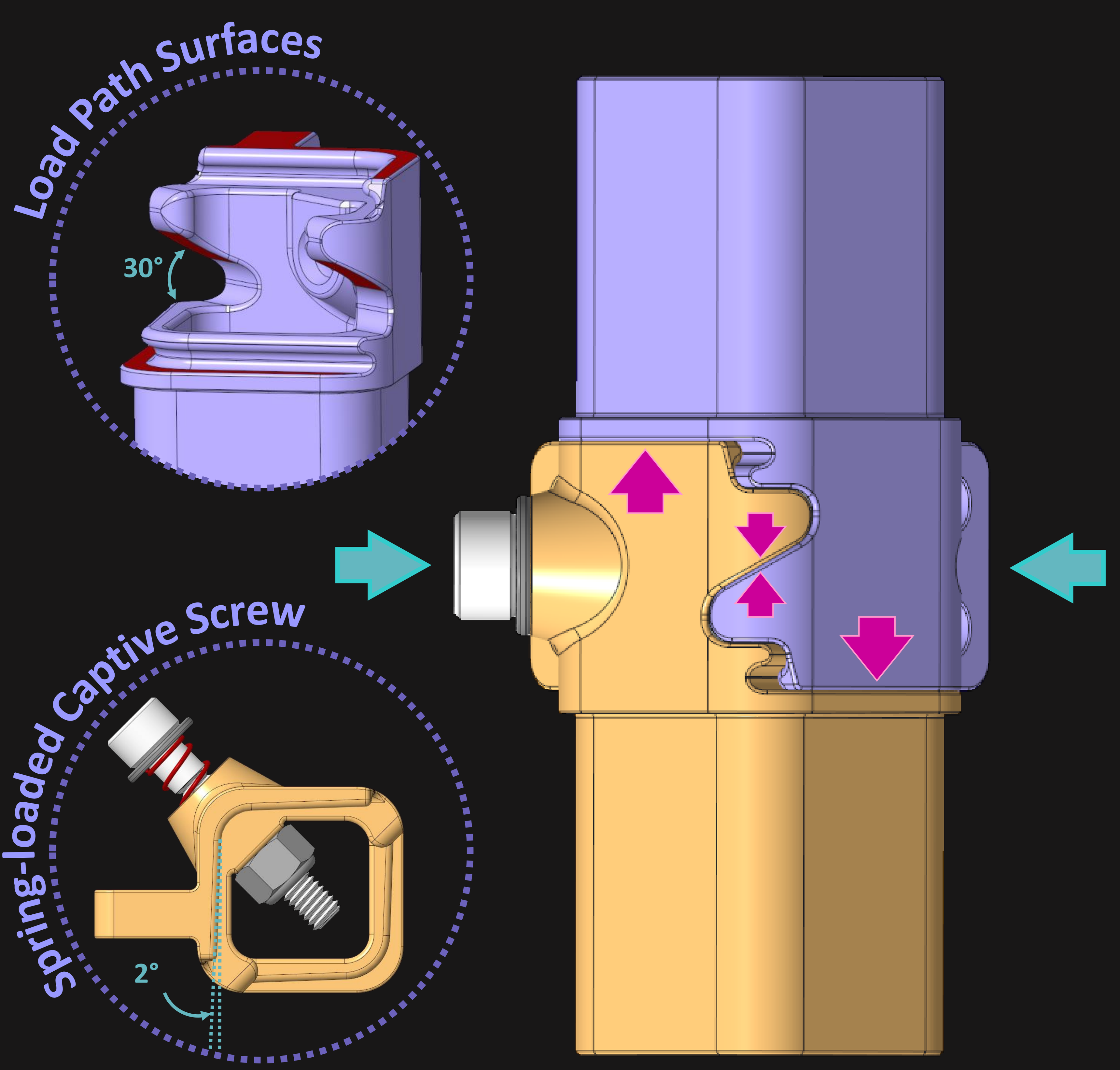


A. The joint-halves will align and be pushed together at the pre-lock position.

B. The torque limited screwdriver will then engage with the locking bolt.

C. The torque limited screwdriver will catch the socket of the locking bolt within one rotation and continue driving the bolt until the driving torque limit.

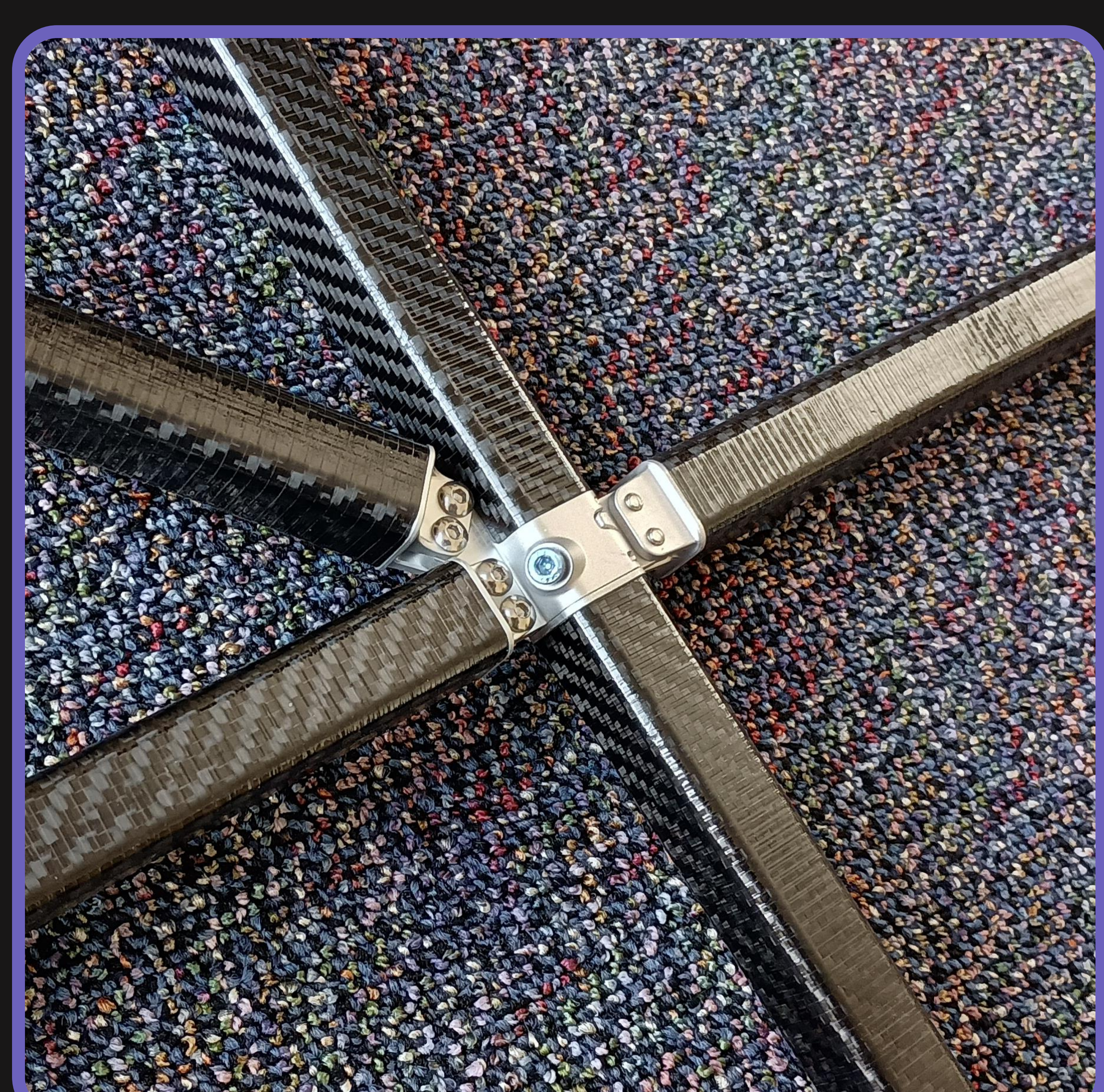
D. The torque limited screwdriver will disengage with the locking bolt as the joining procedure is completed.



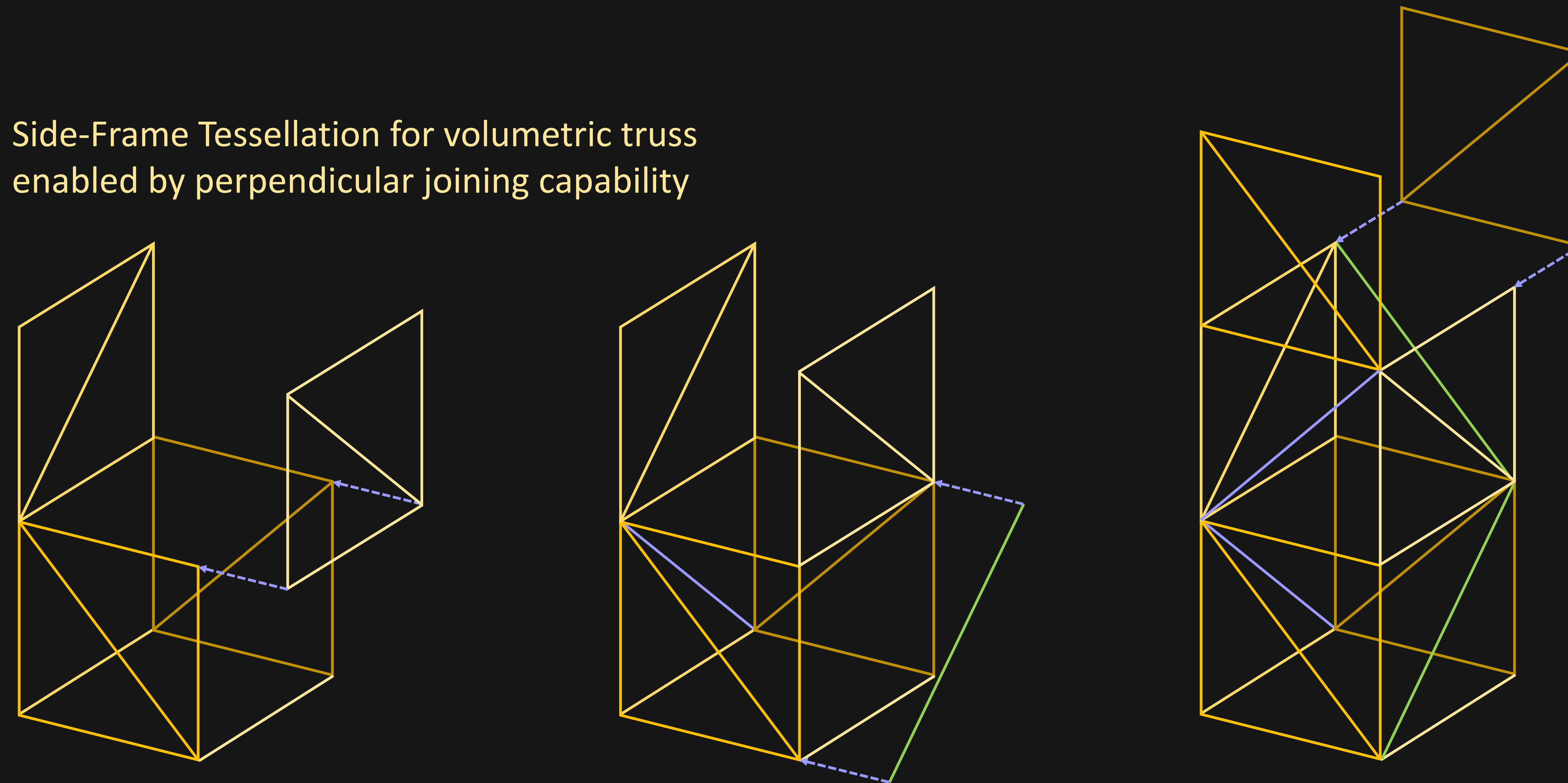
SSS-Joint

Single-action-lock Structural Space Joint

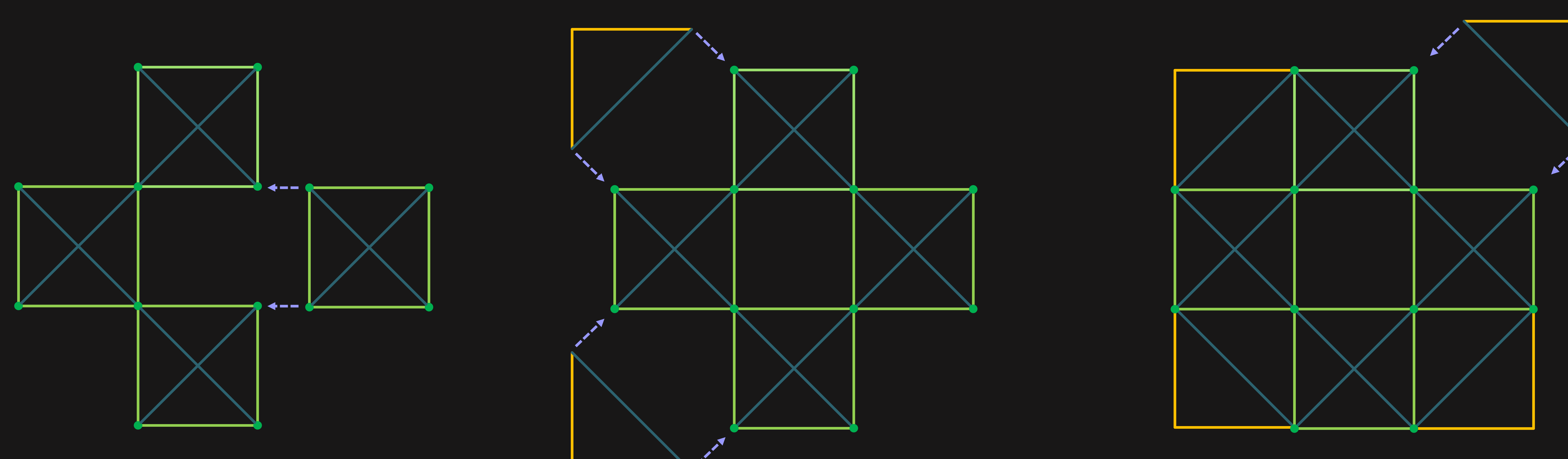
SSS-Joint *Truss Tessellation*



Side-Frame Tessellation for volumetric truss
enabled by perpendicular joining capability



Flat-Frame Tessellation for planer truss
enabled by parallel joining capability



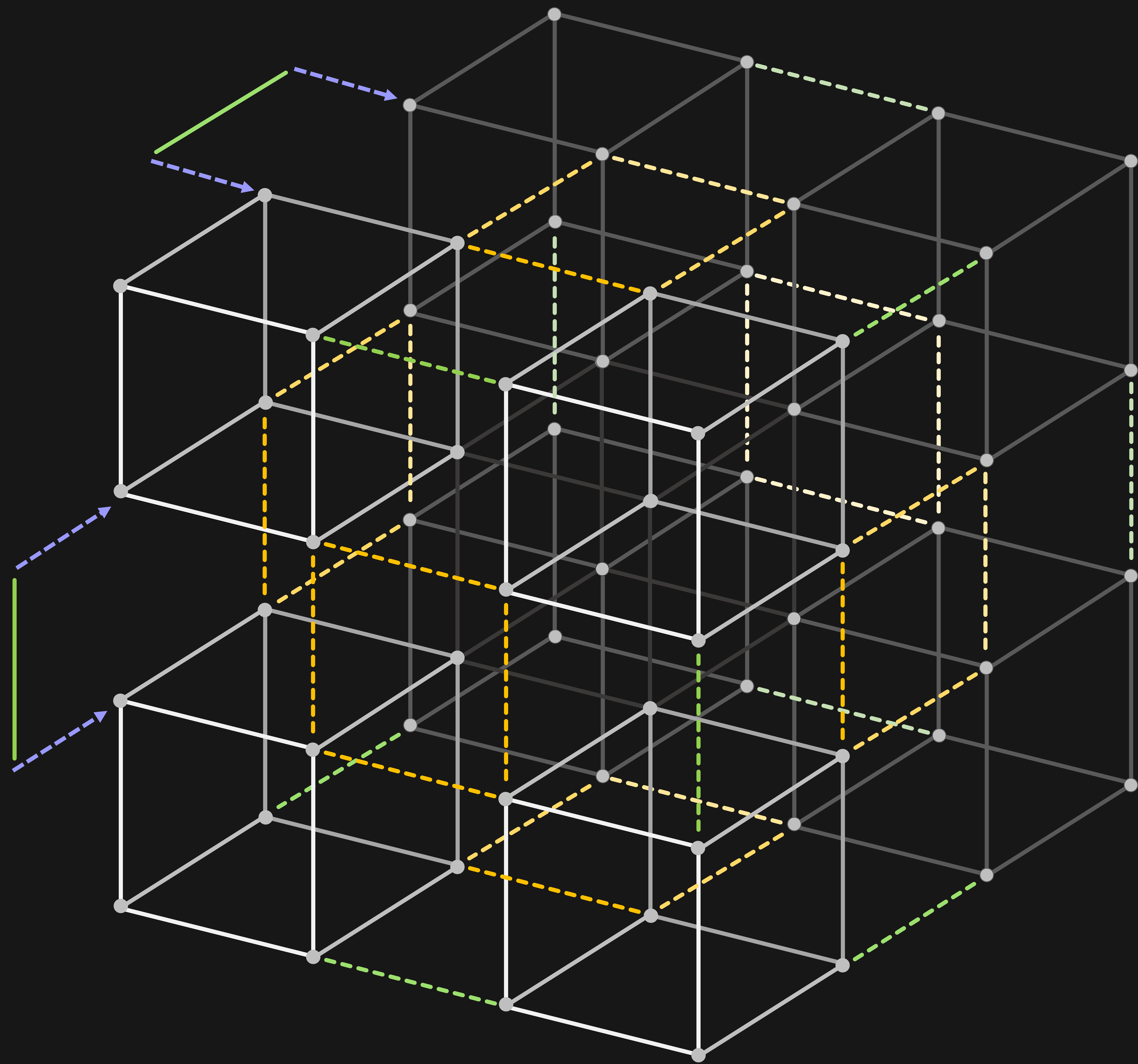
SSS-Joint

Single-action-lock Structural Space Joint

SSS-Joint *Truss Tessellation*

The SSS-Joint joining interface enables multi-layer complex truss structures to be tessellated into 1D, 2D, or even 3D self-stable sub-truss modules. Every sub-truss level component is completed with no loose corners. The SSS-joint enables tessellation that maximizes structure stability during assembly, while minimizing the complexity of the assembly process.

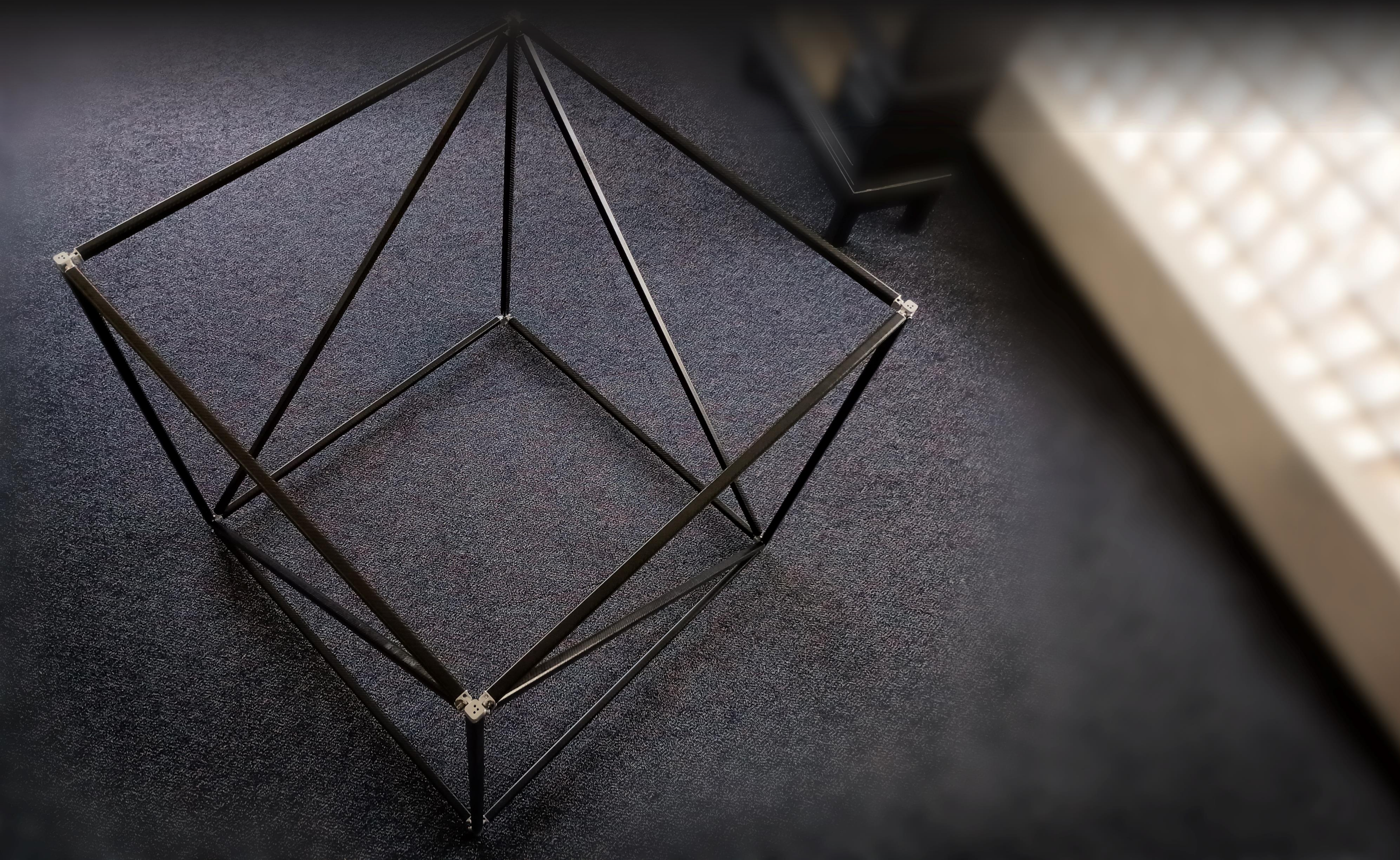
A multi-layer orthogonal truss, for example, can be broken down into smaller Cubic Trusses, Side-Frame Trusses, and Single Struts. Such complex structures can be utilized for applications such as Multidirectional Phased Array Radar Antennas, and other advanced uses.



SSS-Joint

Single-action-lock Structural Space Joint

SSS-Joint *Test Article - One m Cube*



SSS-Joint

Single-action-lock Structural Space Joint

LSMS - L35

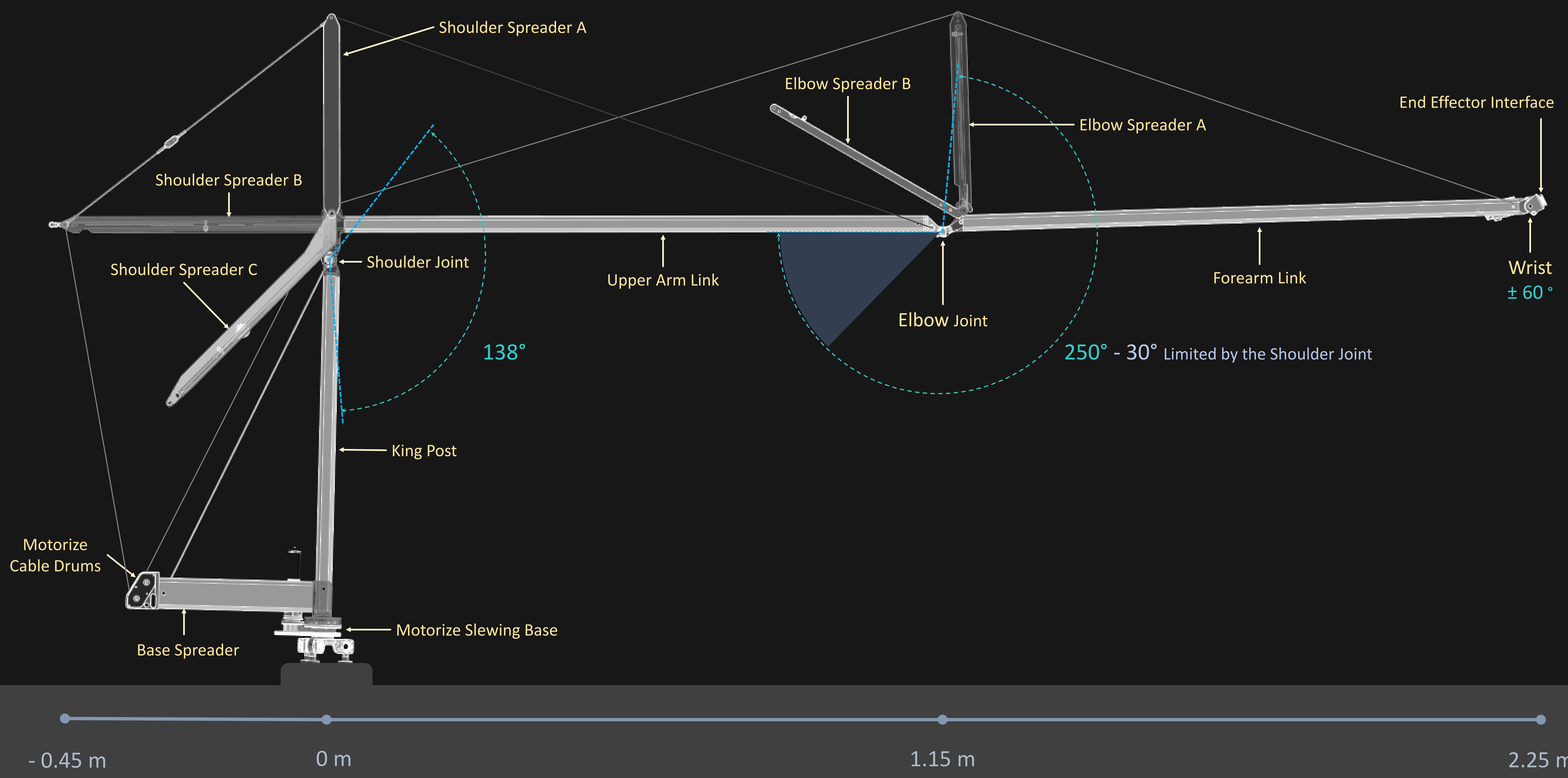
Lightweight Surface Manipulation System

The Lightweight Surface Manipulation System Lunar 35 (LSMS – L35), a small robotic crane based on the LSMS – L1000 architecture, was developed to explore payload offloading options on Commercial Lunar Payload Services (CLPS) missions aboard CLPS class landers. The LSMS – L35 is designed with a lifting capability of 35 kg at a reach of 2.25 m reach on the lunar surface.

The LSMS – L35 are designed to be stowed during launch and self-deploy once the lander lands on the moon. Following deployment, the LSMS – L35 will perform a self-evaluation sequence to ensure that everything functions as intended before any payload is offloaded from the lander.

The arm-links and spreaders on the LSMS – L35 can be configured prior to flight to best meet mission requirements, optimizing mass and minimizing complexity. LSMS – L35 can be integrated with other surface vehicles and can be equipped with various end effectors to perform a broad range of tasks beyond payload offloading.

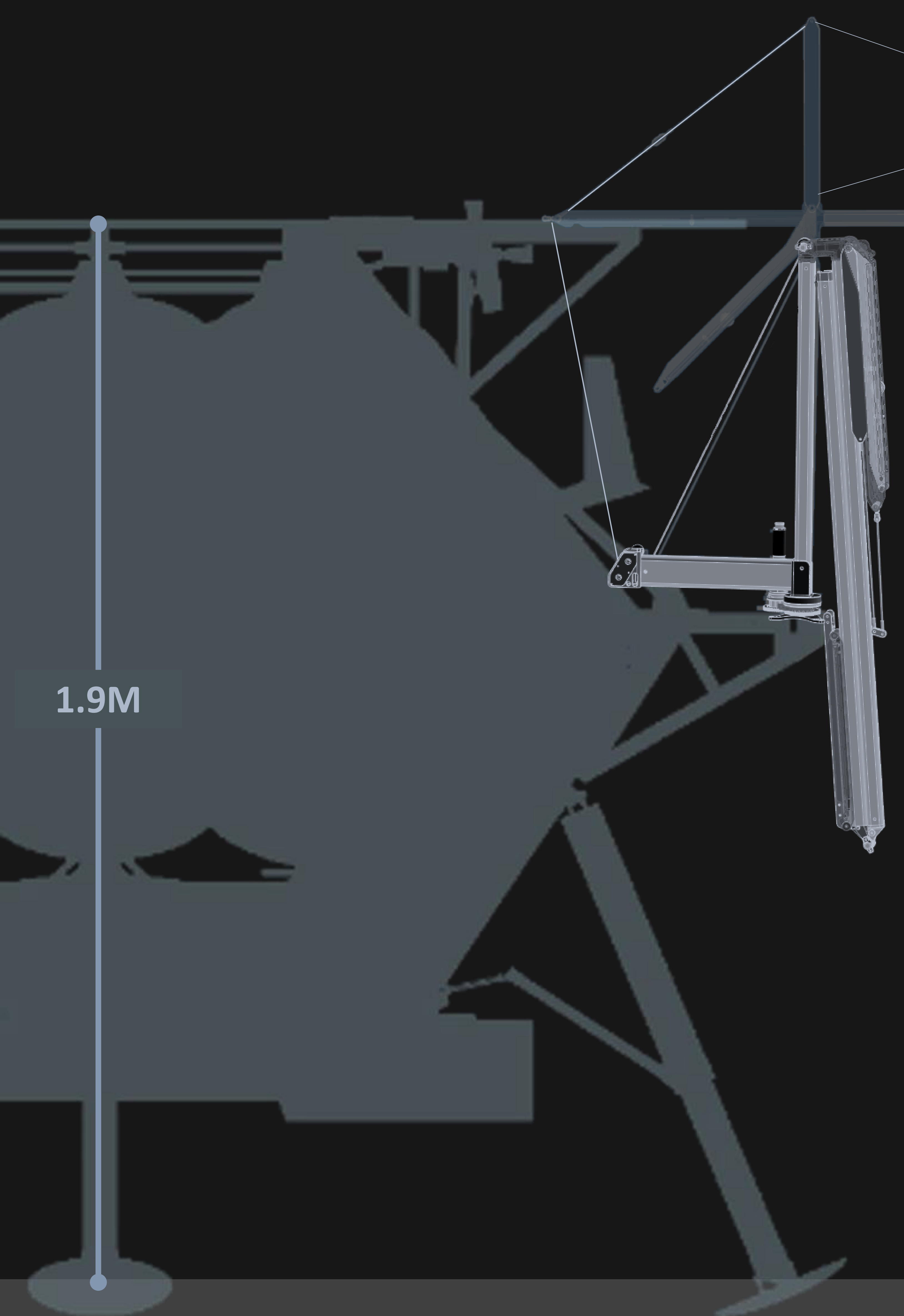
LSMS – L35 *Key Mechanical Component Diagram*

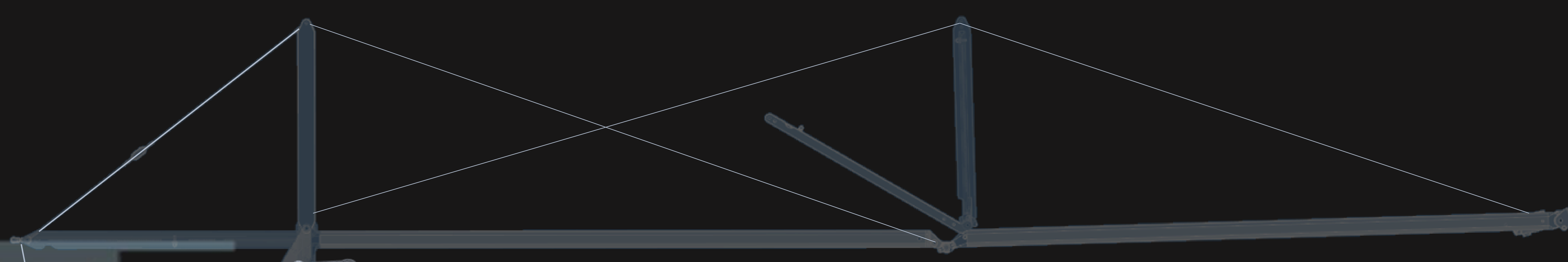


LSMS - L35

Lightweight Surface Manipulation System

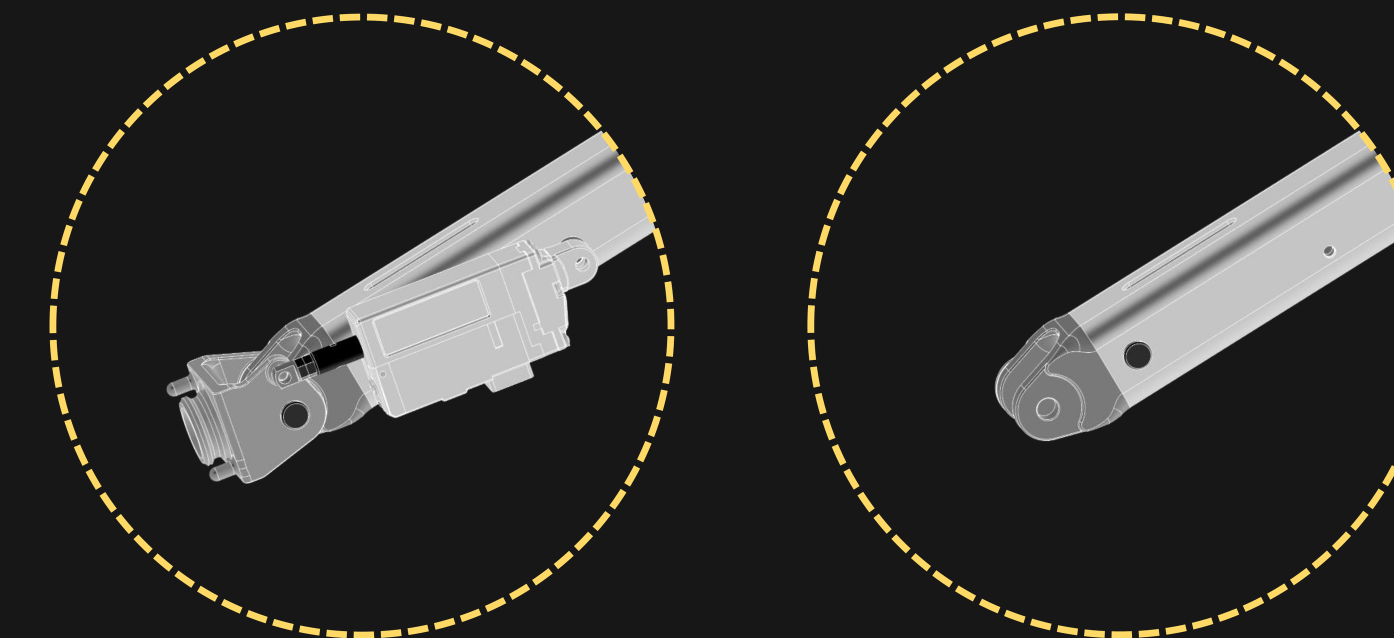
LSMS – L35 *Stow and Deployment*



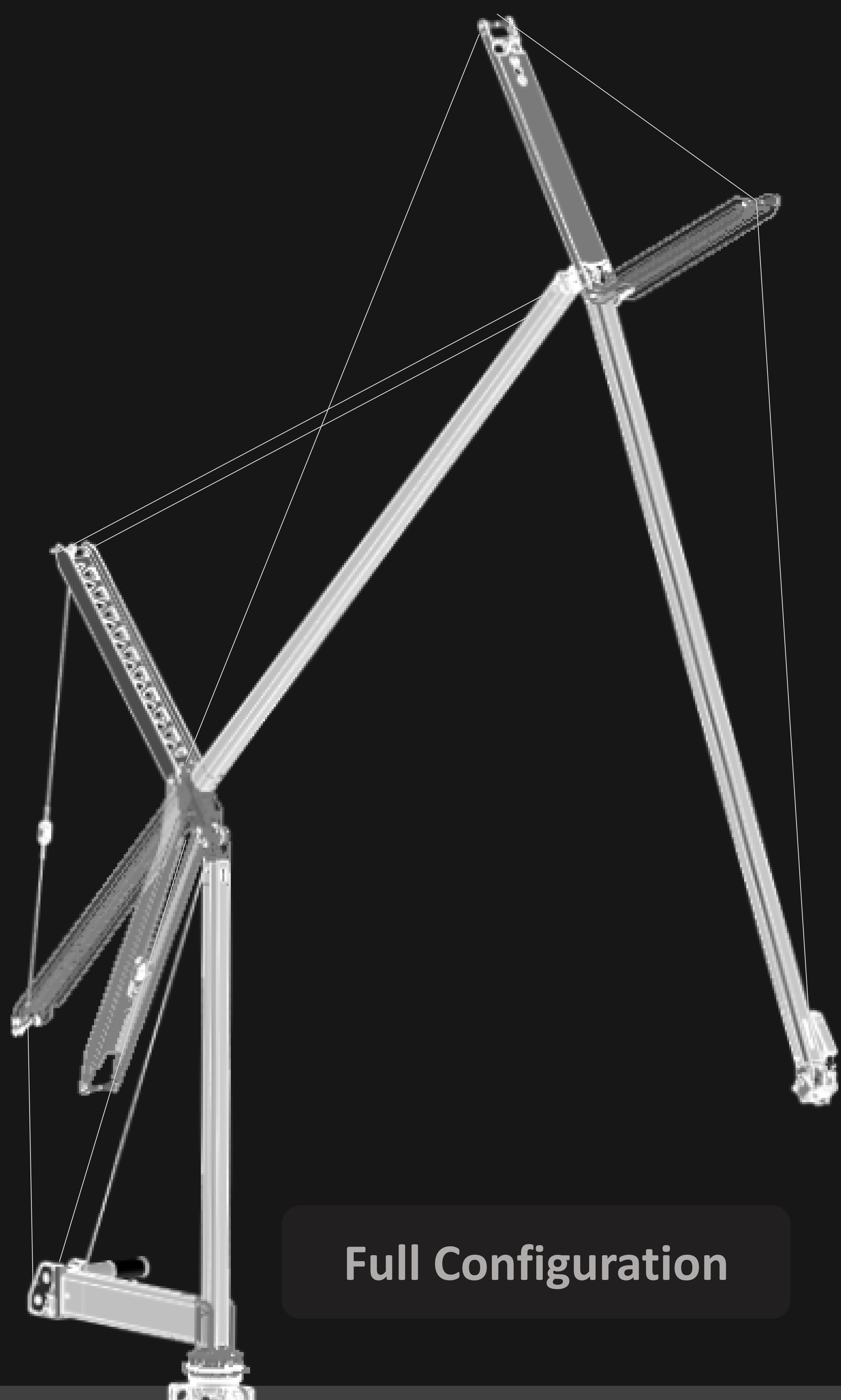


- LSMS – L35 can be stowed in a very compact configuration. When stowed, the forearm folds underneath the upper-arm, and both arm-links are packed tightly against the king post.
- The LSMS – L35 packaging scheme allows the system to be tightly packed and integrated with a wide range of lander configuration.
- LSMS – L35 will perform self-deploy and post deployment checks before commencing operations.

LSMS – L35 *Alternative Configurations*



With and Without Wrist Joint and End Effector Interface



Full Configuration

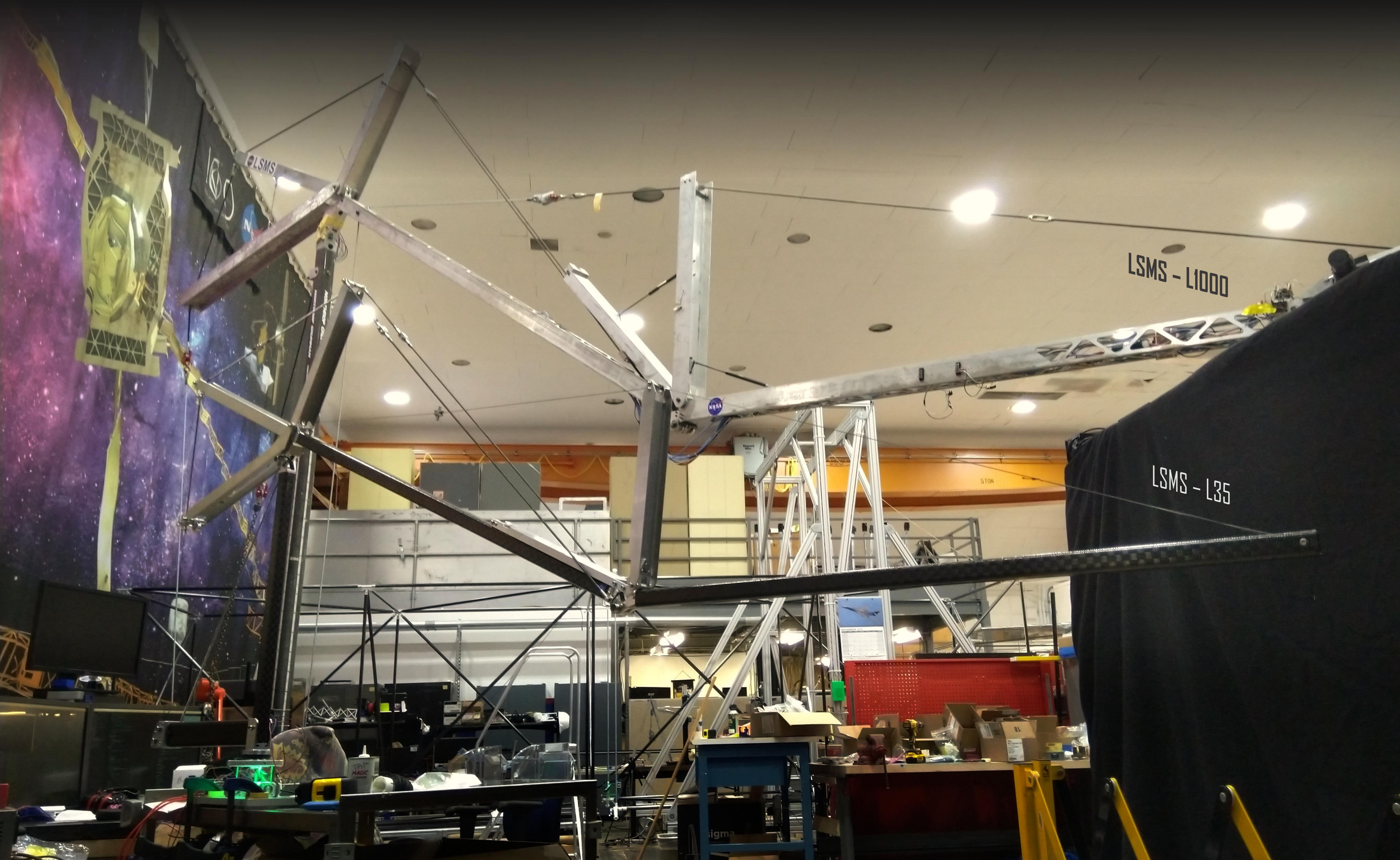
Reduce Spreaders

Remove Forearm

LSMS -L35

Lightweight Surface Manipulation System

LSMS – L35 *Scalability*



LSMS - L35

Lightweight Surface Manipulation System

PLSASLP

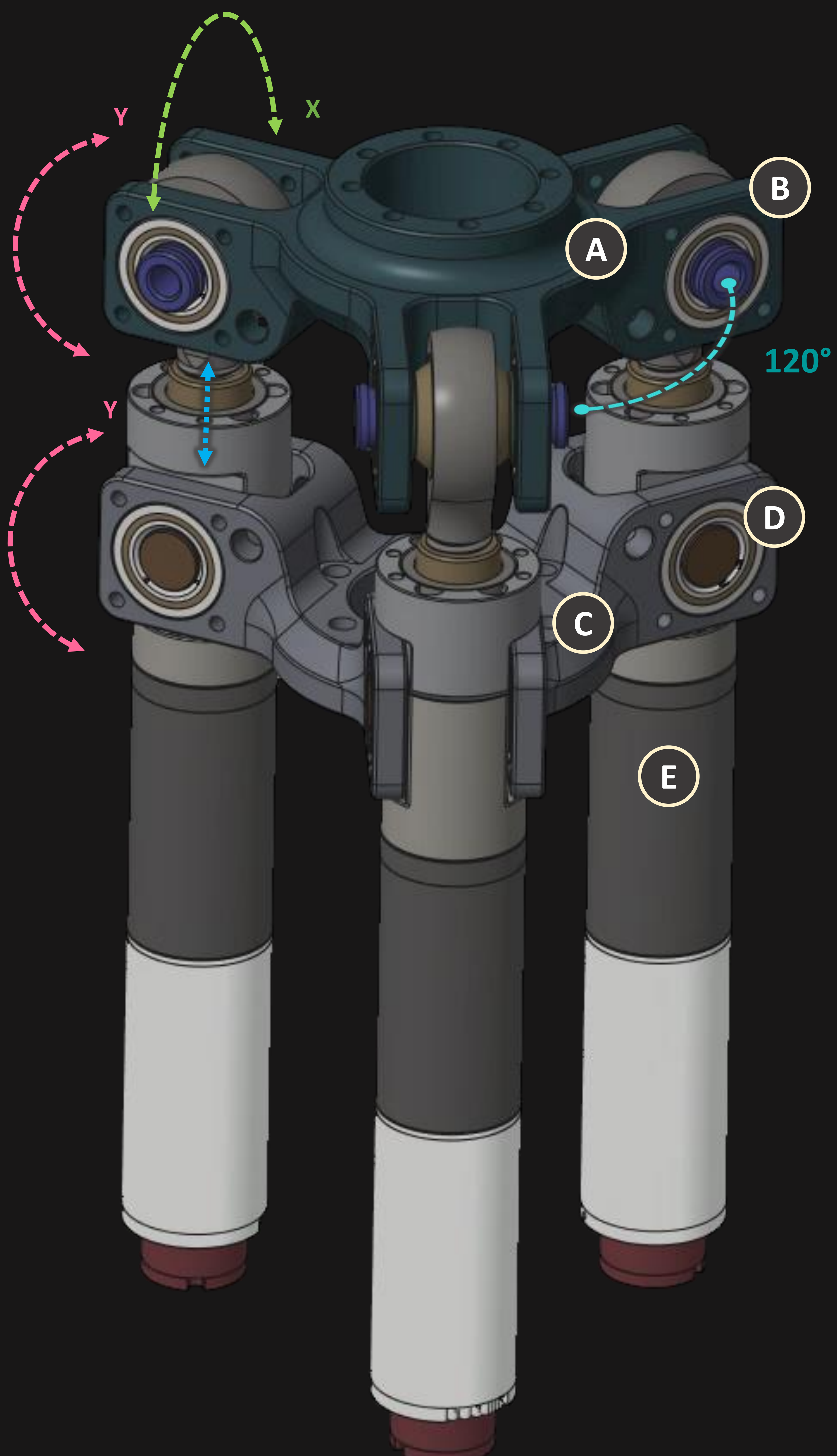
Programmable Lead Screw Actuated Self-Leveling Platform

The Programmable Lead Screw Actuated Self-Leveling Platform (PLSASLP) was initially designed to assist in leveling the Lightweight Surface Manipulation System Lunar 35 (LSMS – L35), a miniature robotic crane, from inclined surfaces up to 15 degrees. In addition to PLSASLP’s leveling capability, the PLSASLP can also be utilized as a pointing device with a 30-degree crone of pointing capability.

The PLSASLP achieves leveling or pointing by utilizing a set of two or three linear actuators arranged in an equilateral triangle formation. Each linear actuator connects the base platform to a one degree of freedom rotary joint and the motion platform to a two degrees of freedom swivel joint, satisfying the geometric articulation needed to actuate the platform.

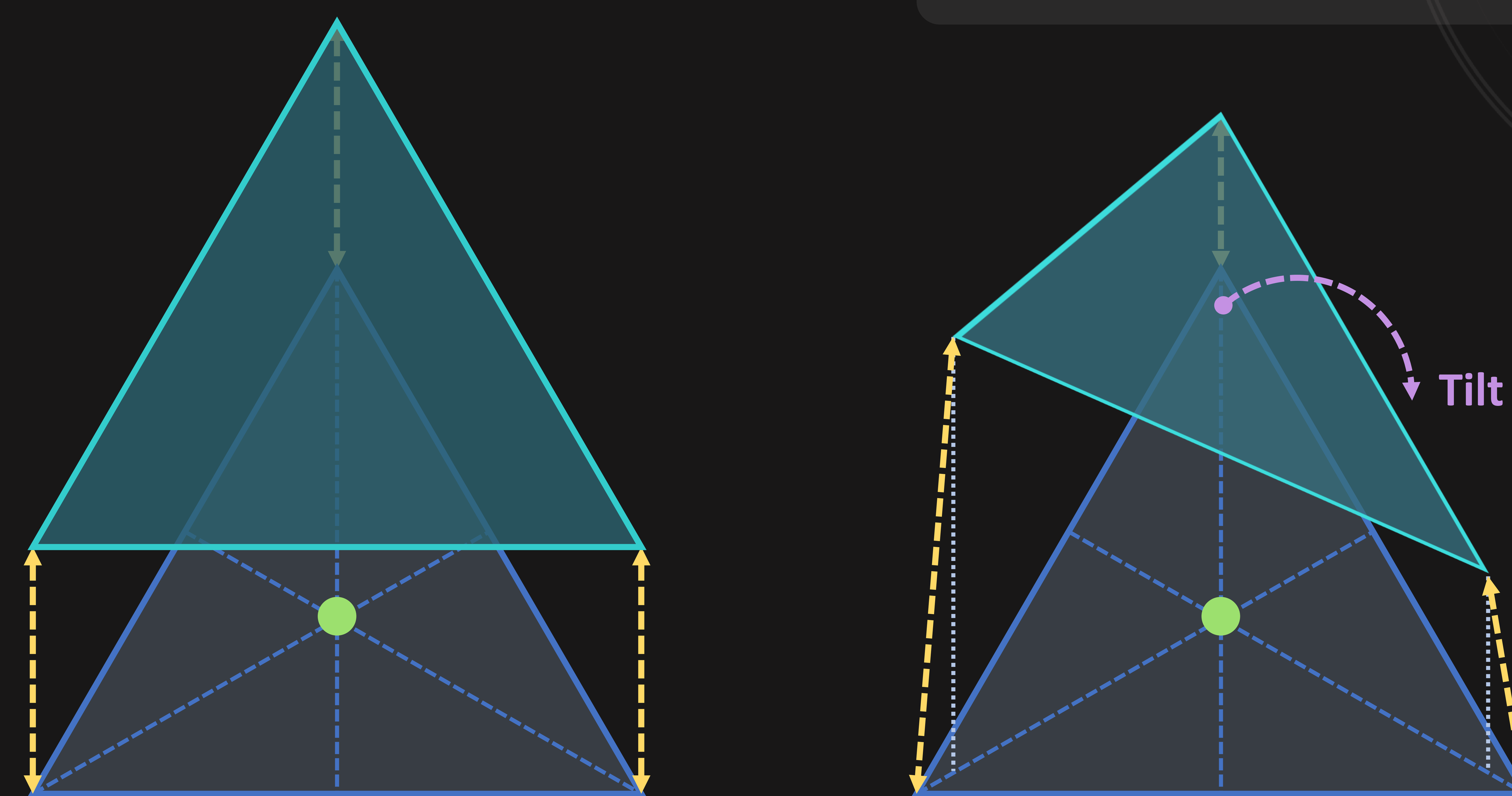
The PLSASLP can effectively satisfy both rotational degrees of freedom required for leveling and pointing with just two linear actuators. When three linear actuators are employed, the PLSASLP will also be capable of vertical translation, while providing redundancy for the level and pointing function.

PLSASLP *Leveling Platform Architecture and Kinematic*



A. Motion Platform
B. Swivel Joint (x3)
C. Base Platform
D. Rotary Joint (x3)
E. Linear Actuator (x3)

Kinematic Diagram

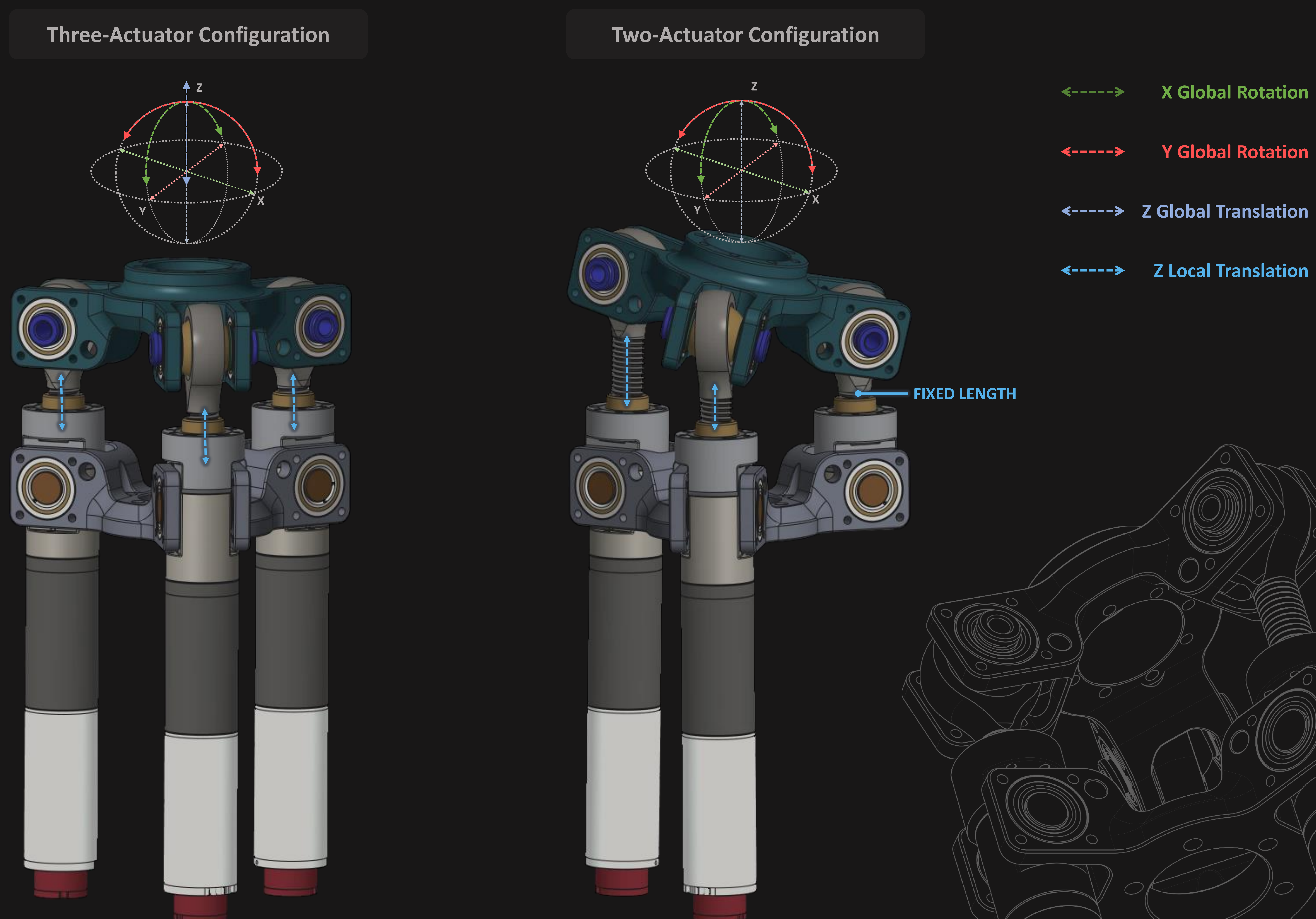


Center Point
Motion Platform
Joint Moving Paths
Variable Links
Base Platform
Tilting Motion

PLSASLP

Programmable Lead Screw Actuated Self-Leveling Platform

PLSASLP *Leveling Platform Motion*

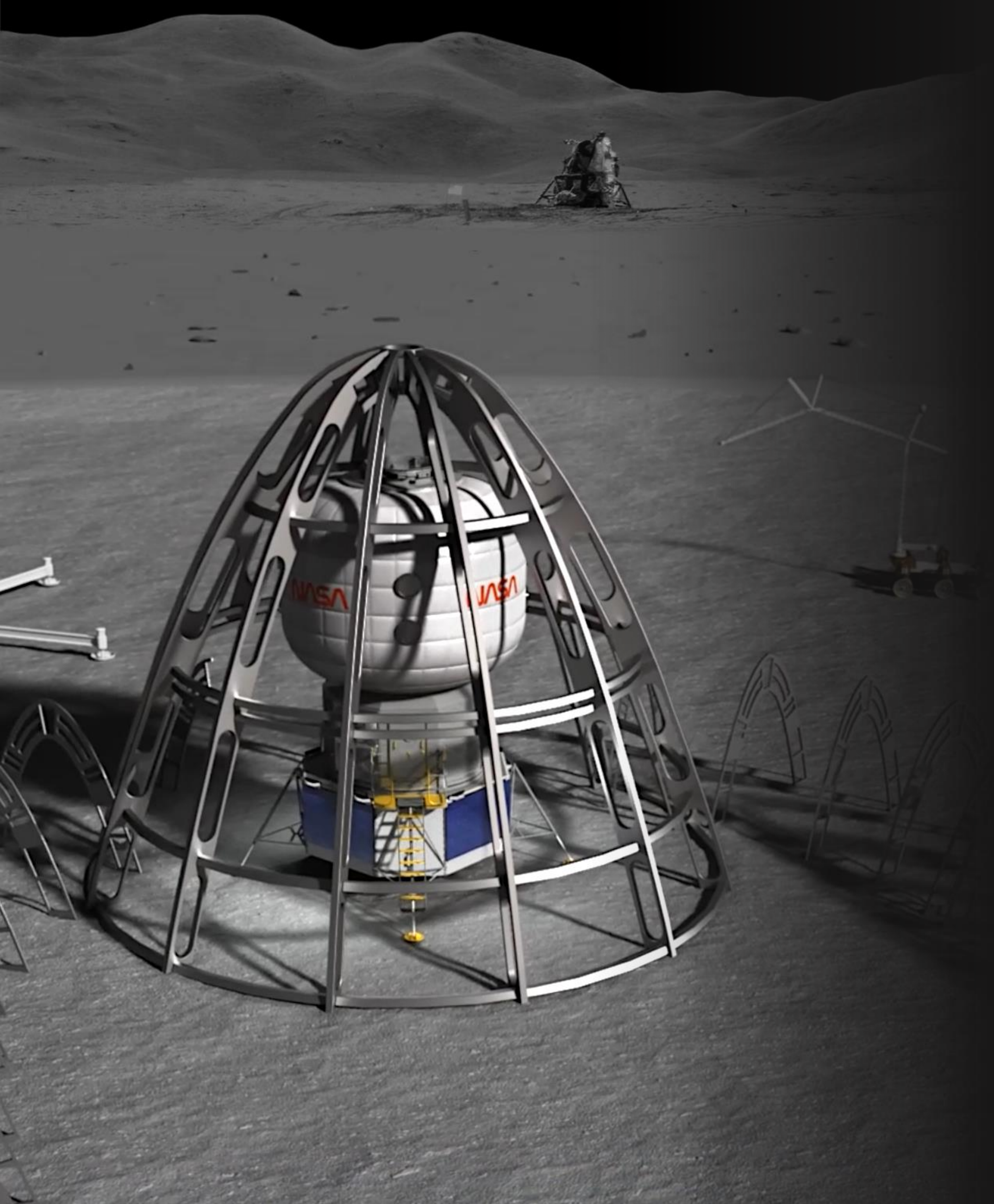


PLSASLP

Programmable Lead Screw Actuated Self-Leveling Platform

LSH

Lunar Safe Haven



The Lunar Safe Haven (LSH) Project aims to investigate the architecture design, construction methods, and requirements necessary to build the radiation protection shelters over a landed habitation module and other lunar surface assets.

Parabolic or weighted centenary arches were chosen as the base shape for the shelter due to the load bearing efficiency, and feasibility with either prefabricated structures shipped from Earth or in-situ masonry materials created using lunar regolith.

The sizing of all sheltered spaces, including the main shelter area and egress routes, were determined based on the given lunar assets. The thickness of the shielding layers is calculated to meet the NASA standards on radiation exposure for astronauts, not to exceed 600 mSv of effective radiation for the entire career of the astronaut.

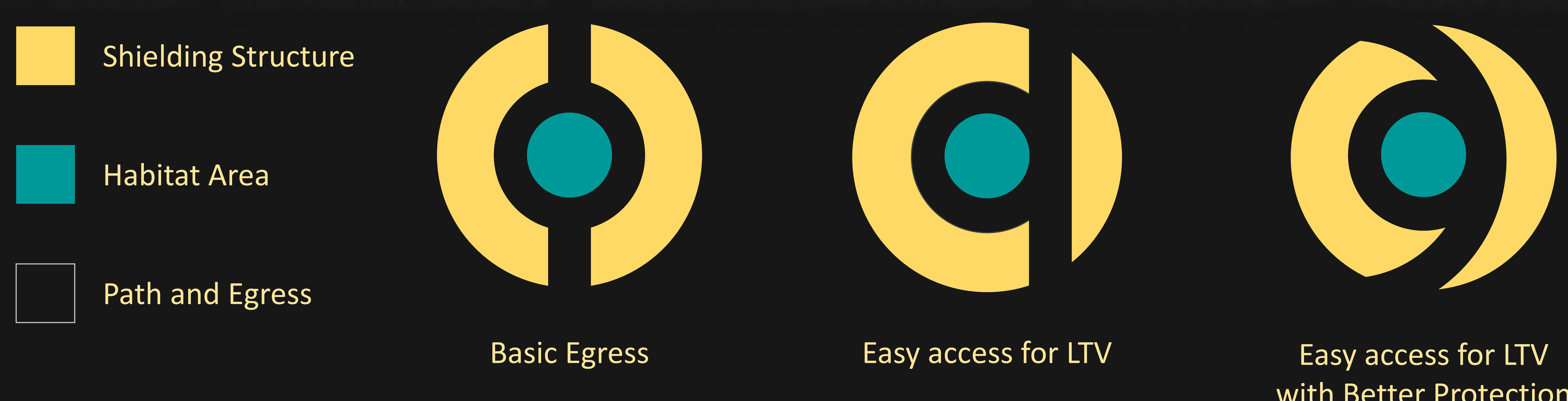
The effective radiation exposure reduction provided by LSH can effectively increase the time made available for the astronauts to do Extravehicular Activity (EVA) for Moon exploration.

Lunar Safe Haven *Space Sizing*

Regolith barrier will be used to cover the structure frame. Compacted regolith and Geo-mate infused regolith will be used to keep regolith stable to form the radiation protection shielding.

LSH
Lunar Safe Haven

Lunar Safe Haven *Egress Design*



Direct straight paths to the exterior shall be avoided in favor of curved paths that can better utilize the surrounding mass to block the cosmic rays penetrating the frequently used routes. Unpressurized shelters shall also follow the “two means of egress” rule for occupied spaces

LSH

Lunar Safe Haven

Lunar Safe Haven *Elongated Concept*

Project Patch

One Project in One Image