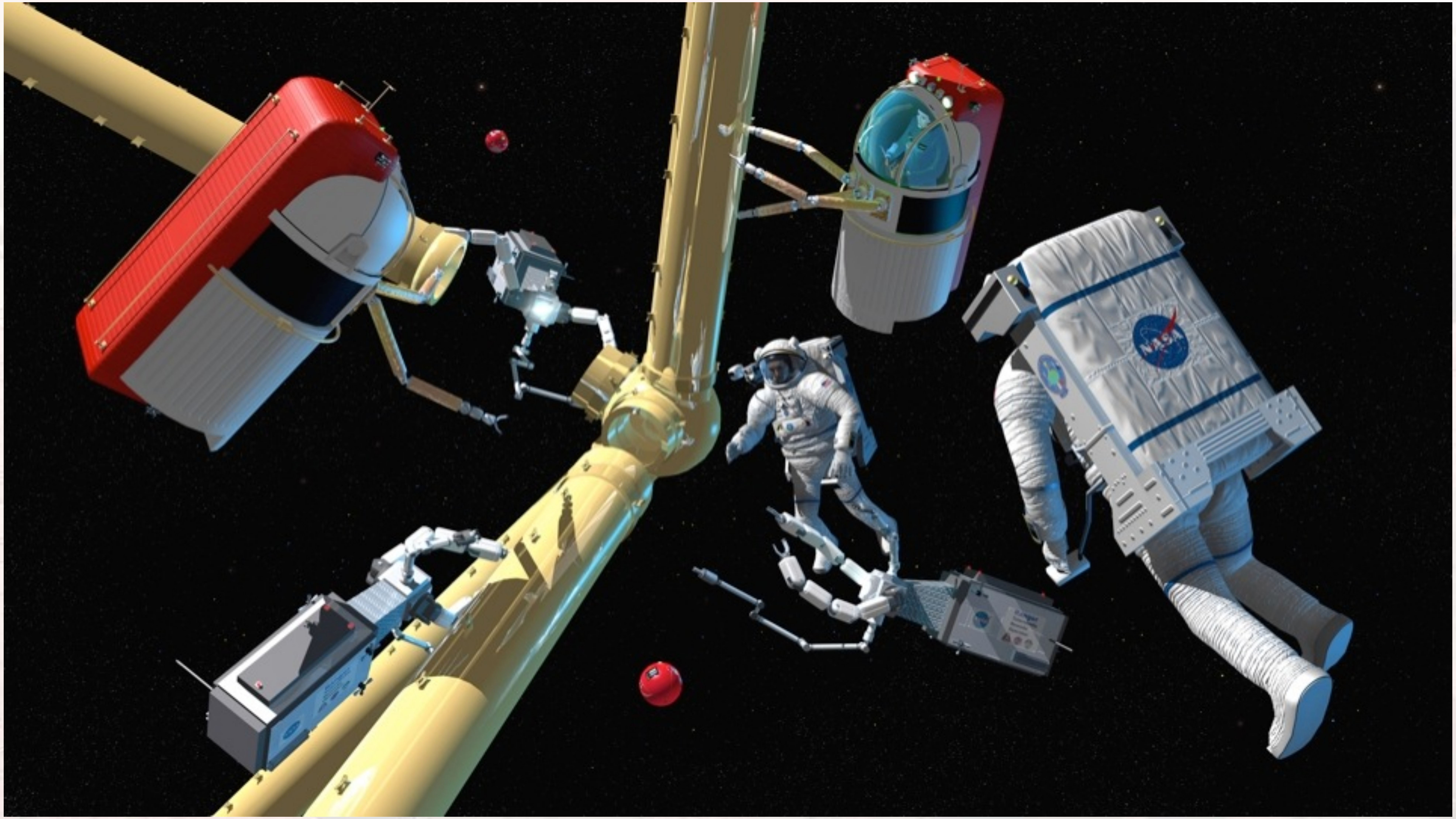
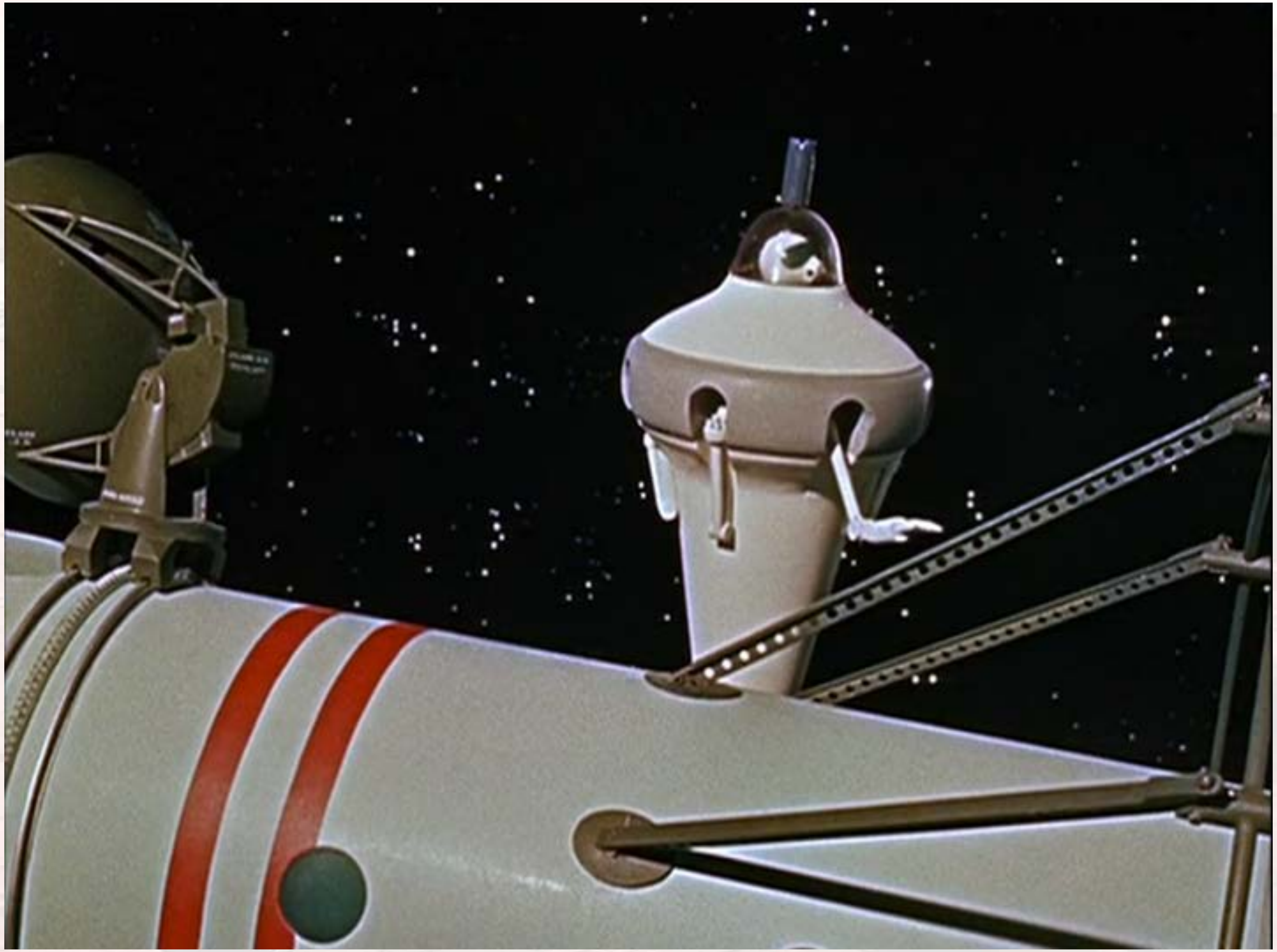
Extravehicular Activity 4

- Spacesuit alternatives

The Future In-Space Worksite

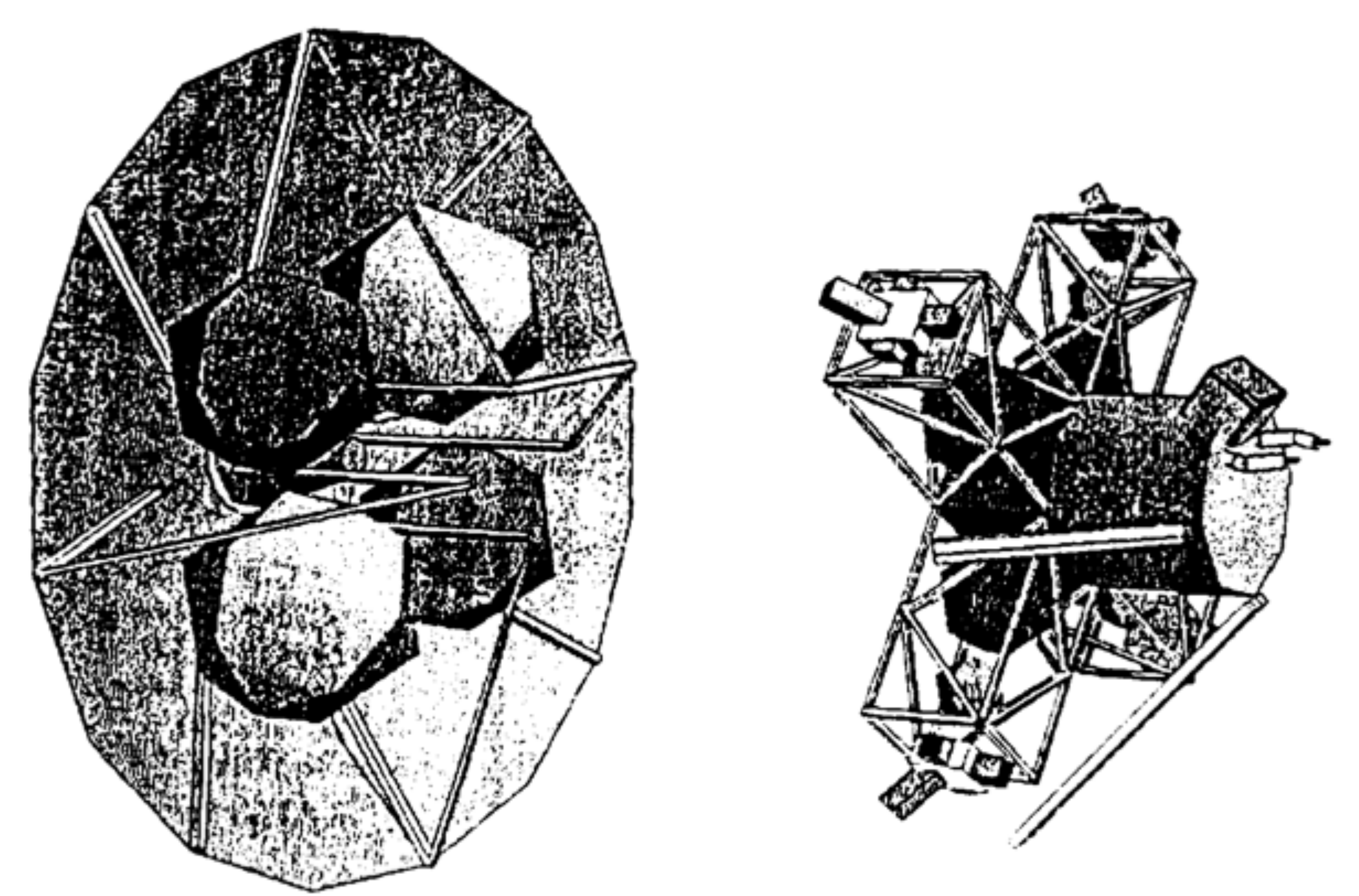


Von Braun Bottle Suit (Disney 1956)



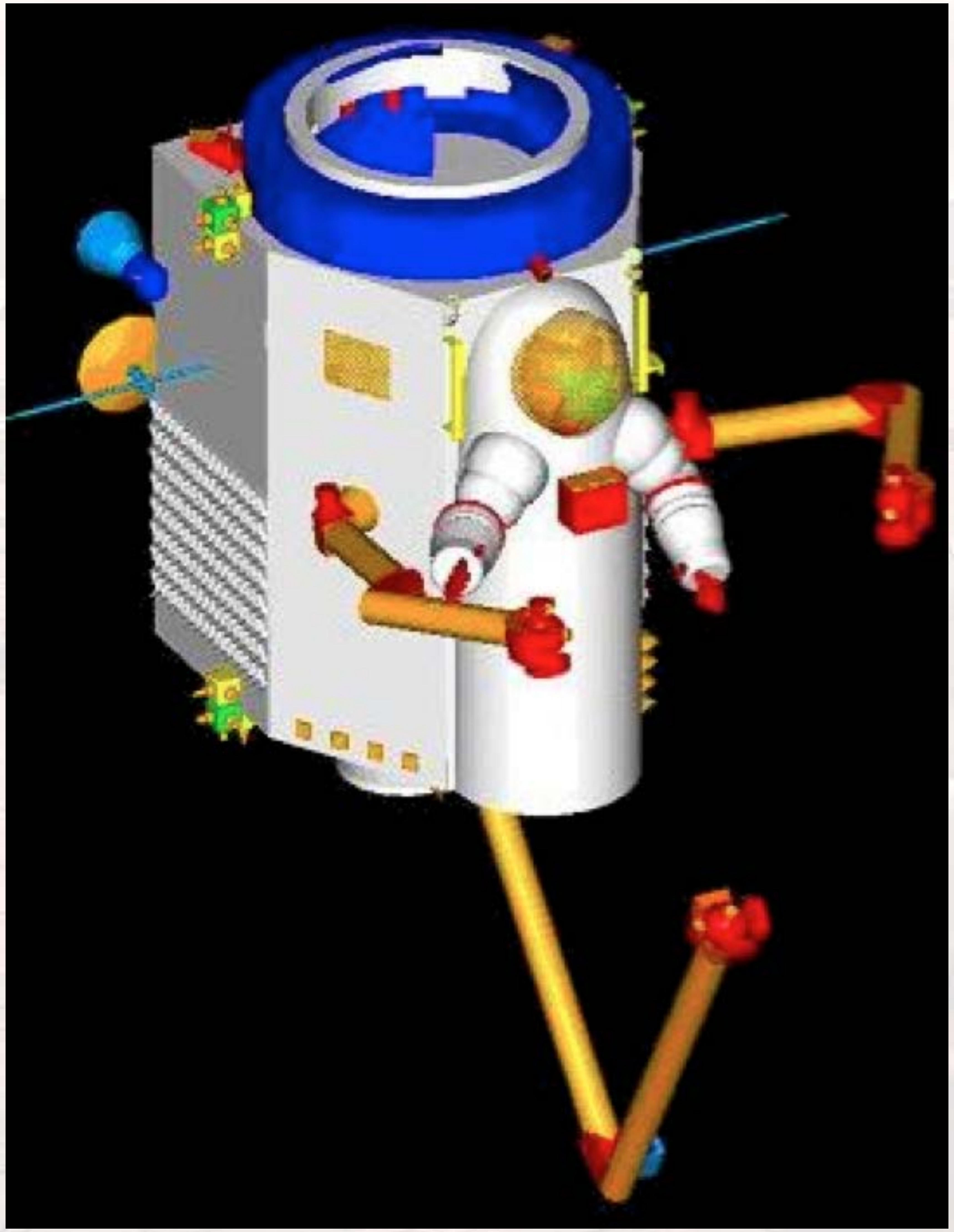
Pod from *2001: A Space Odyssey*

MOOSE Servicing Concept (UMd 1993)



MOOSE: Manned On-Orbit Servicing Equipment

SCOUT Design (UMd 2003)

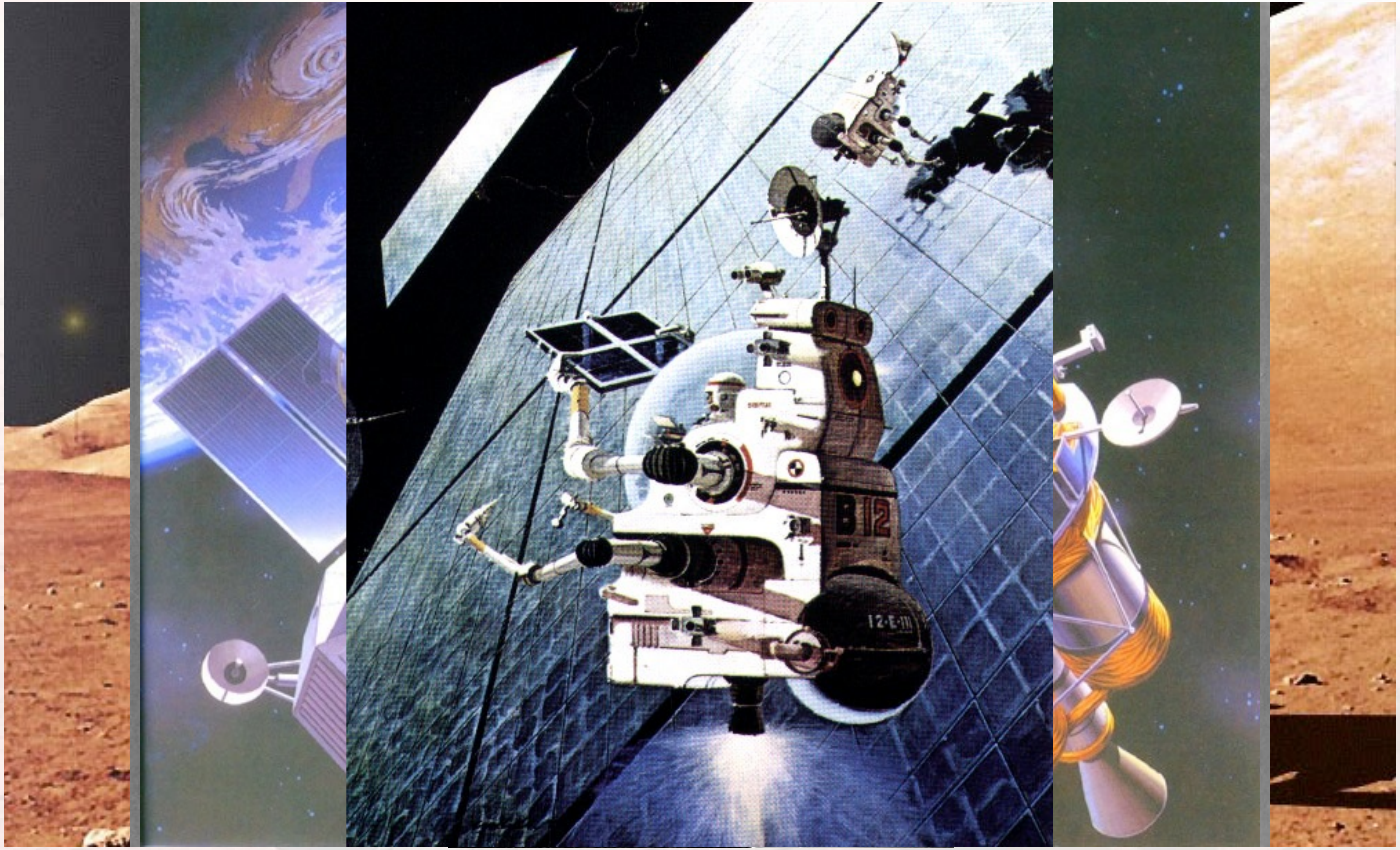


SCOUT:Space Construction and Orbital Utility Transport

Definition of a Space Utility Vehicle

- Shirtsleeve environment for one or more crew
- Ability to maneuver to, from, and around a space worksite
- Ability to directly manipulate components in the worksite
- Dedicated to the space mission (i.e., not capable of launch and entry/descent/landing)

Half a Century of Concepts...



...and Little to Nothing to Show for It...

- No flight hardware
- Few (if any) significant ground analogue studies
- Few detailed design studies (and many of those have been lost)
- Few publications
- Pretty much ignored in mission architectures

...Not Even a Name

- “Pod”
- “Bottle Suit”
- “Manned Autonomous Work System”
- “Space Construction and Orbital Utility Transport”
- “Manned On-Orbit Servicing System”
- “Single-Person Spacecraft”
- “Flexcraft”
- “Orbital Work System”

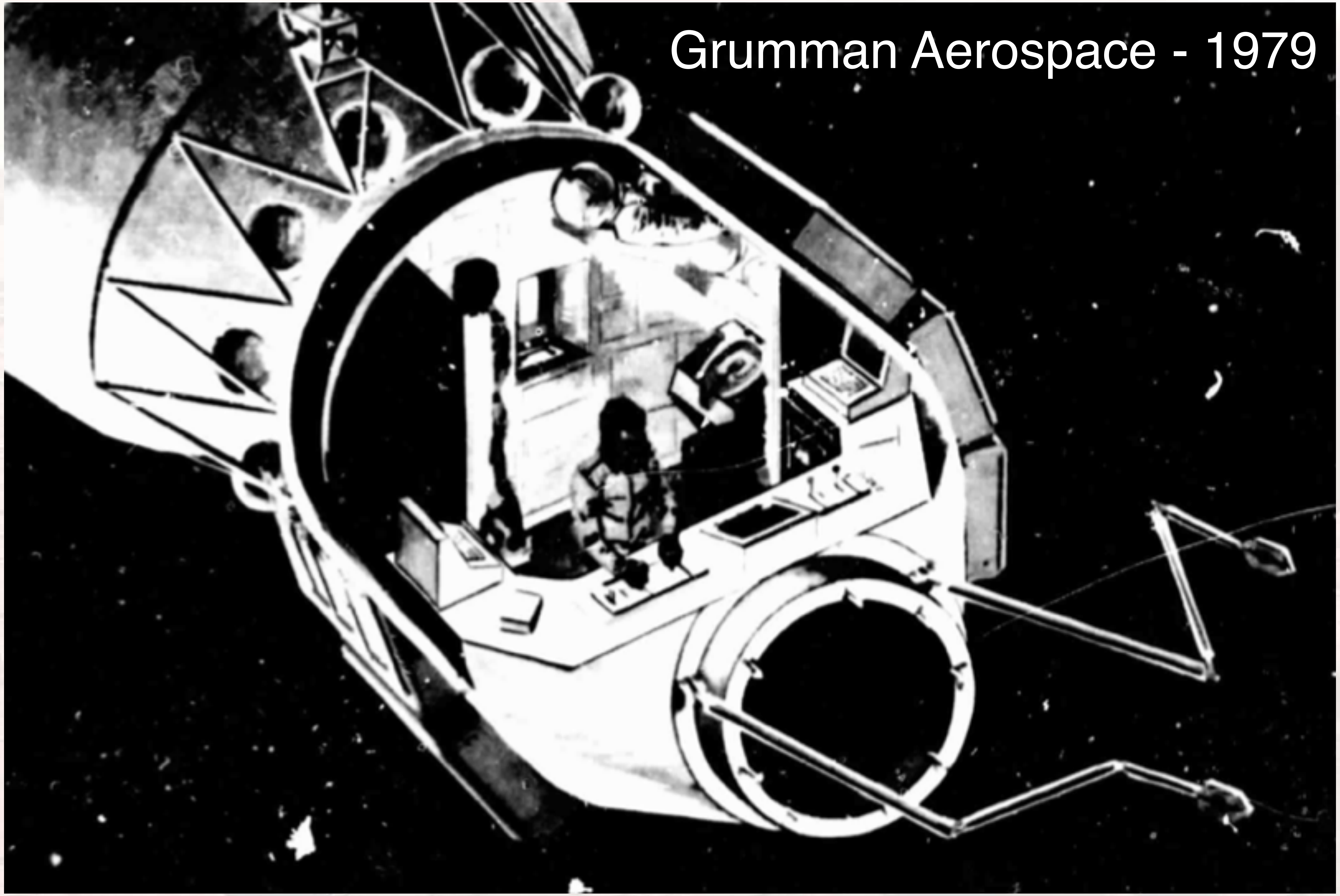
but we always seem to come back to...

The Name from Hell

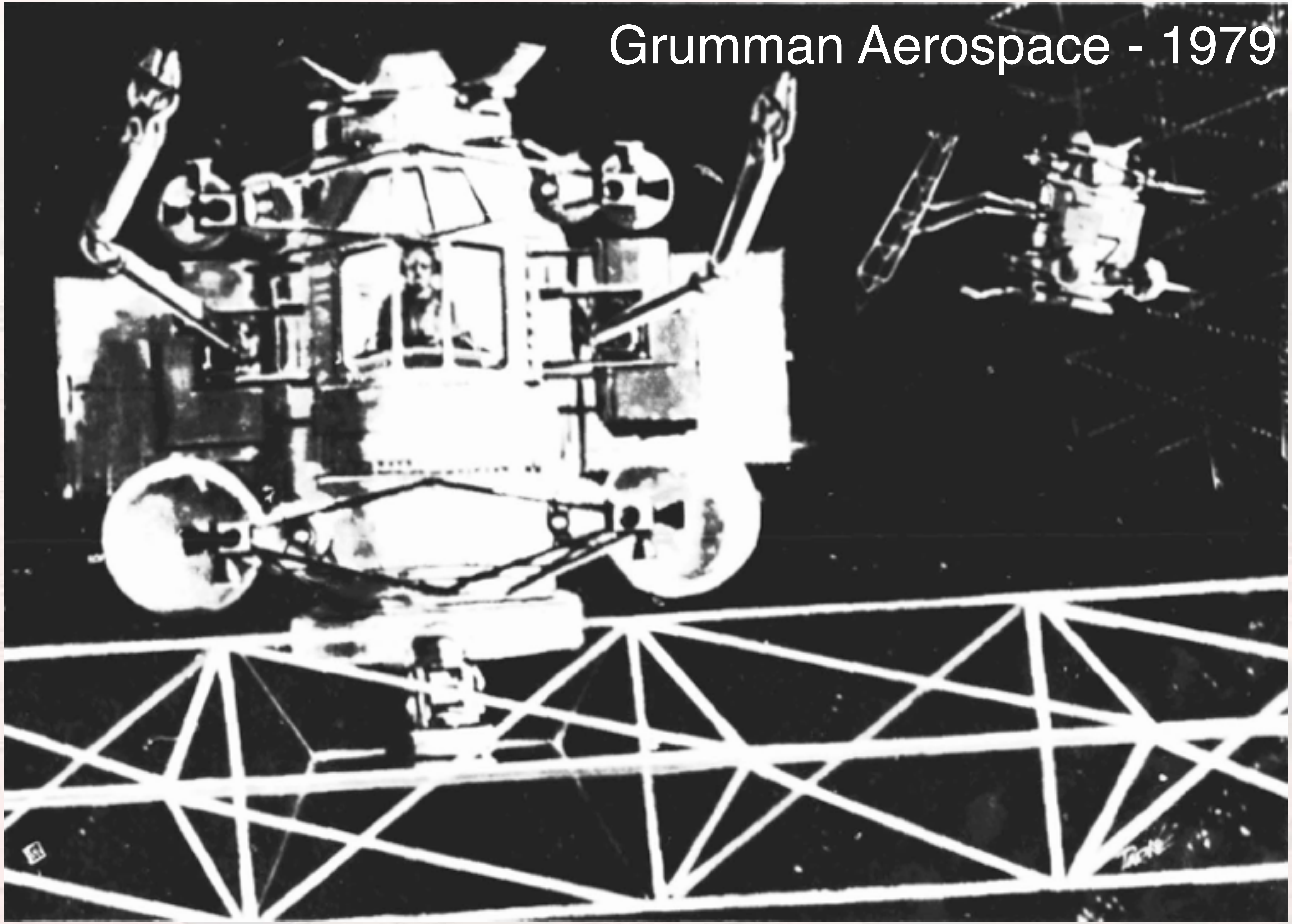
The Canonical System Studies

- Looking for SUV system designs with sufficient published data to quantify critical mission parameters
- Had to include studies not necessarily of SUVs, but of systems with SUV capabilities
- Comprehensive search led to six candidates
  - Manned Orbital Transfer Vehicle - Grumman (1979)
  - Manned Remote Work Station - Grumman (1979)
  - Manned On-Orbit Servicing Equipment - UMd (1993)
  - Space Construction and Orbital Utility Transport - UMd (2003)
  - MAWS/Flexcraft - Griffin/NASA Marshall (1988/2011)
  - Multimission Space Exploration Vehicle - NASA Johnson (2011)

Manned Orbital Transfer Vehicle (MOTV)

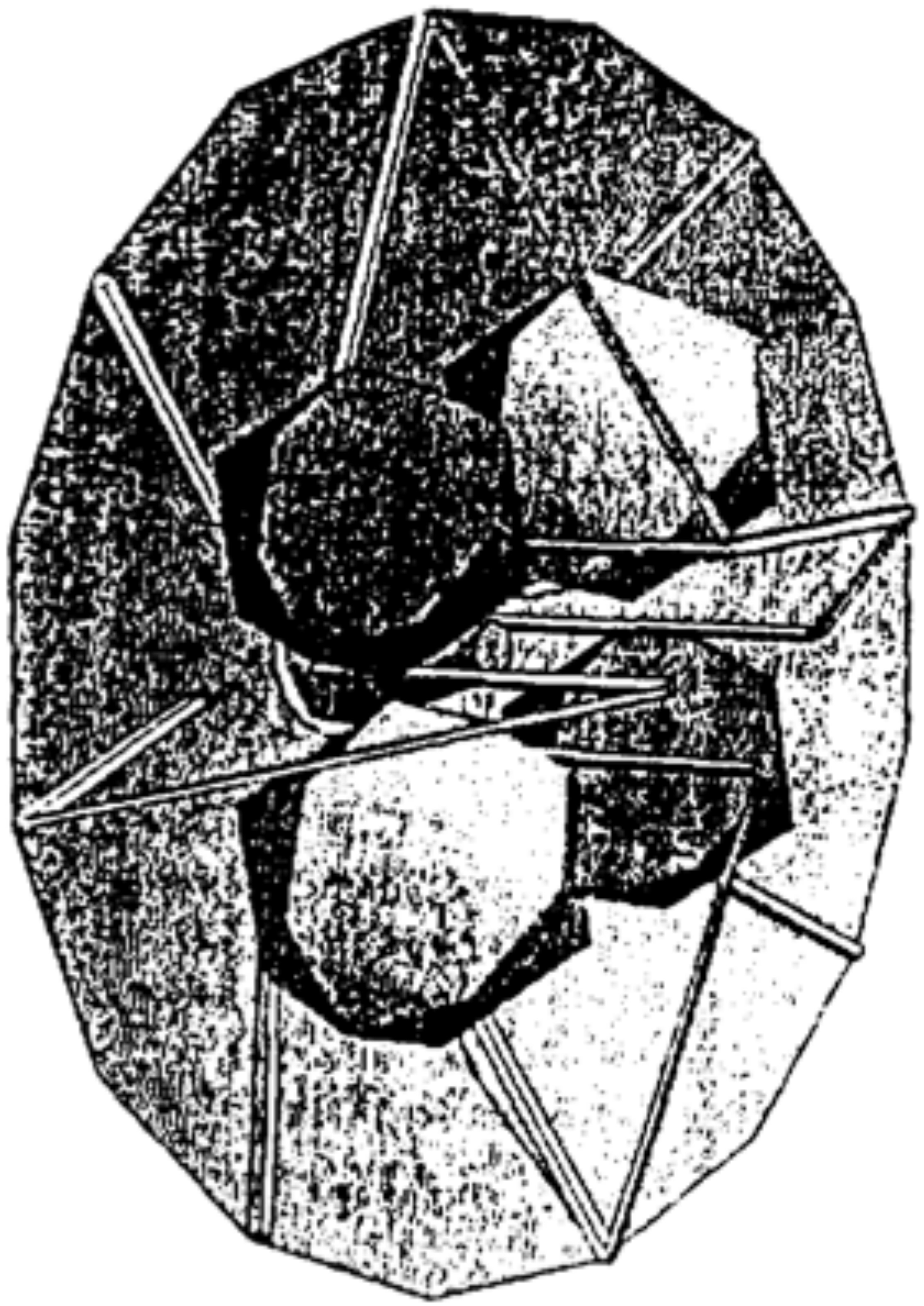


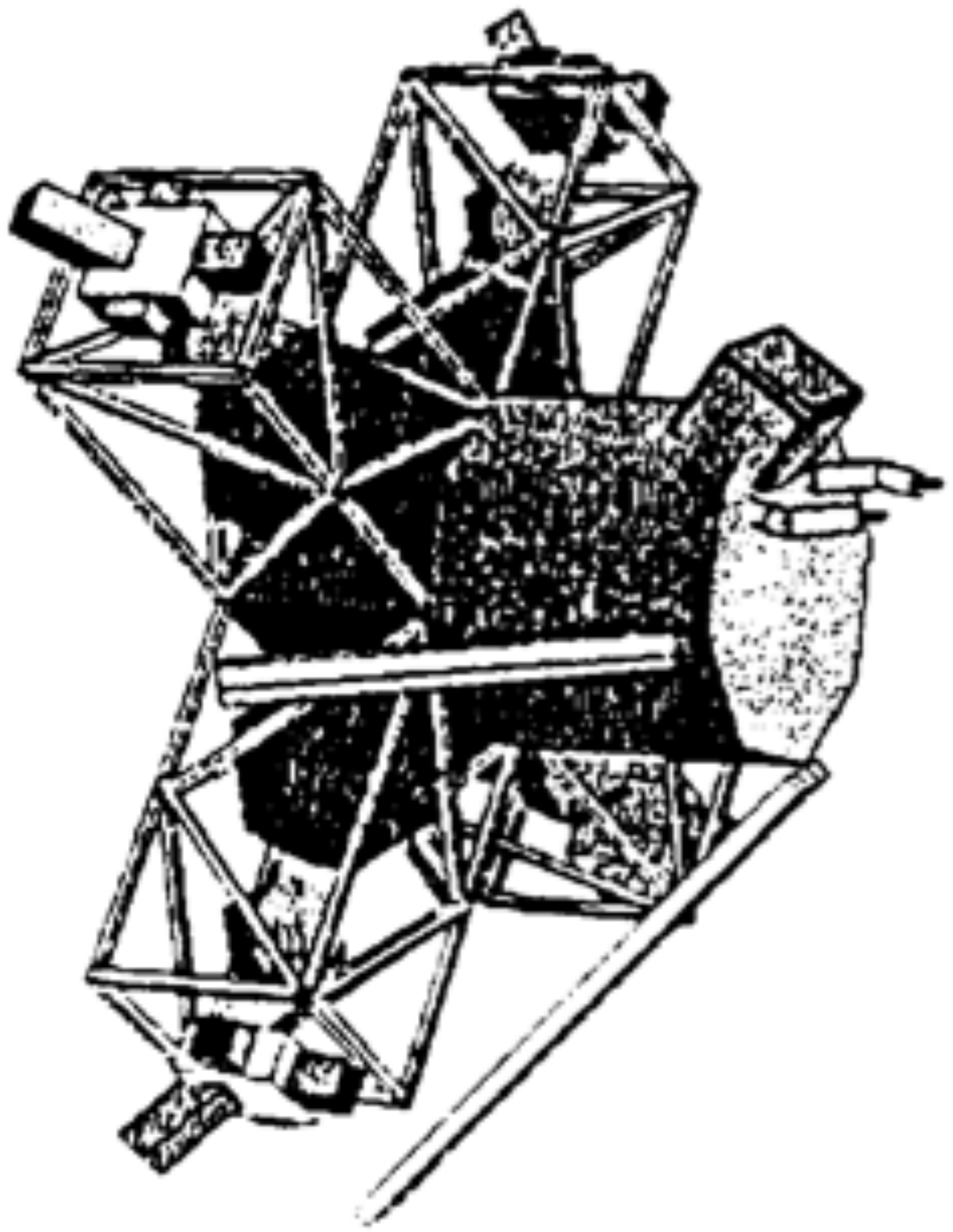
Manned Remote Work Station (MRWS)



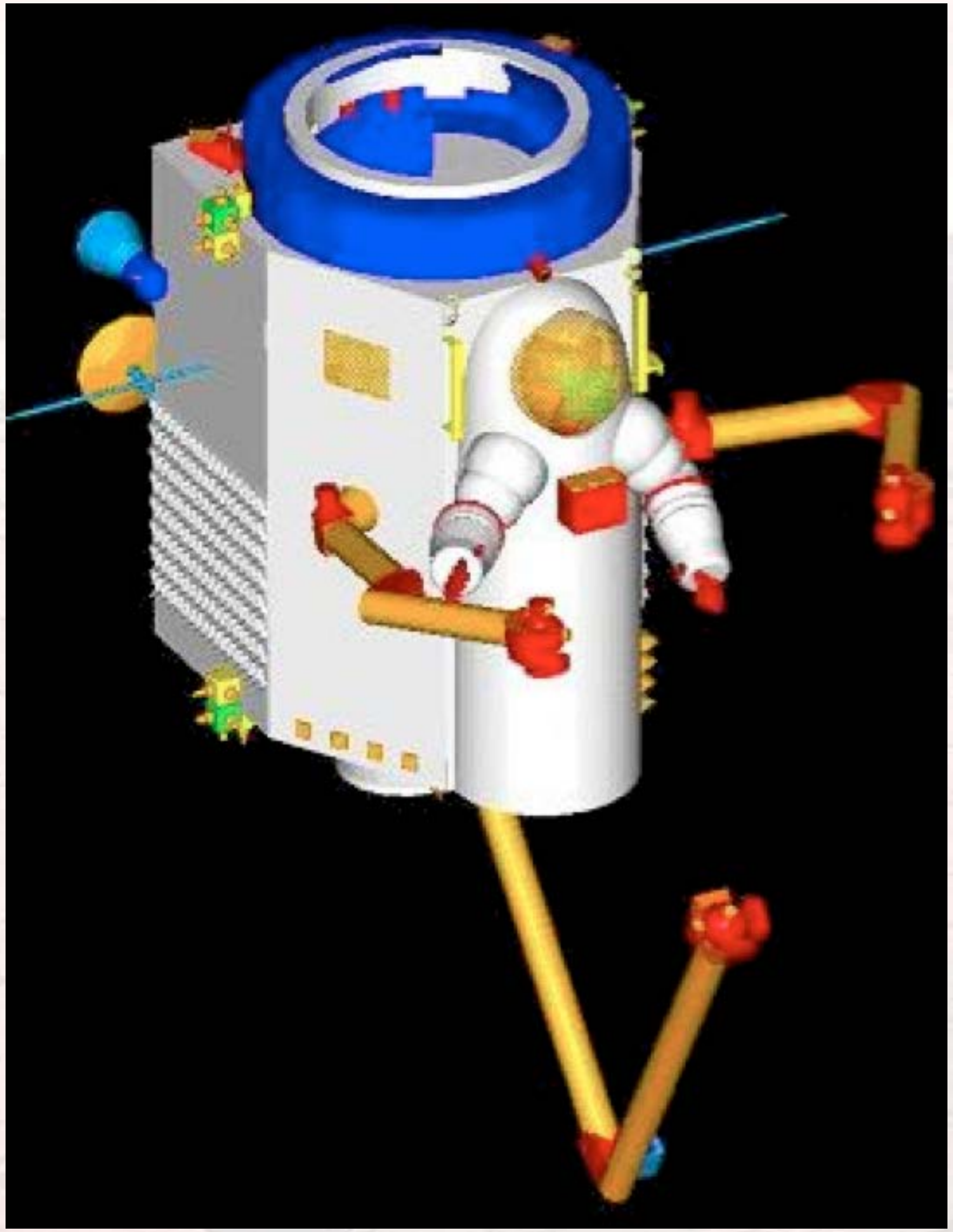
Manned On-Orbit Servicing Equipment (MOOSE)

University of Maryland - 1993

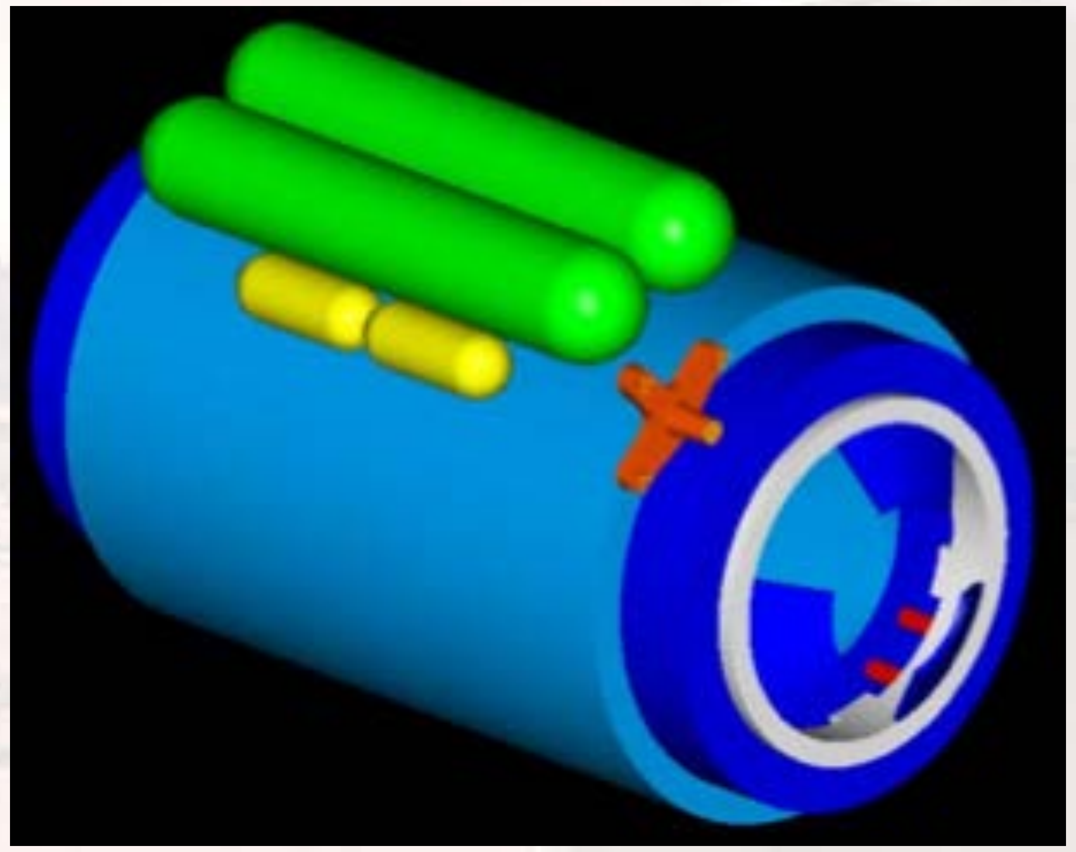


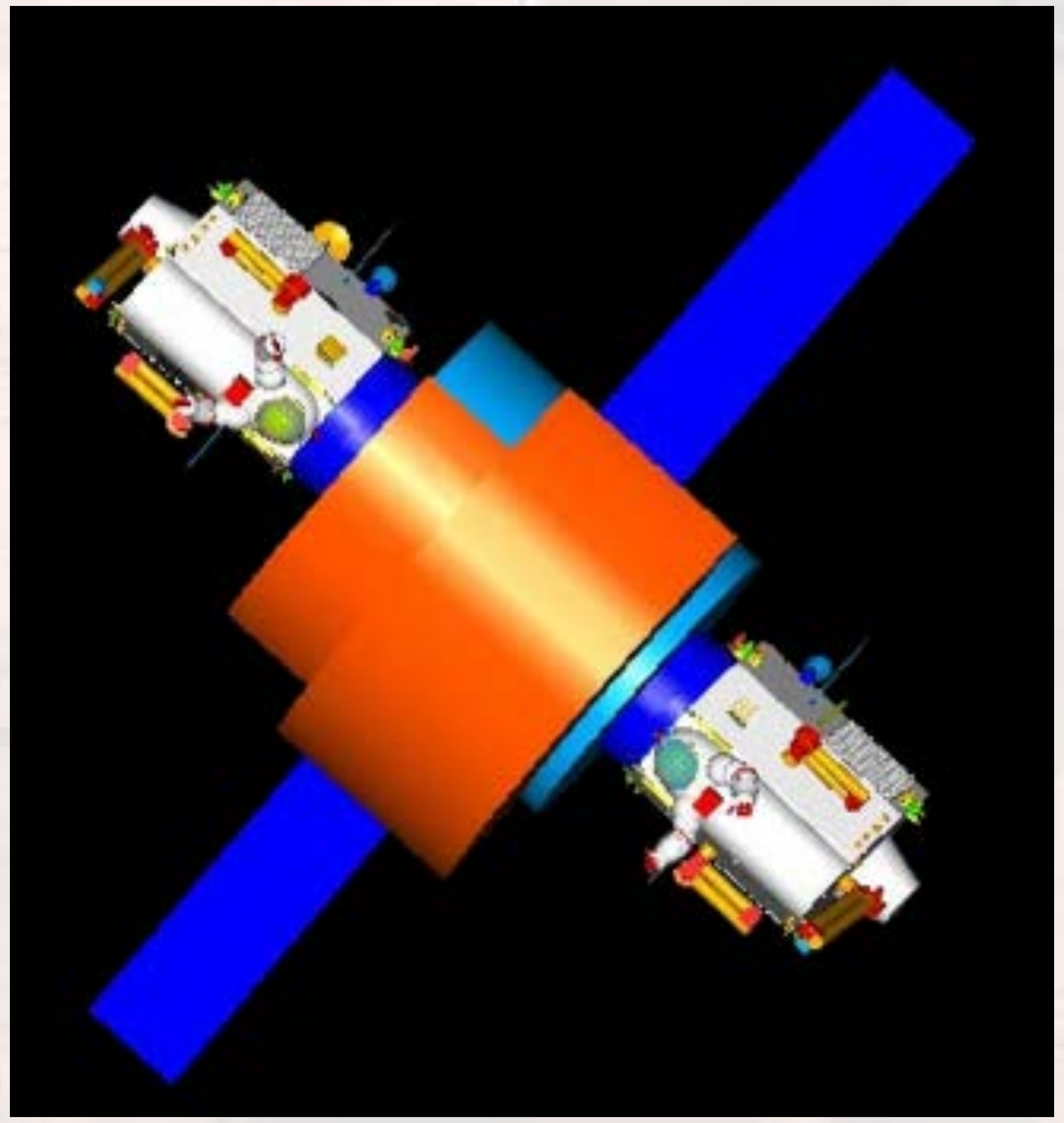


Space Construction and Orbital Utility Transport (SCOUT)

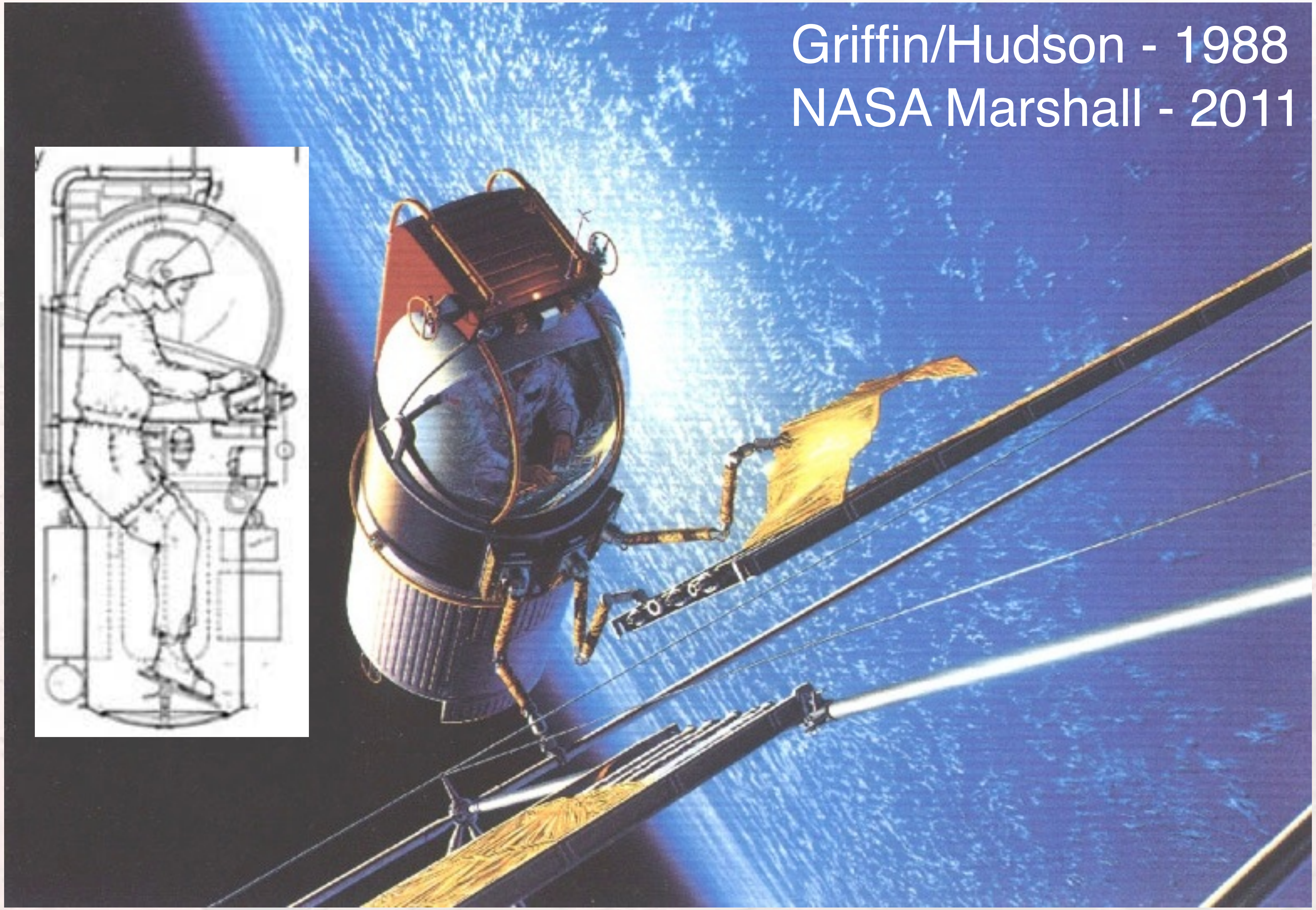


University of Maryland - 2003

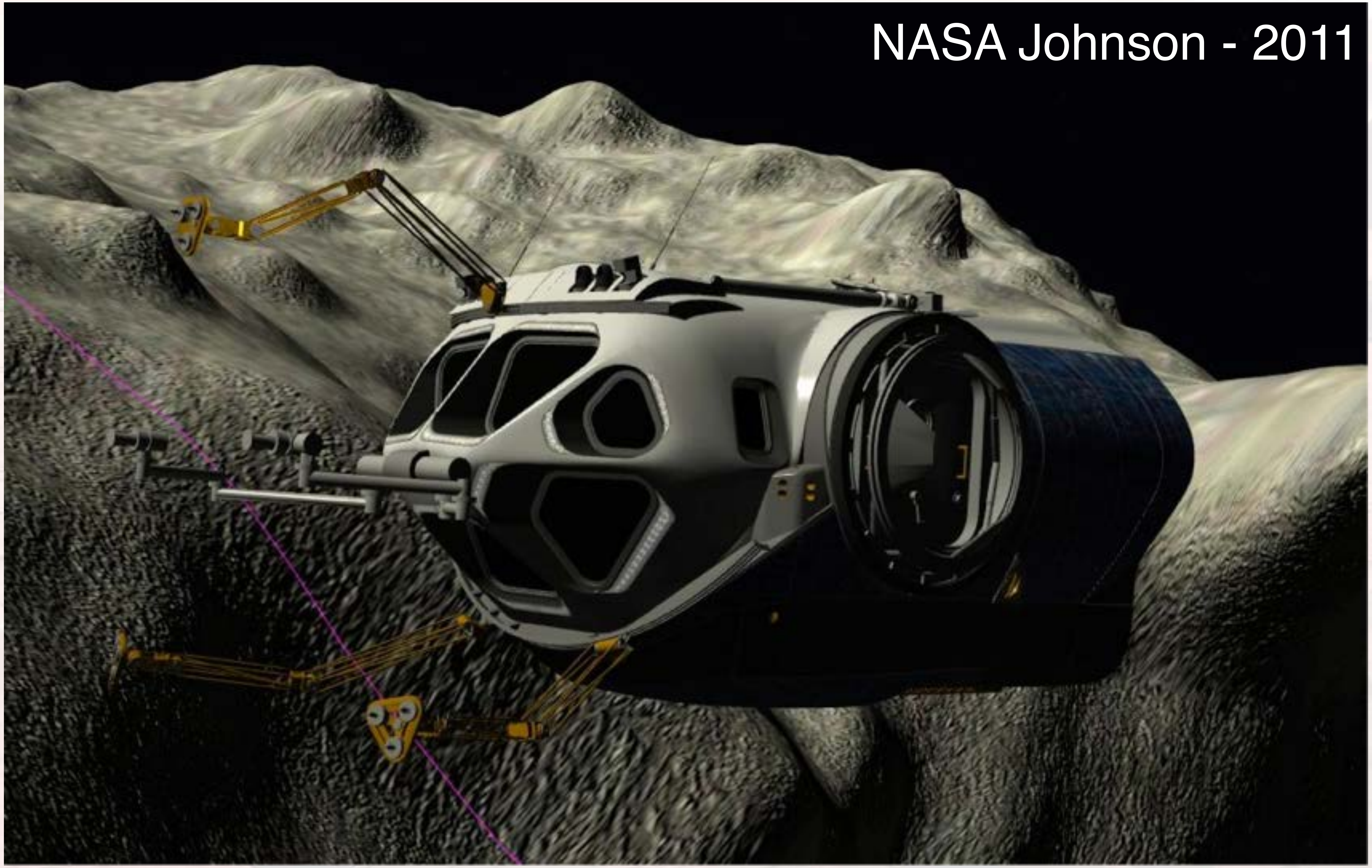




MAWS/Flexcraft



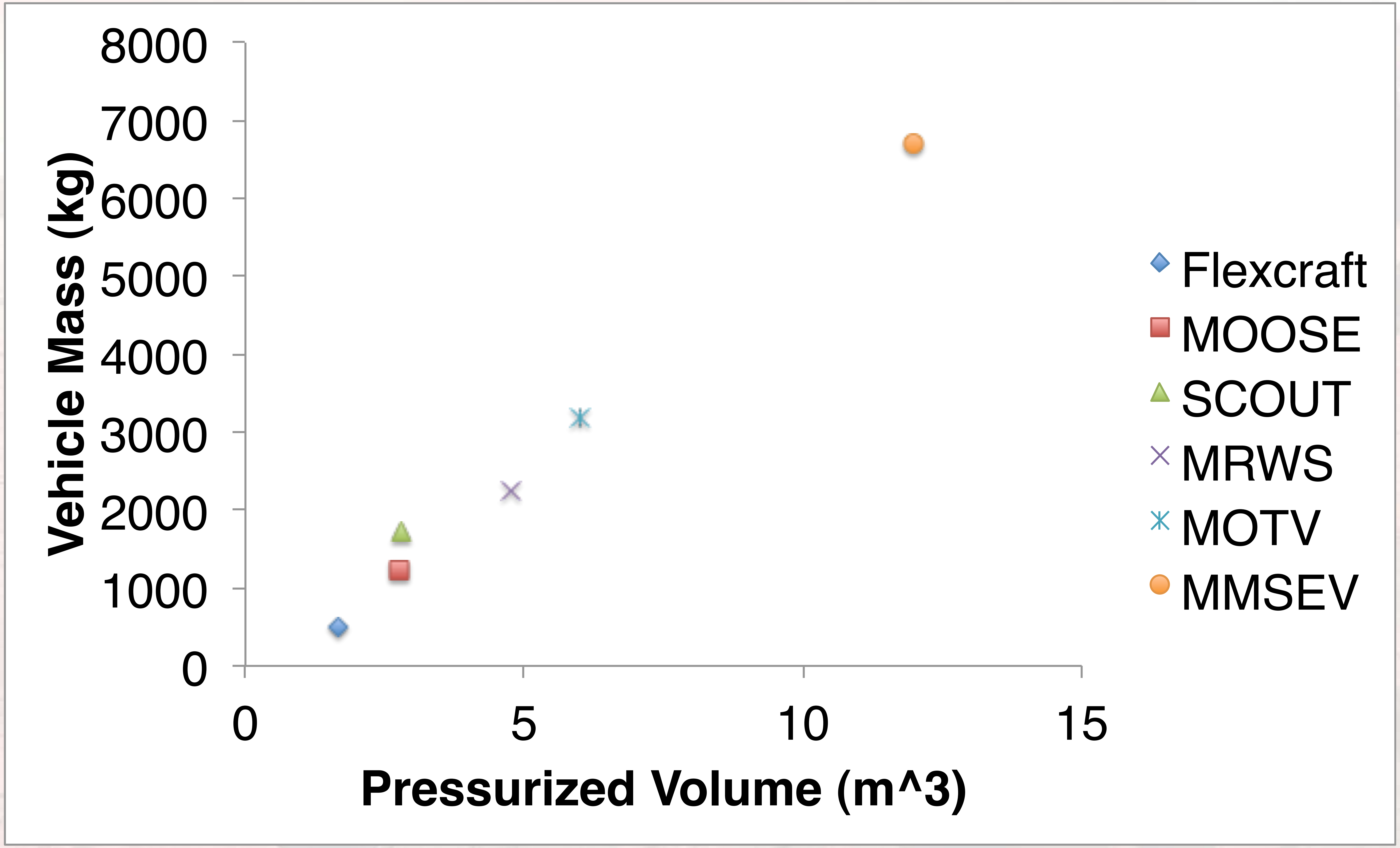
Multimode Space Exploration Vehicle (MMSEV)



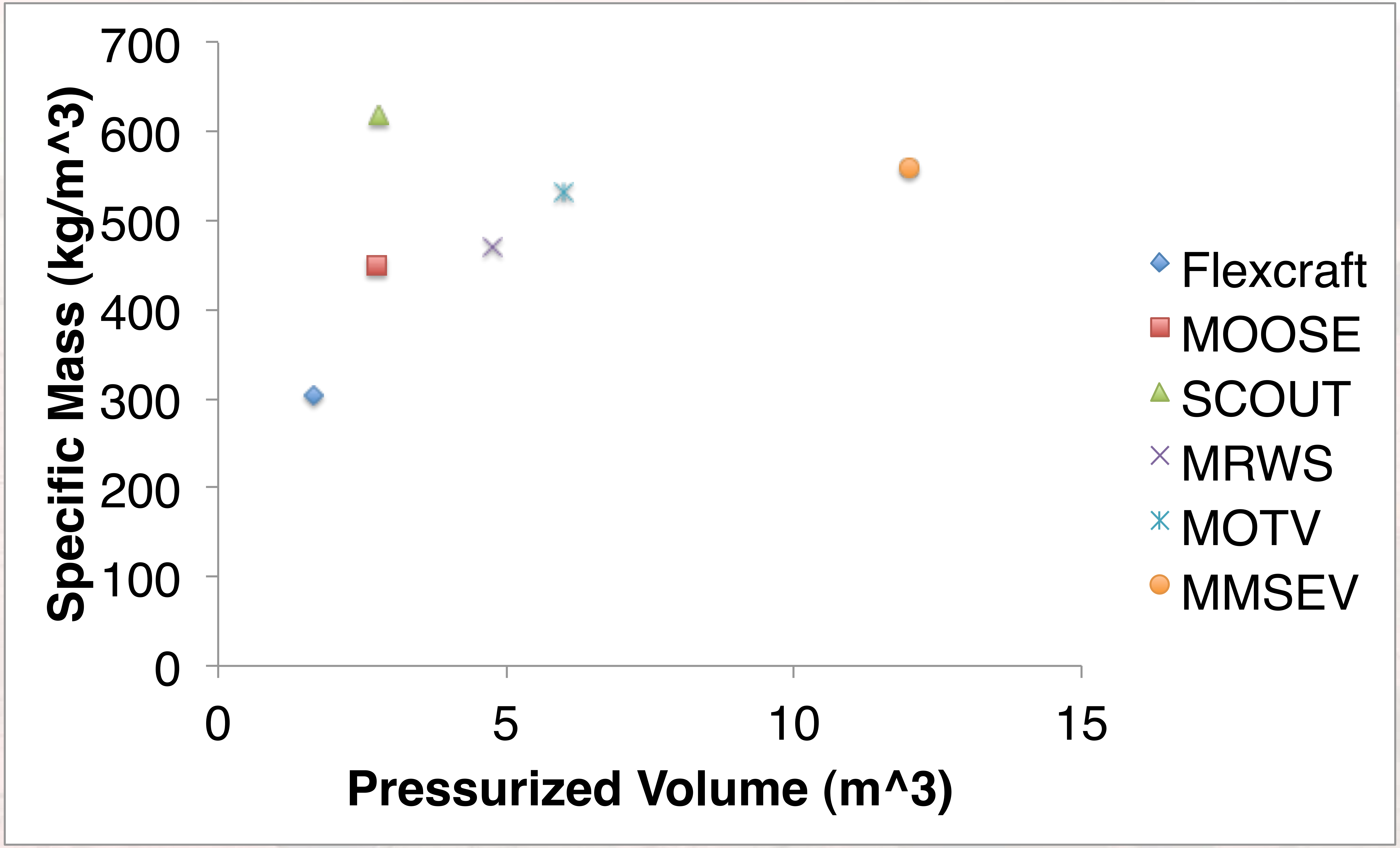
SUV Design Parameter Compilation

Parameter	MRWS[8]	MOTV[13]	MOOSE[17]	SCOUT[18]	MMSEV[23]	Flexcraft[20,21]
Mass (kg)	2244	3190	1235	1730	6700	500
Diameter (m)	1.70	3.0	1.75	1.5	4.5	1.2
Height (m)	2.50	2.8	1.3	2	6.8	2.5
Volume (m^3)	4.76	6.0	2.75	2.8	12	1.65
Crew size	1	2	1	1	2	1
Duration (hrs)	10	96	72	11	168	6
Dexterous arm(s)	2x2m	2x2.5m	1x4m	2x1.53m	2-3(?)	3x1m
Grapple arm(s)	1x1.3m	1x2 m	1x5m	1x2.89m	–	–
Human worksite access	Robotics	EVA	Suit arms/ robotics	Suit arms/ robotics	EVA	Robotics

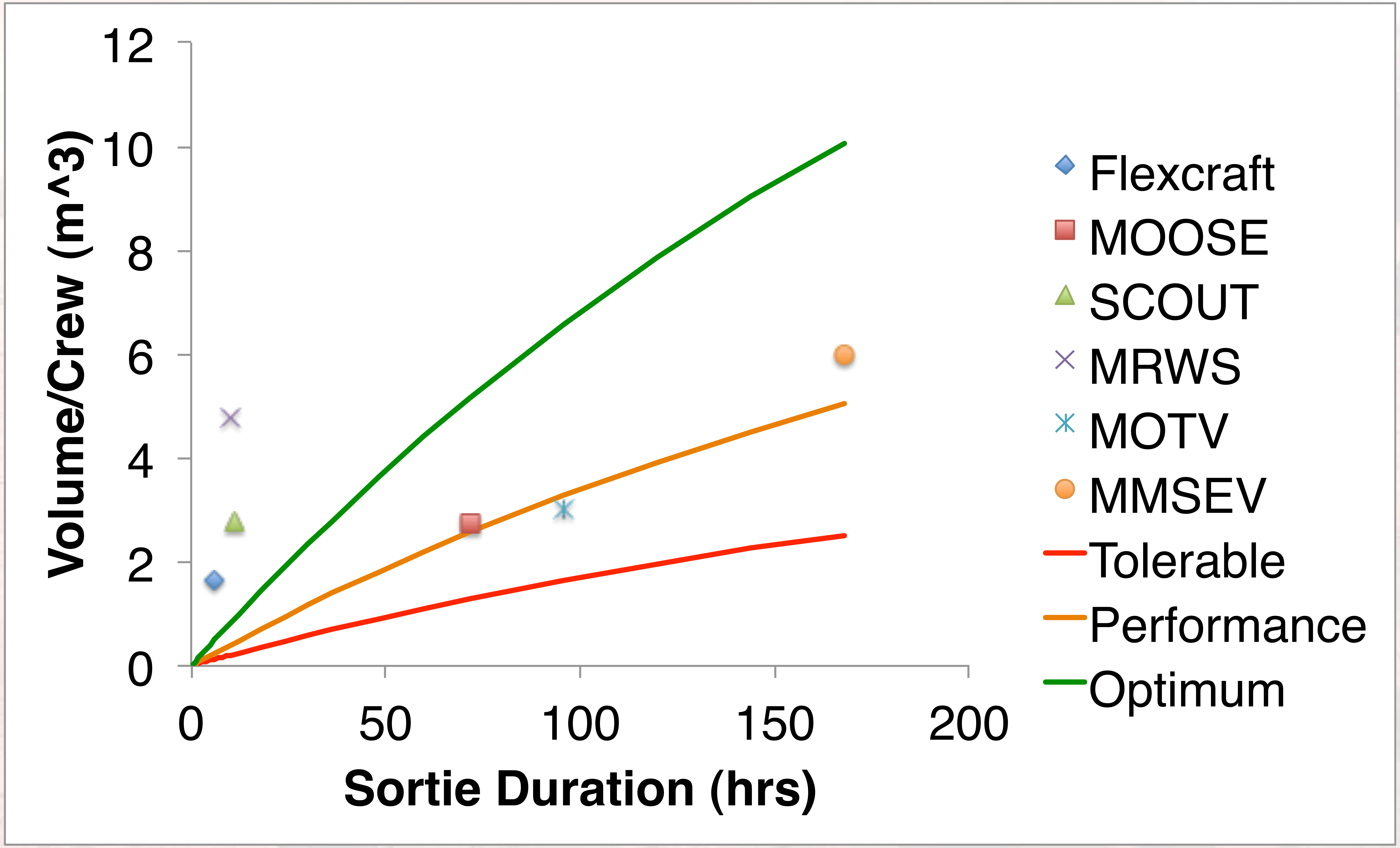
Vehicle Mass vs. Pressurized Volume



Specific Mass vs. Volume



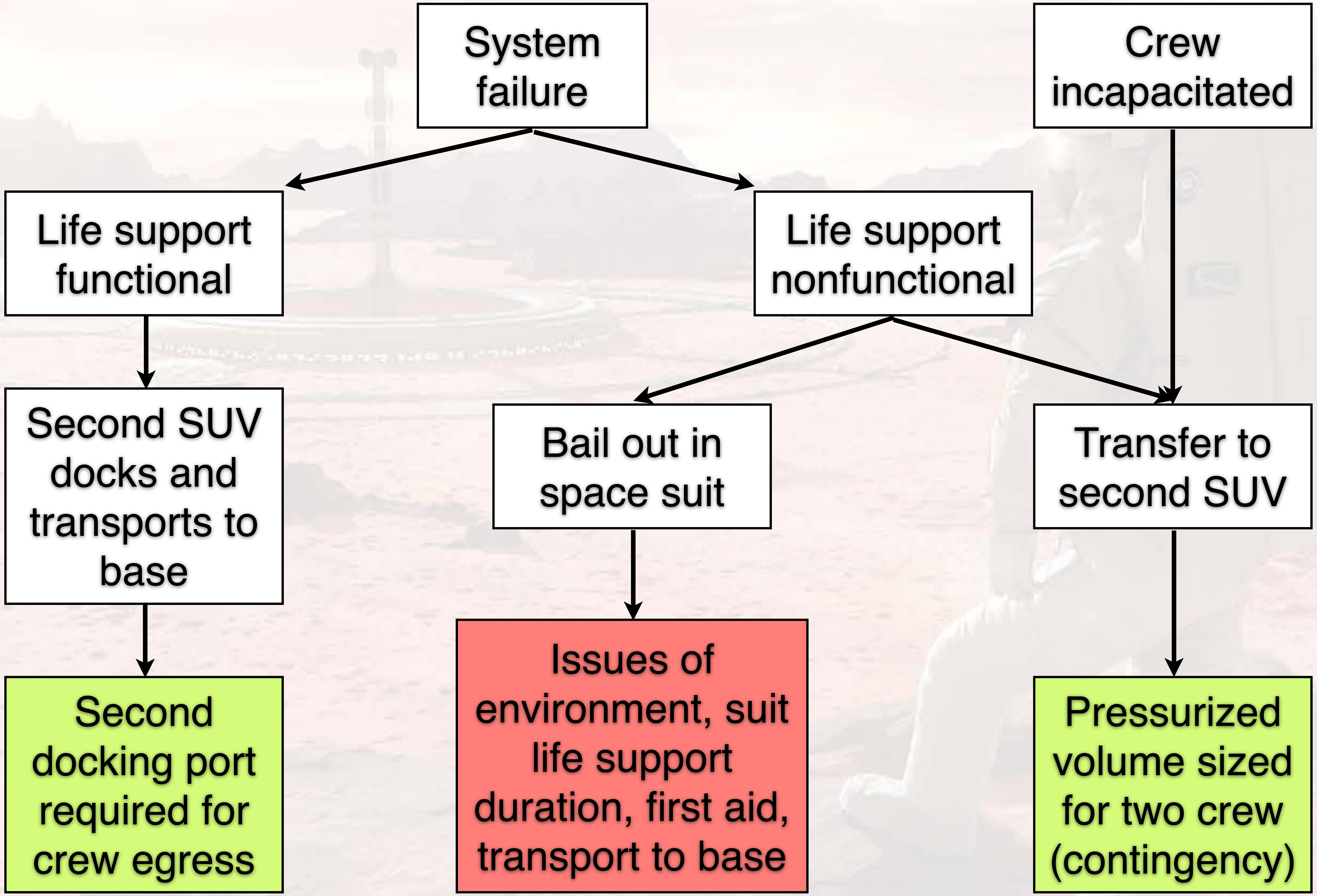
Volume Allocation vs. Celentano Curves



SUV Design Study Assumptions

- Single-person spacecraft
- Suit arms, dexterous robotics, and grappling arms
- No suit or suitport
- Dual SUV sorties for reliability
- Transport two crew in contingency
- Dual docking interfaces
- 10-12 hour sorties

Safety Implications of Dual SUV Sortie

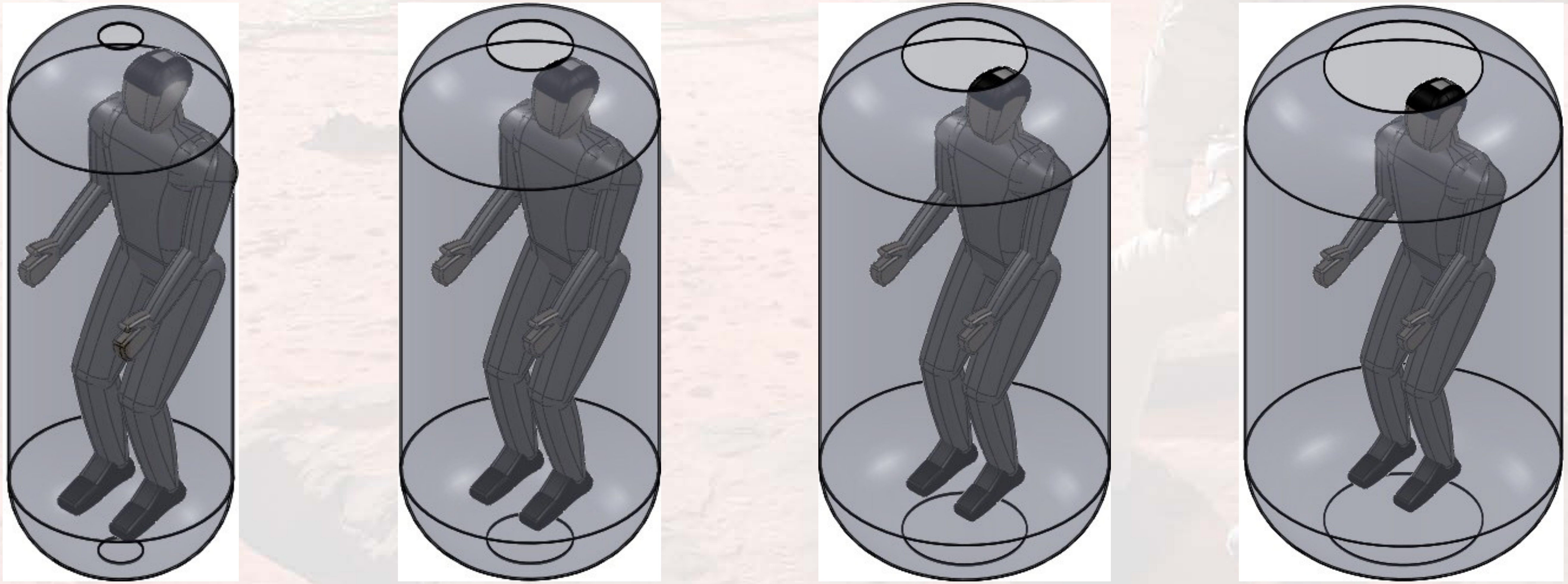


Pressure Hull Sizing Study

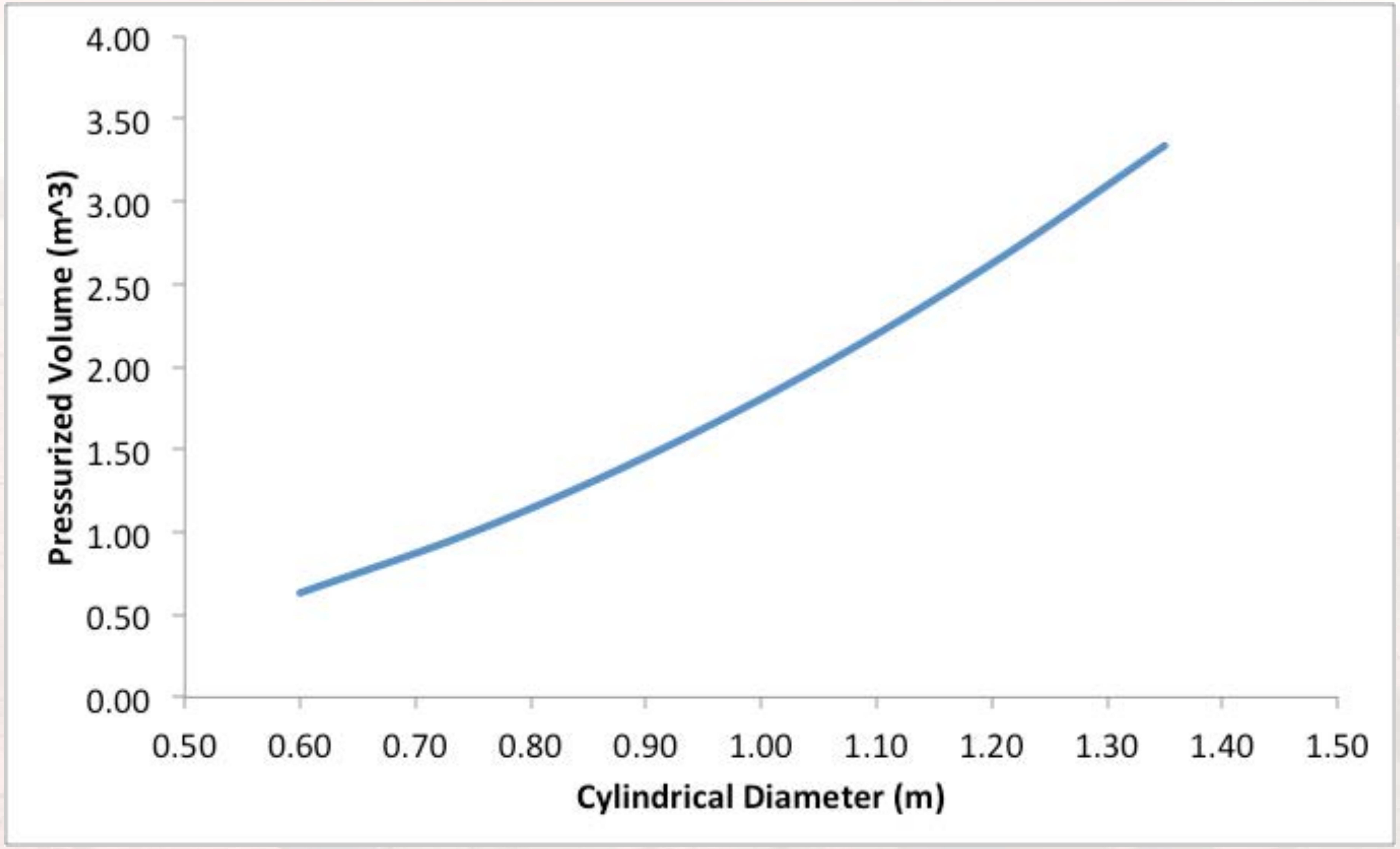
- Match pressure hull volumetric shape to human --> cylindrical hull
- Assume height of 2.13m (84in) and vary diameter
- Maintain constant diameter cylinder to allow docking interface on each end

Variation of Hull Diameter

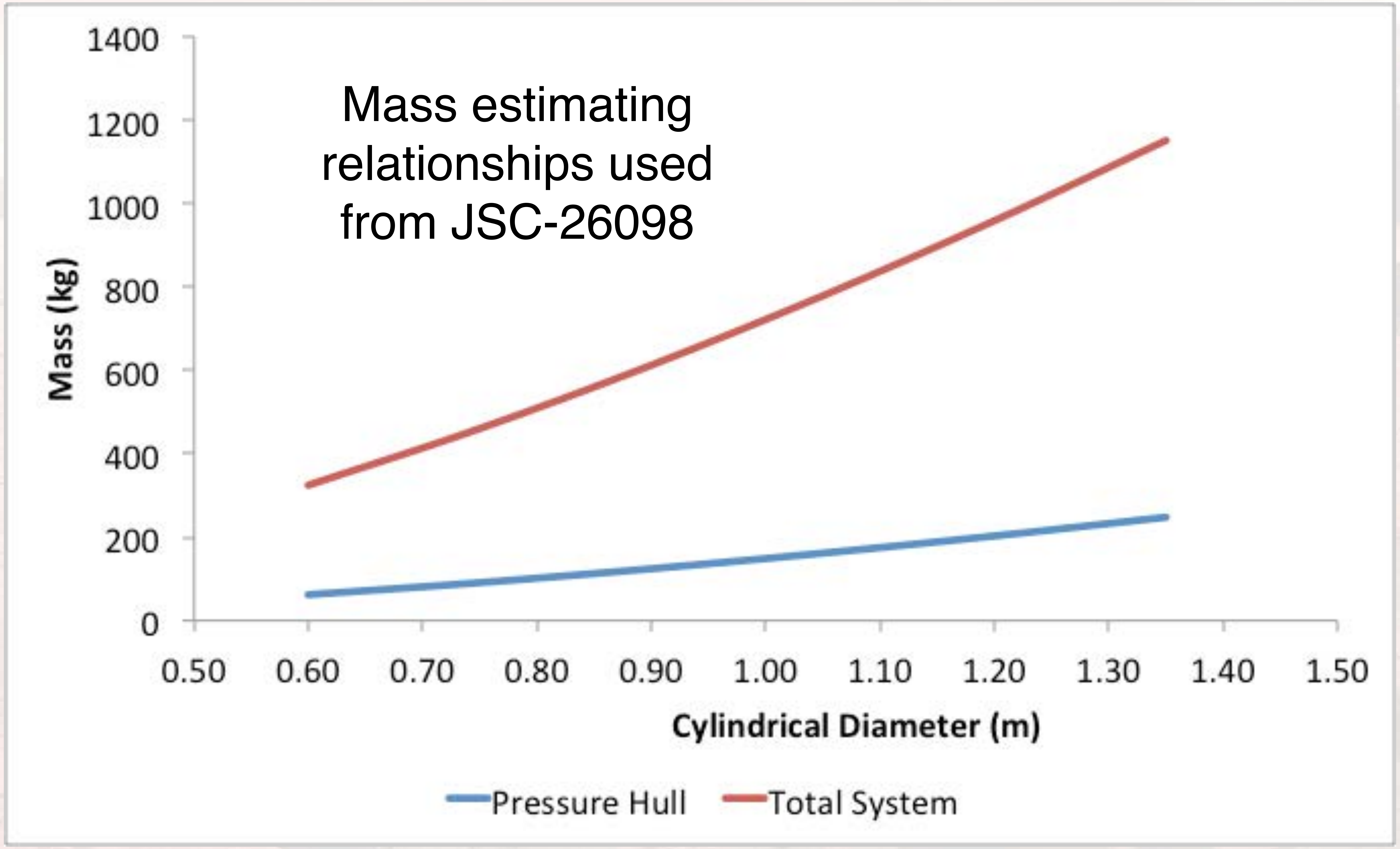
0.76 m 30 in | 0.91 m 36 in | 1.07 m 42 in | 1.22 m 48 in



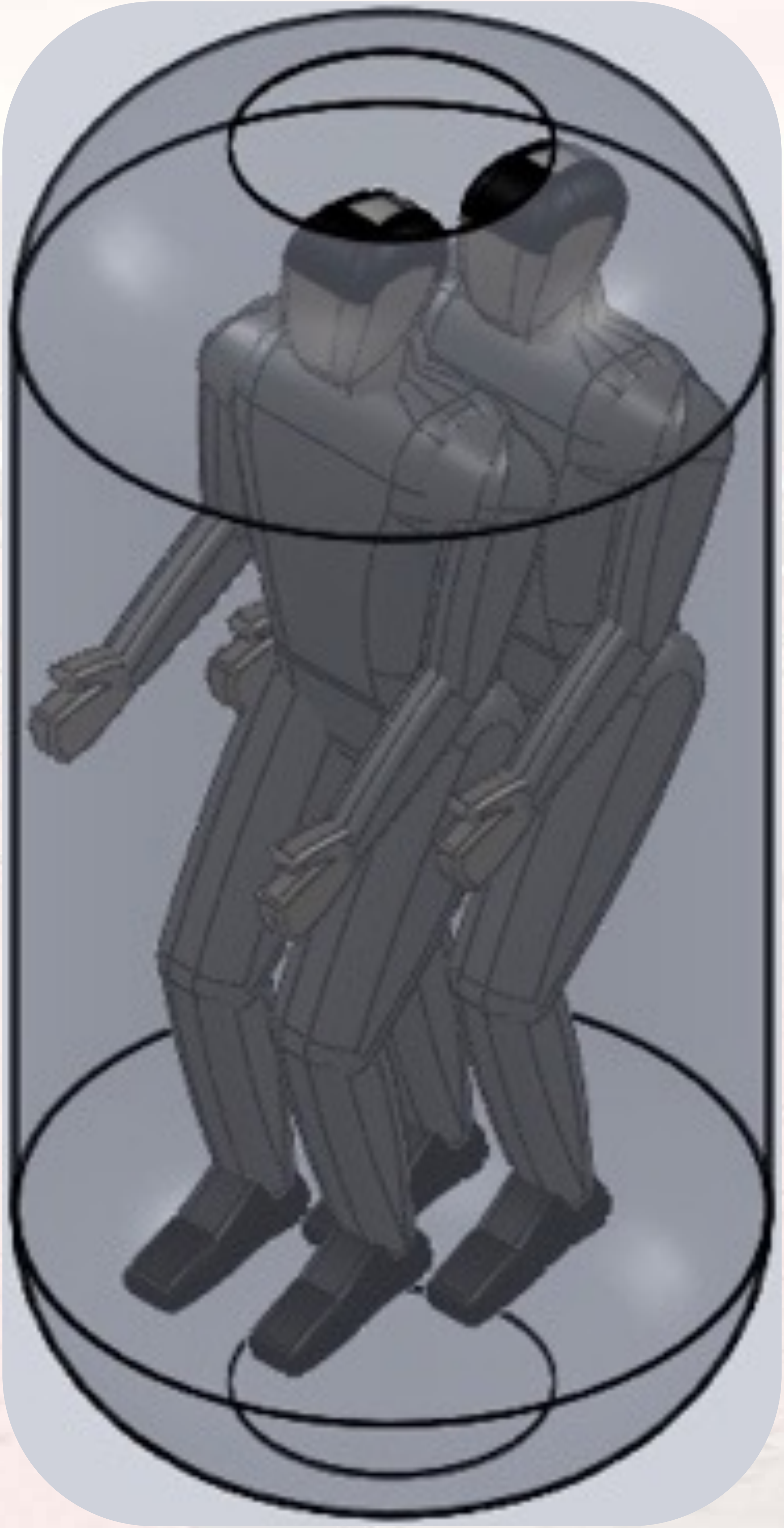
Variation of Volume with Diameter



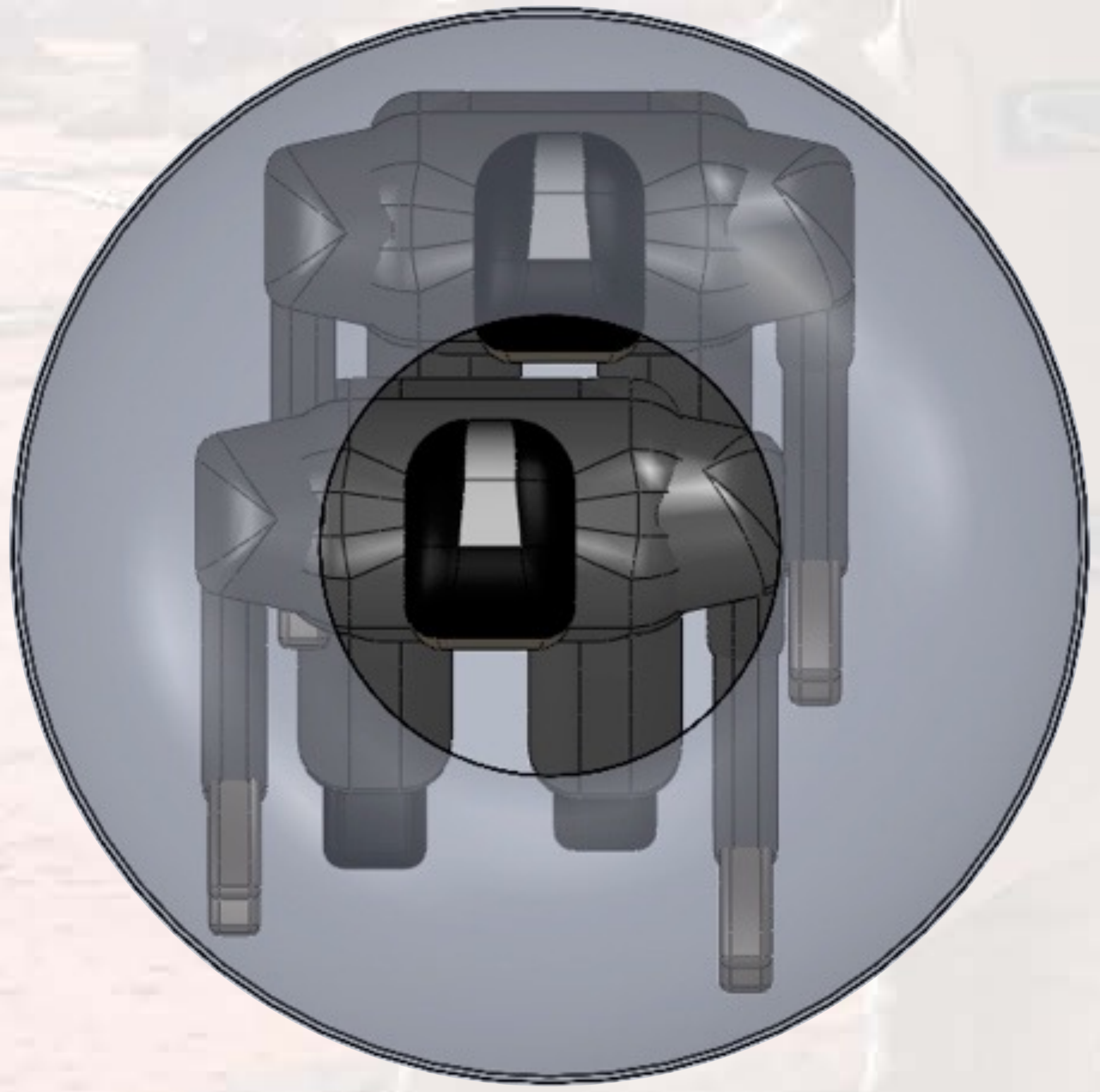
Estimated Mass with Diameter



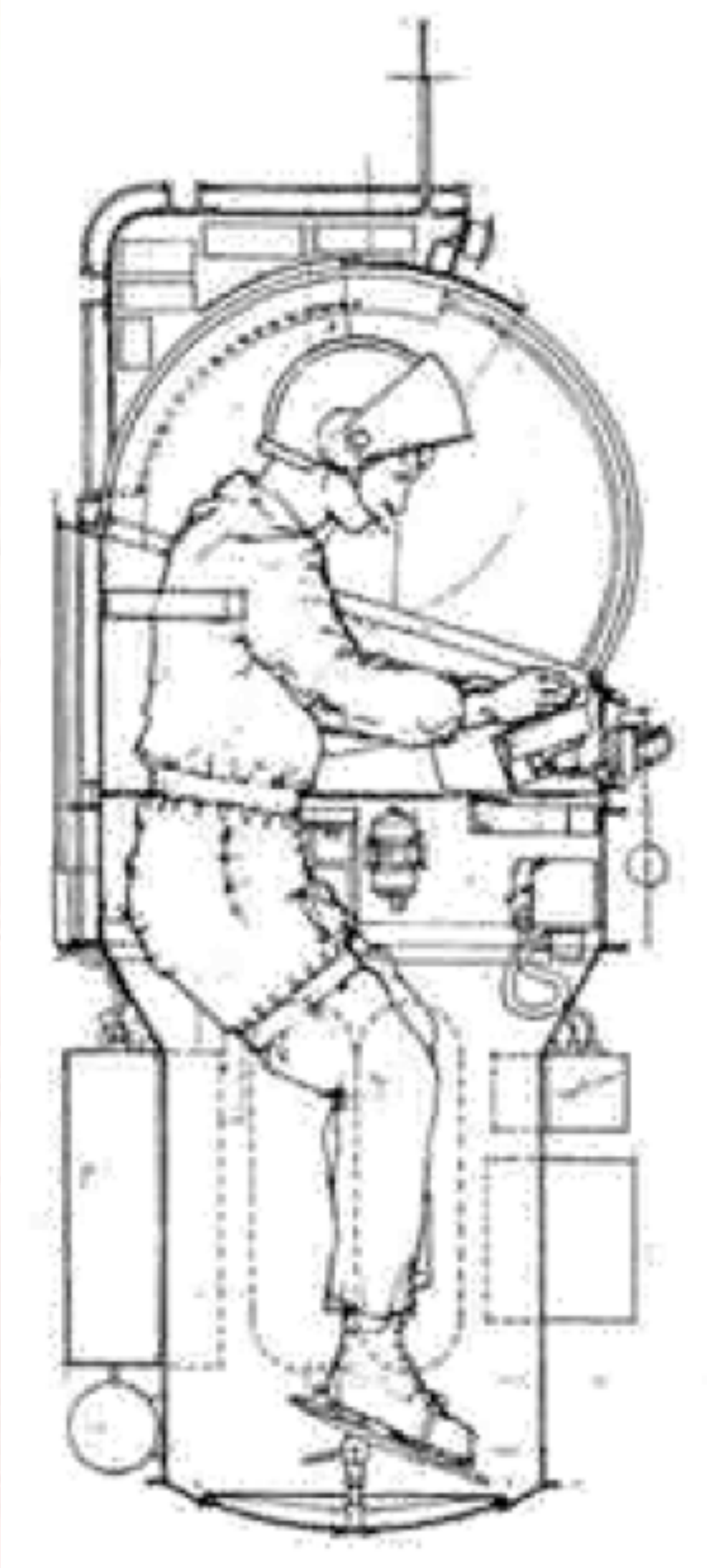
Two-Person Contingency Transport



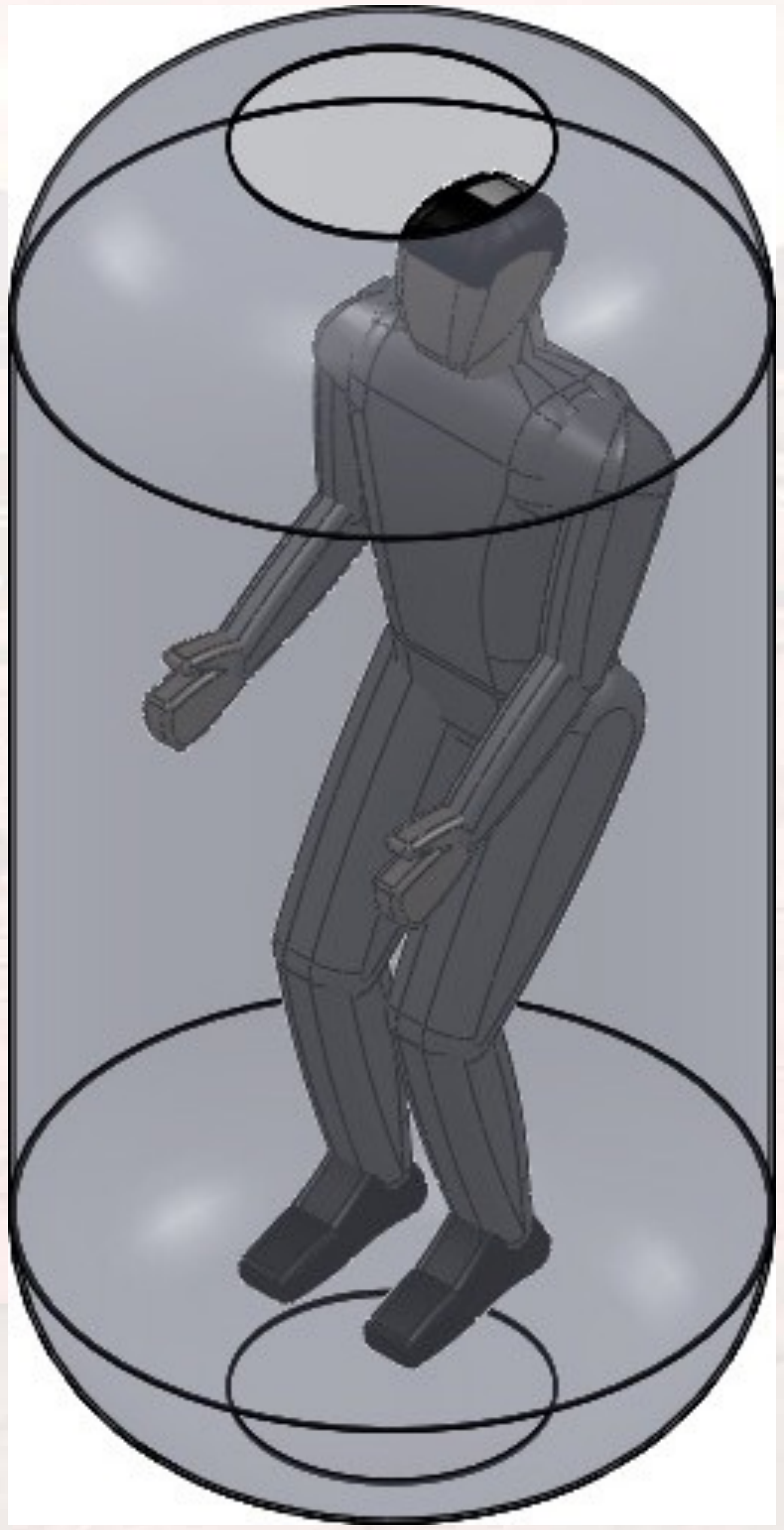
Hull diameter shown 1.07 m (42 in)

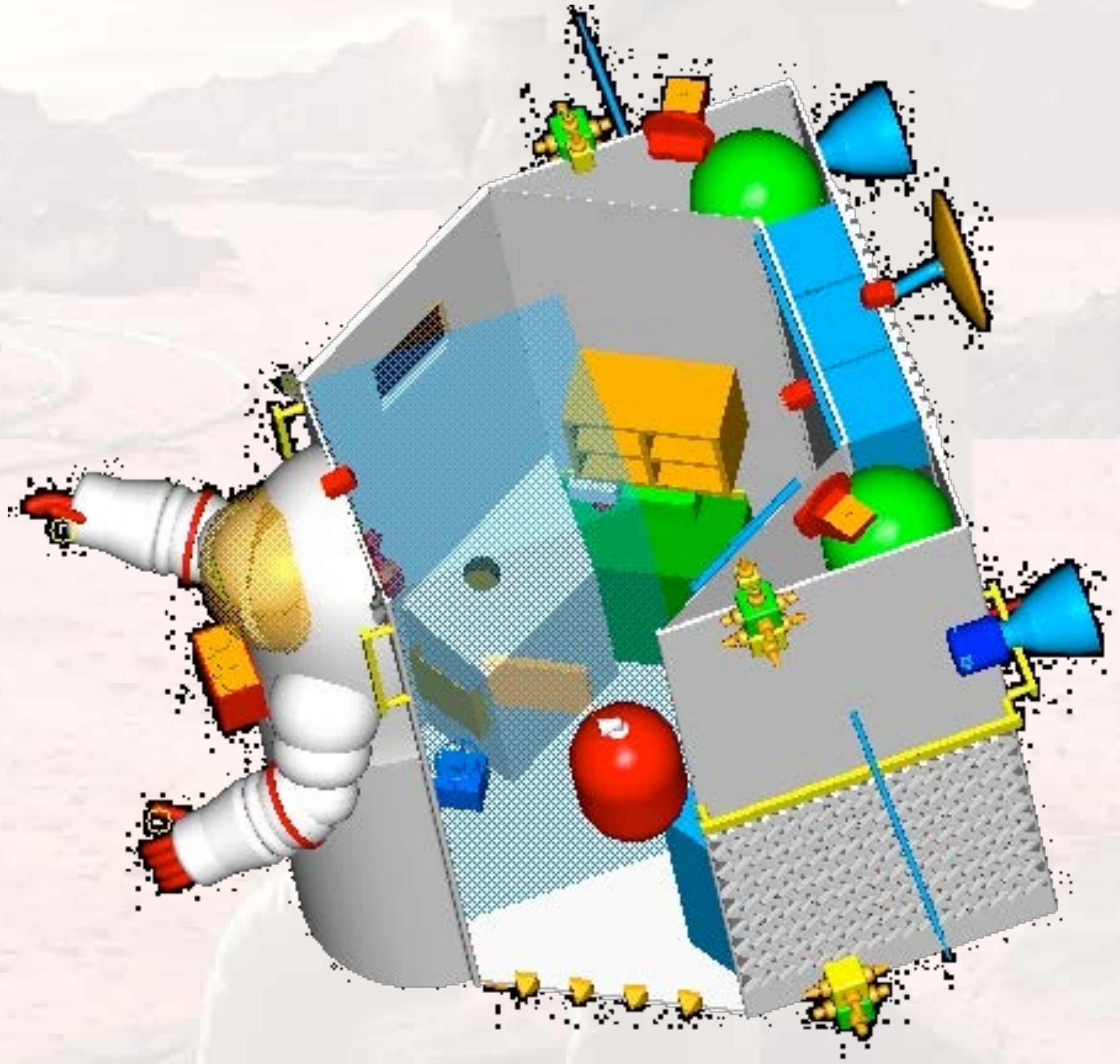


Comparison to Previous Designs



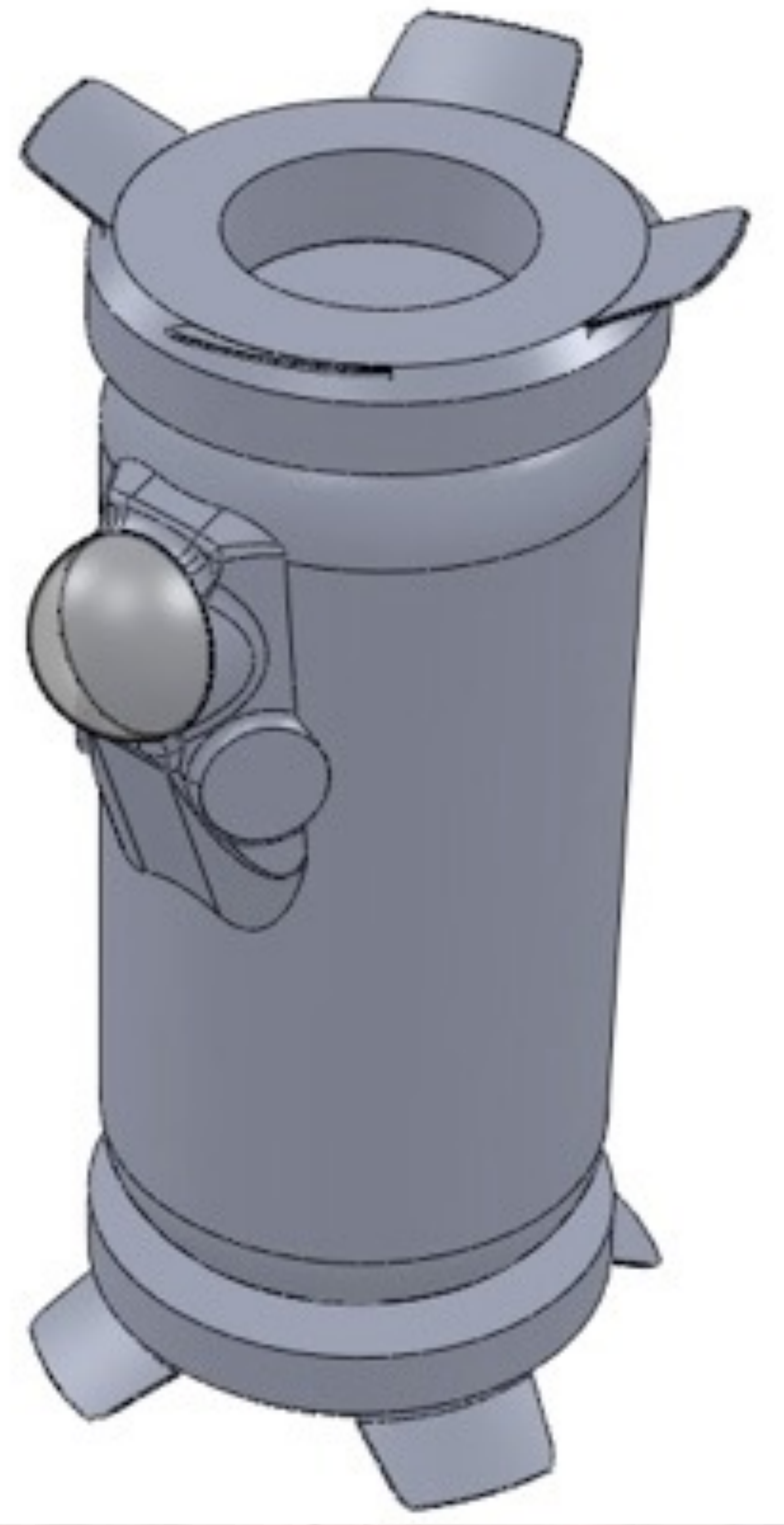
Flexcraft



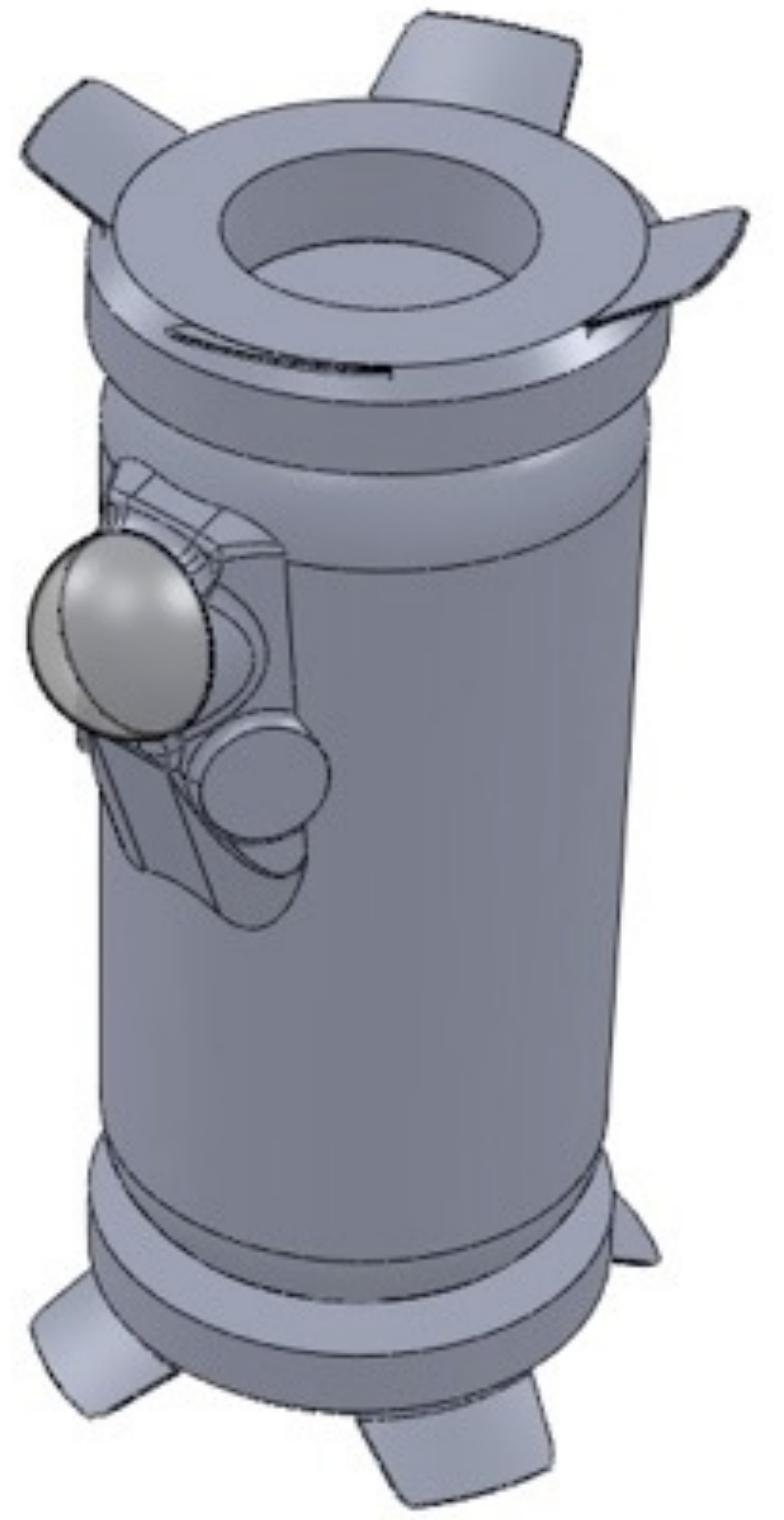


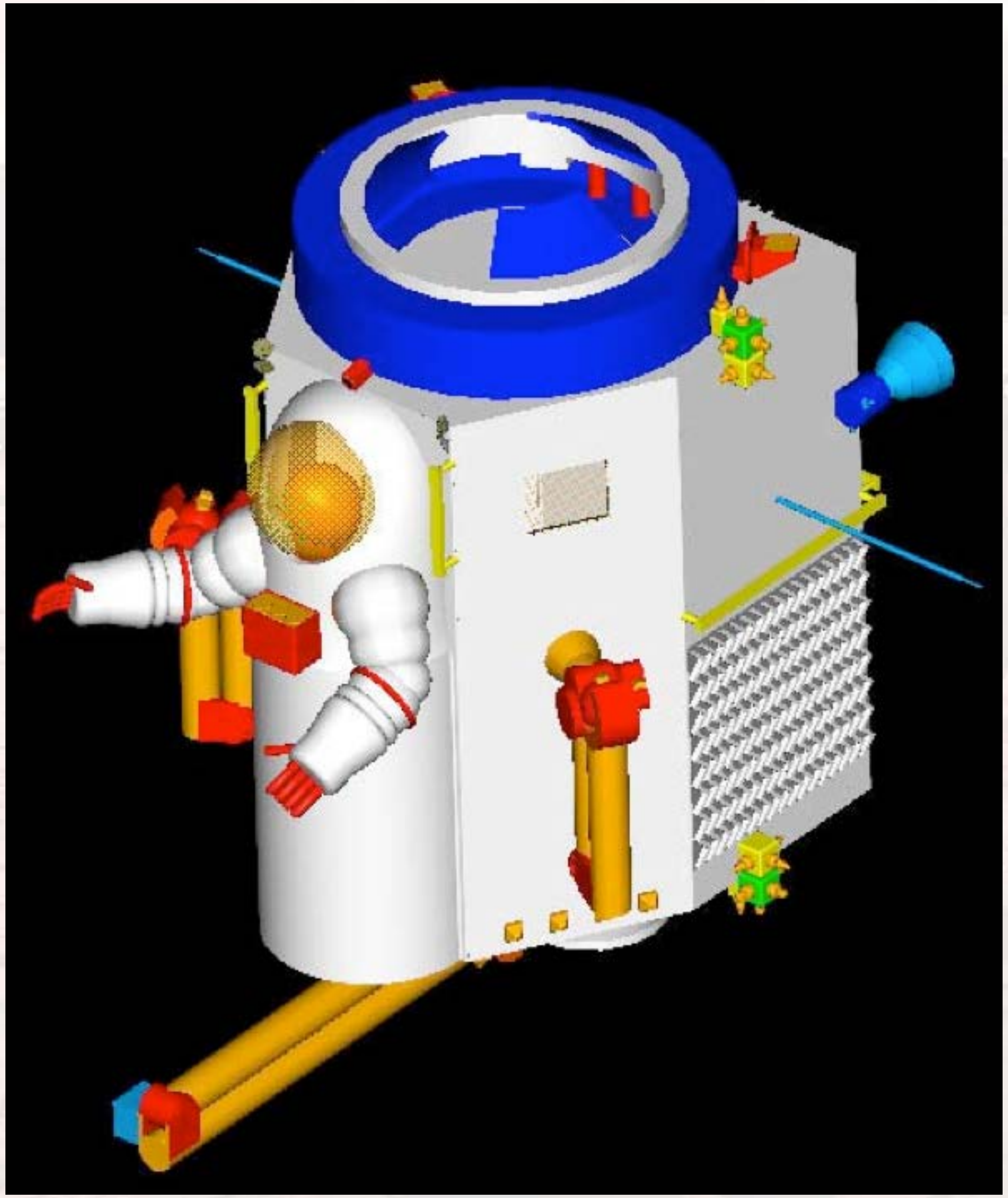
SCOUT

(Very) Notional SUV Configuration



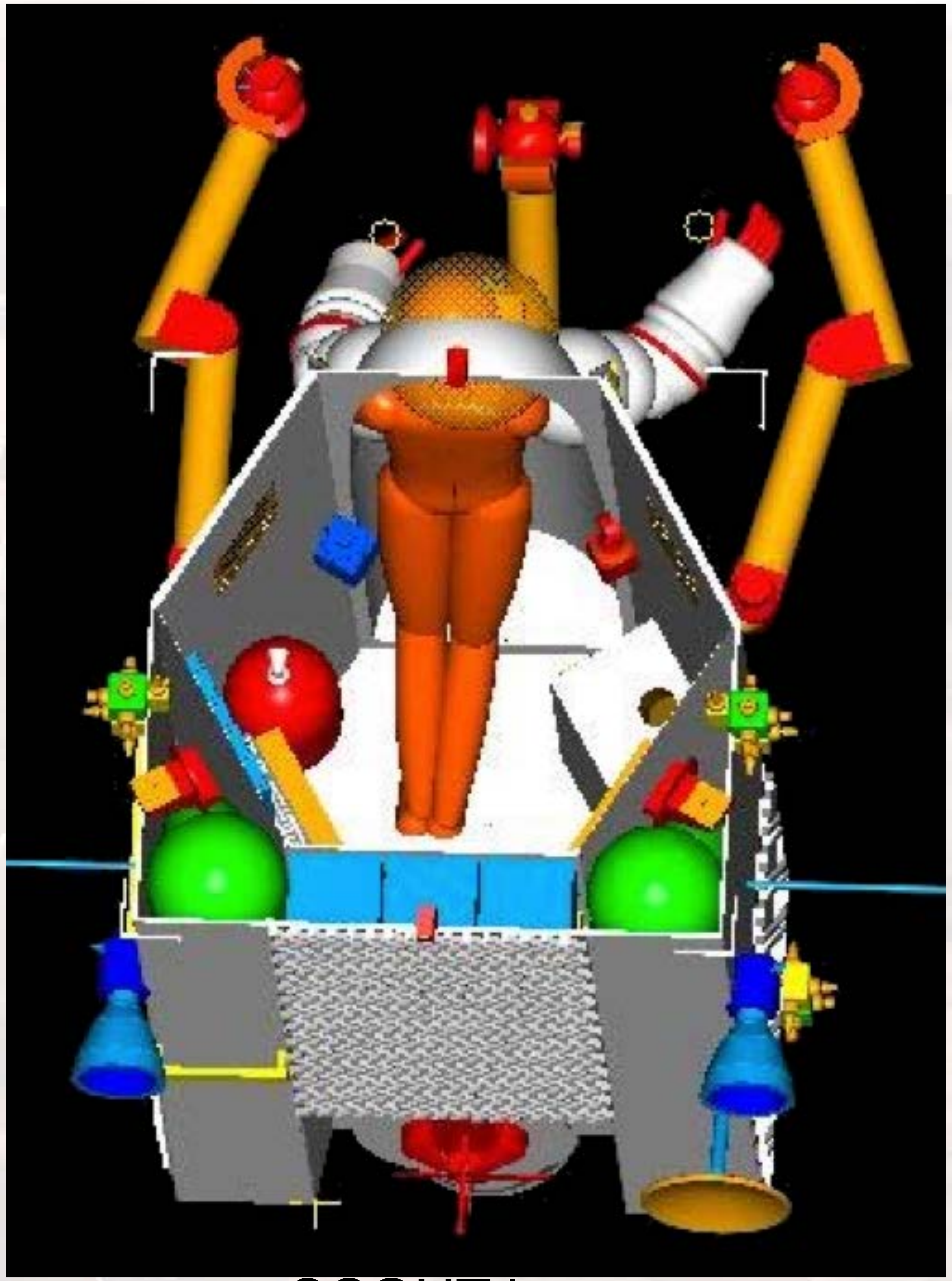
(Very) Notional SUV Configuration





External EVA Work Control Station

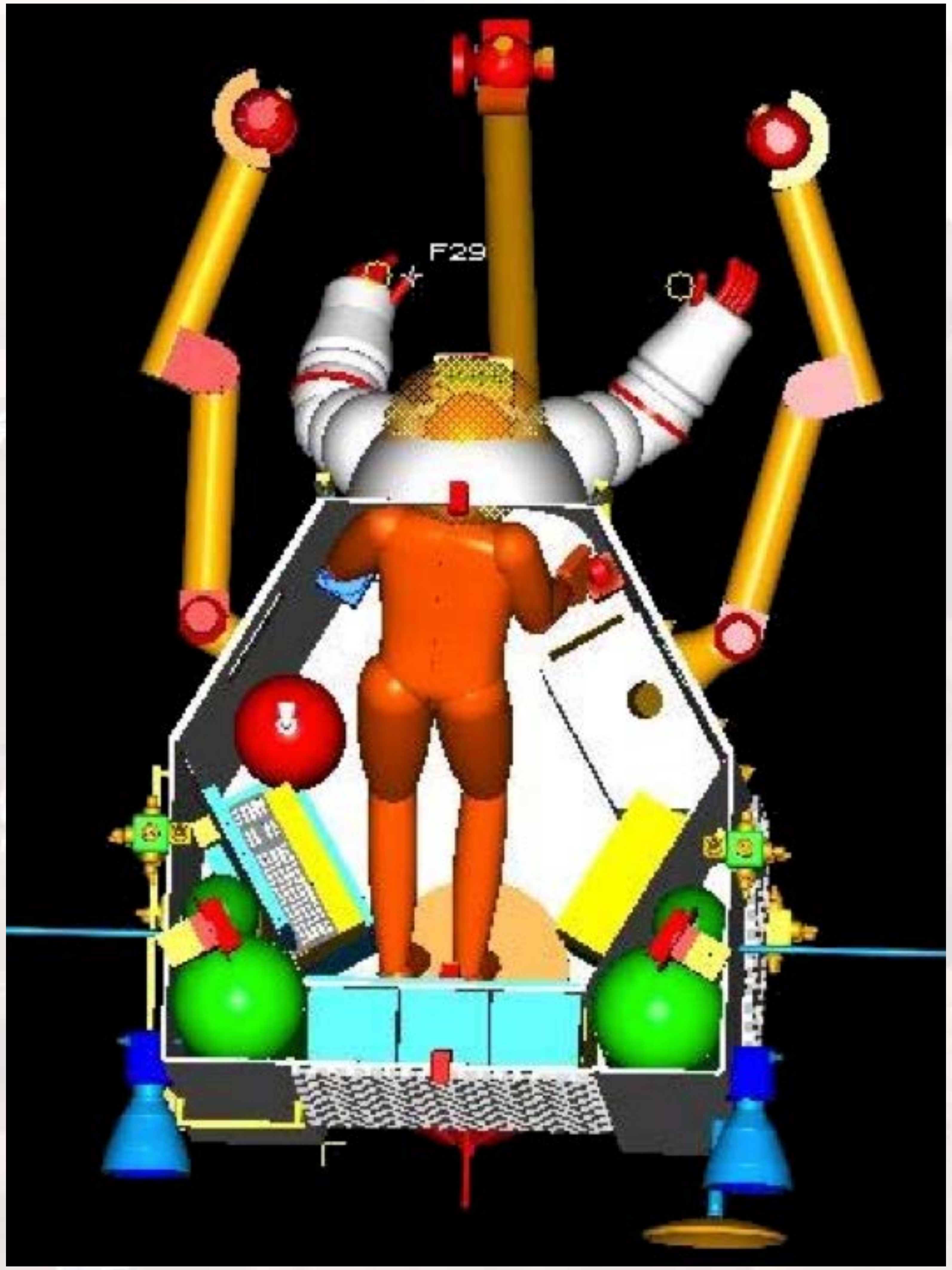
- External operations including use of suit arms
- Head in bubble helmet and arms in suit arms
- Supervisory control of manipulators and vehicle by voice and gestural commands
- Displays projected in bubble



SCOUT image

External Robotic Control Station

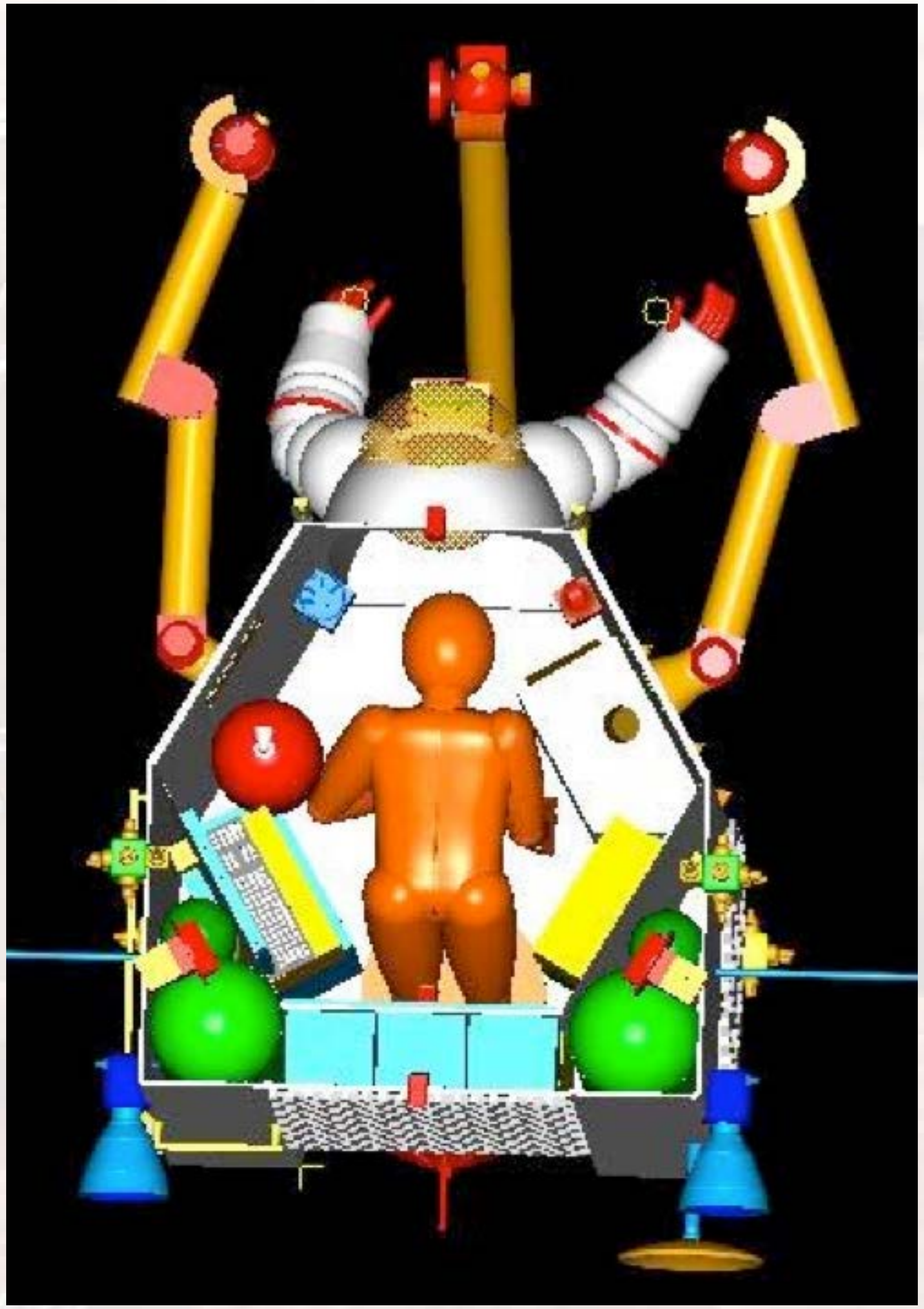
- External operations involving vehicle control or robotic manipulation
- Head in bubble and arms internal on hand controllers
- Simple motion to withdraw head to access supplemental internal displays



SCOUT image

Internal Control Station

- Crew entirely inside cylindrical volume
- Operations using conventional controls and displays
- Cameras available for external reference
- Used for vehicle systems monitoring, orbital maneuvering, crew operations


SCOUT image

Critical SUV Design Parameters (1)

- Interaction with the work site
  - Robotics and suit arms
  - *Allows crew to be "hands on" with work site when necessary with maximum environmental protection*
- Crew complement
  - One
  - *Two crew in two spacecraft minimize LOC probability when both can occupy one spacecraft in a contingency*
- Overall size
  - 2.5-3 m^3
  - *Minimize vehicle size while supporting two-person contingency operations*

Critical SUV Design Parameters (2)

- External visibility
  - Suit-type bubble plus windows
  - *Head-sized bubble easier to shield and protect than a full dome, while maximizing external situational awareness*
- Sortie duration
  - 13 hours
  - *Eight hours of nominal operations with three hours of translation to and from worksite and two hours of contingency*

Critical SUV Design Parameters (3)

- Dexterous manipulation
  - Two 1.5-2 meter dexterous manipulators with 7-8 DOF and interchangeable end effectors
  - *Provides maximum adaptability to a wide variety of tasks, and is scaled to provide appropriate work envelope in relation to vehicle size*
- Interface to worksite
  - 2.5-3 meter 6-7 DOF grapple arm compatible with WIF sockets, EVA handrails, and other expected hard points
  - *Provides sufficient restraint and vehicle positioning in relation to a wide variety of servicing targets*

Critical SUV Design Parameters (4)

- Atmosphere selection
  - Variable pressure and mixture from 14.7 psi/21% O_2 to 8 psi/32% O_2, with extension option to 5 psi/80% O_2
  - *Allows zero prebreathe for ISS operations, down to levels to maximize utility of suit arms*
- Environmental protection
  - Whipple shielding for MMOD; additional mass shielding for radiation protection tailorable to mission destination
  - *Provides maximum viable protection against ambient hazards*

Critical SUV Design Parameters (5)

- Host vehicle interfaces
  - Dual lightweight (possibly reduced size) NASA docking system ports
  - *Provides docking redundancy, and allows "rafting" of multiple vehicles to minimize impact on host vehicle*
- EVA support
  - Possible provision of external suit in suitport (?)
  - *Focus on minimizing need for traditional EVA to maximize mission application of SUV, particularly in hazardous environments such as GEO*

Potential SUV Mission Applications

- LEO servicing
  - Launch in Dragon extended trunk
  - Would require matching docking interface on Dragon
  - Supports dedicated servicing missions
- International Space Station maintenance
  - Launch in Dragon extended trunk
  - Would require docking interface adapter on CBM
  - Two SUVs needed for safety
  - Allows contingency external operations without prebreathing

Potential SUV Mission Applications

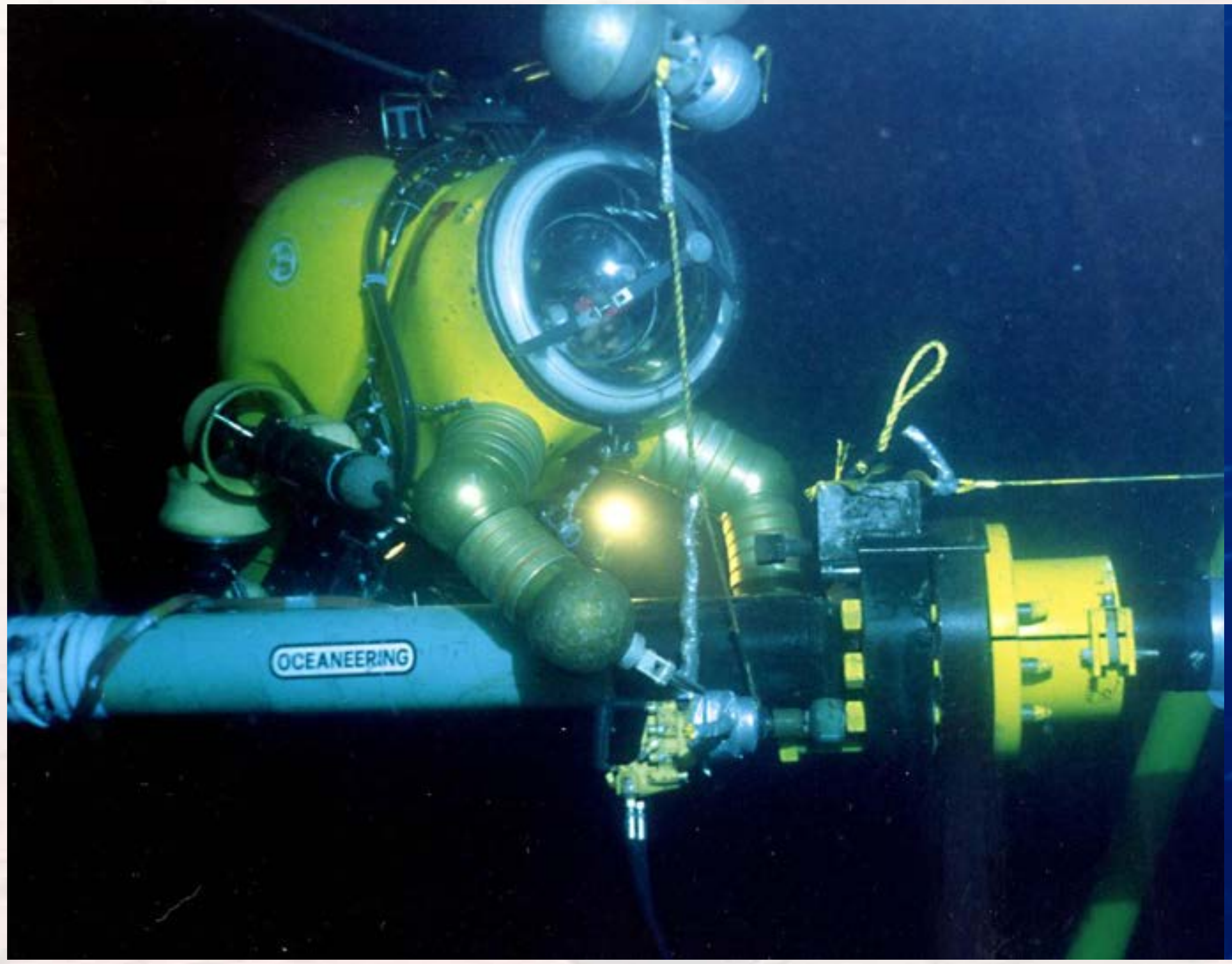
- GEO servicing
  - Can be equipped with radiation shielding for GEO environment
  - Allows human/robotic servicing of critical assets
  - Potentially profitable method to extend human presence beyond LEO in near term
- Asteroid/comet missions
  - SUV provides protection against unknown environmental hazards (e.g., loose aggregates)
  - Free-flight capability provides positional control in microgravity environment
  - Does not require cabin depressurization for EVA

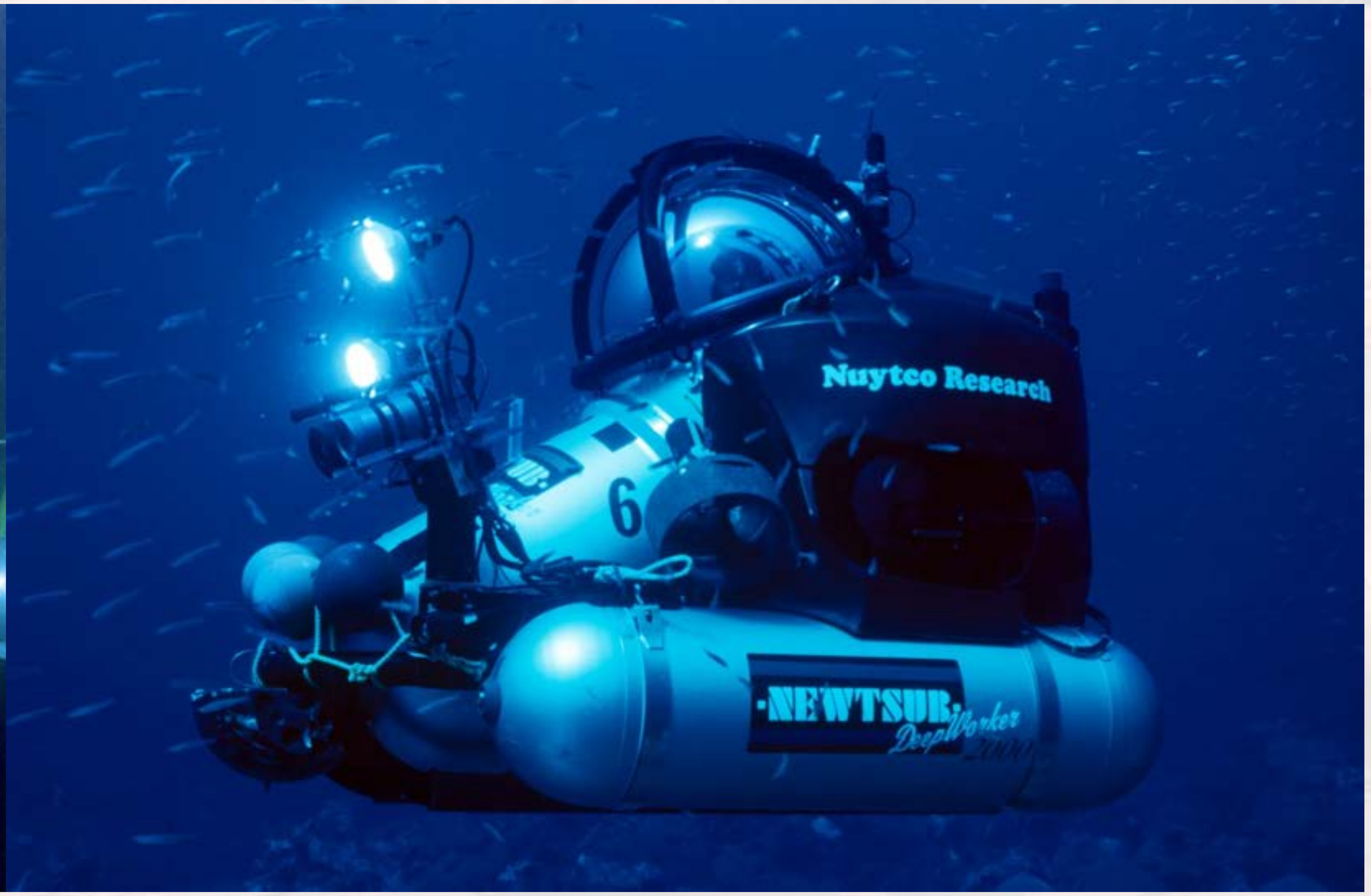
Potential SUV Mission Applications

- Deep Space Habitat support
  - Additional radiation protection
  - No prebreathing
  - Additional capabilities in communications (DTE)
  - Supports servicing across developing infrastructure at L1/L2/low gravitational gradient sites of interest
- Other application domains?

SUV Concept - Reality Check?

- Undersea operations have SUV-class vehicles
- Avoids decompression problems with deep dives
- Viable despite lack of glove analogue, or (in some cases) arms at all





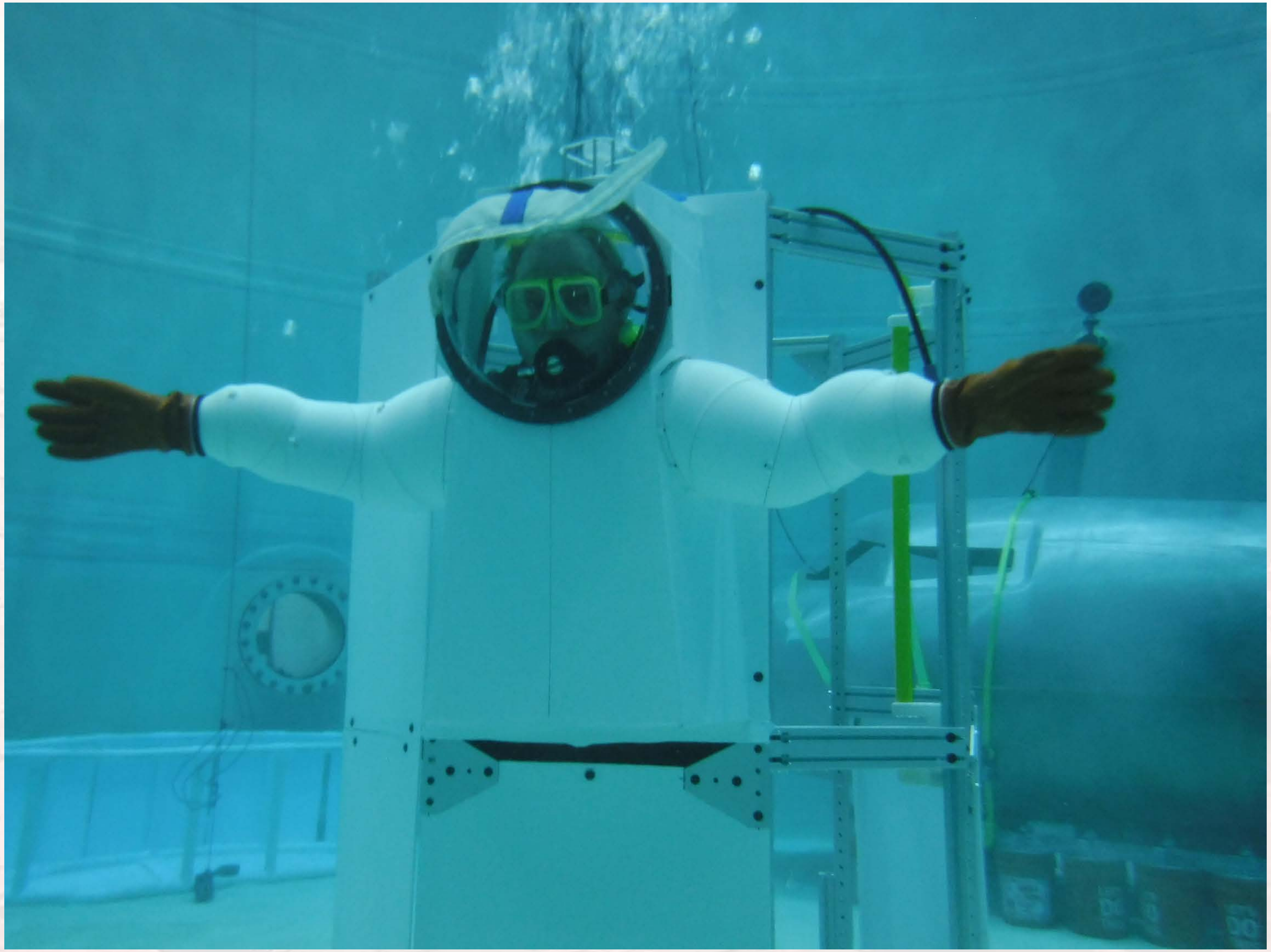
Conclusions

- The SUV concept (in many forms and with many names) has been given short shrift for more than a half century
- Few past studies were done, and few details of those survive
- There is currently no experimental data to indicate the capabilities (and limitations) of the concept
- A moderate development program would allow quantitative evaluation of the concept and refinement of design concepts

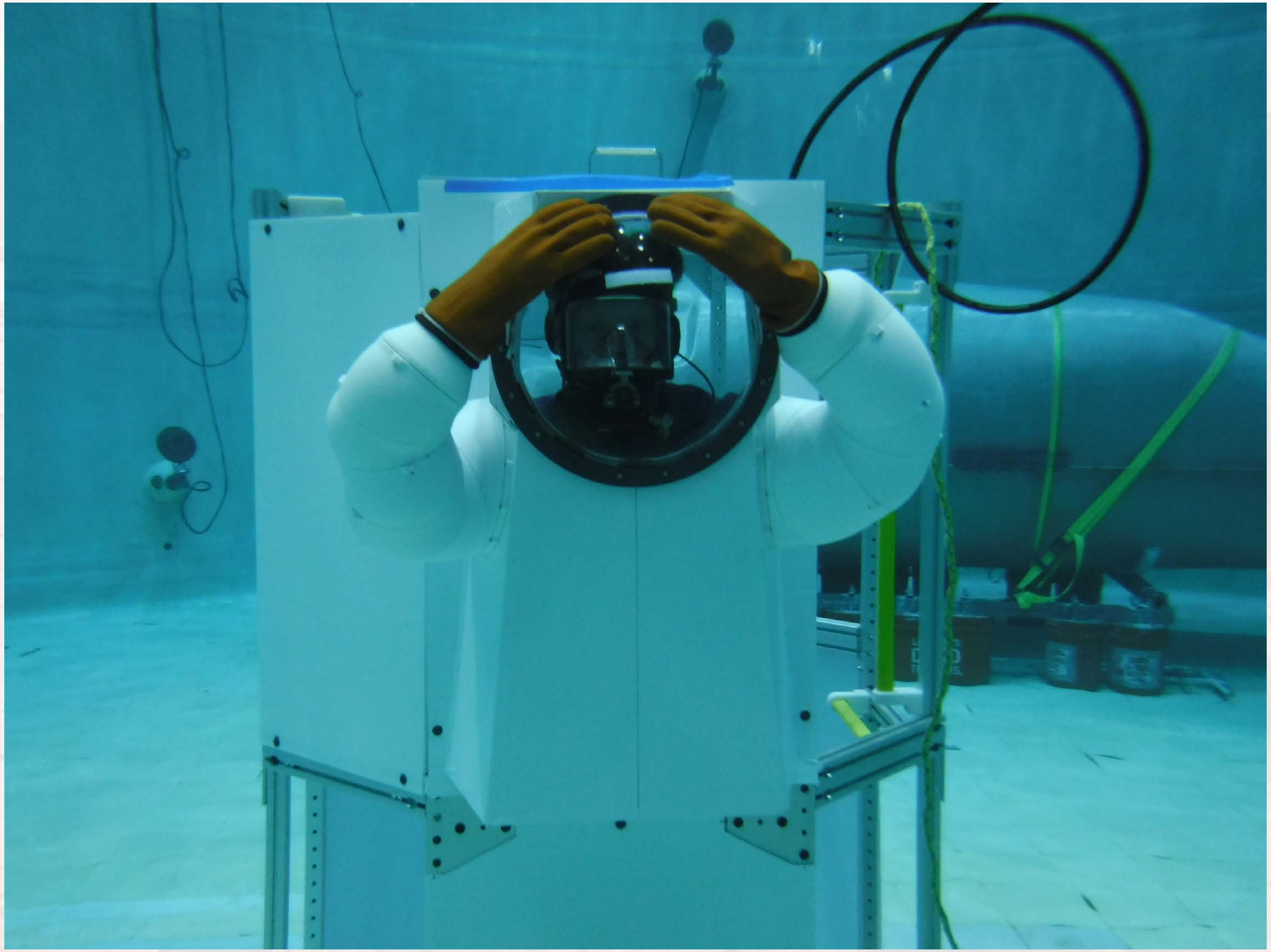
FlexCraft Mockup by Genesis Engineering

FlexCraft Guest Test Pilot Program

Initial Suit Element Testing in Water

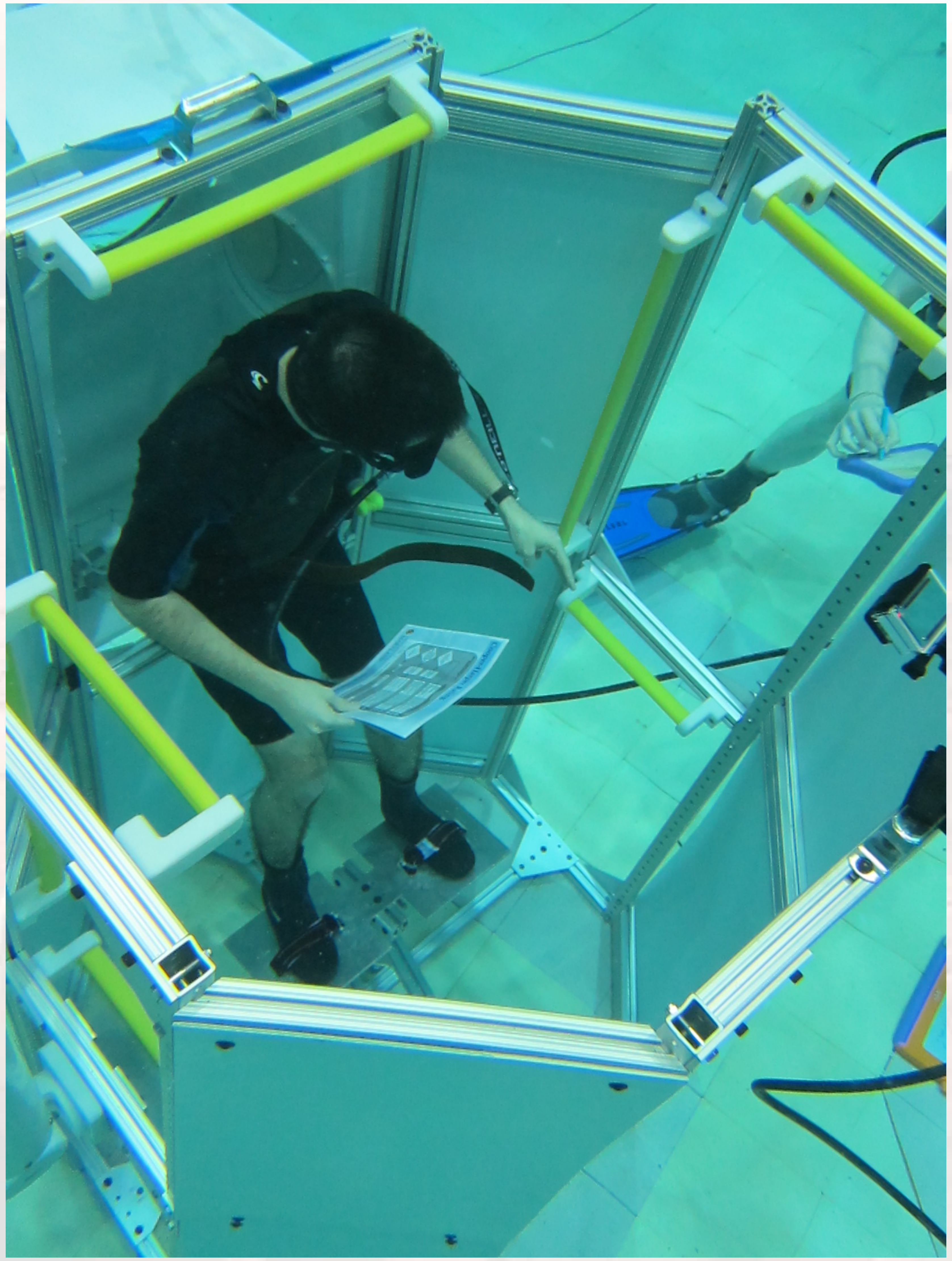


Suit Arm Range of Motion



Internal Handrail Assessment

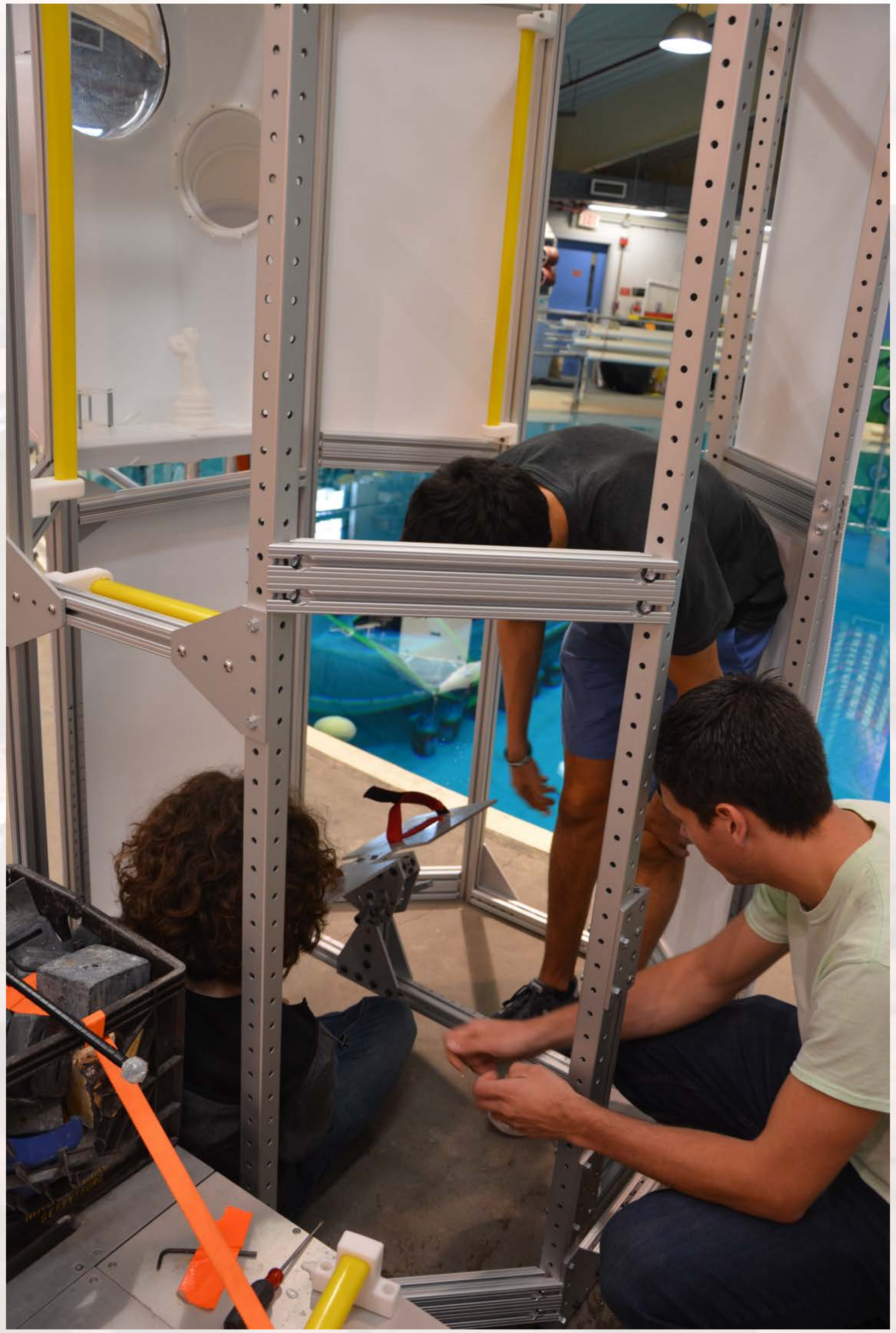
- Handrails are critical for mobility and informal restraints
- Standard handrail extrusion used with 3D printed mounts to attach to 80/20 elements
- Informal assessment of locations and numbers of handrails led to adoption of a baseline configuration



Initial Foot Restraint Configuration

2017 ENAE 100 Project: Foot Restraints

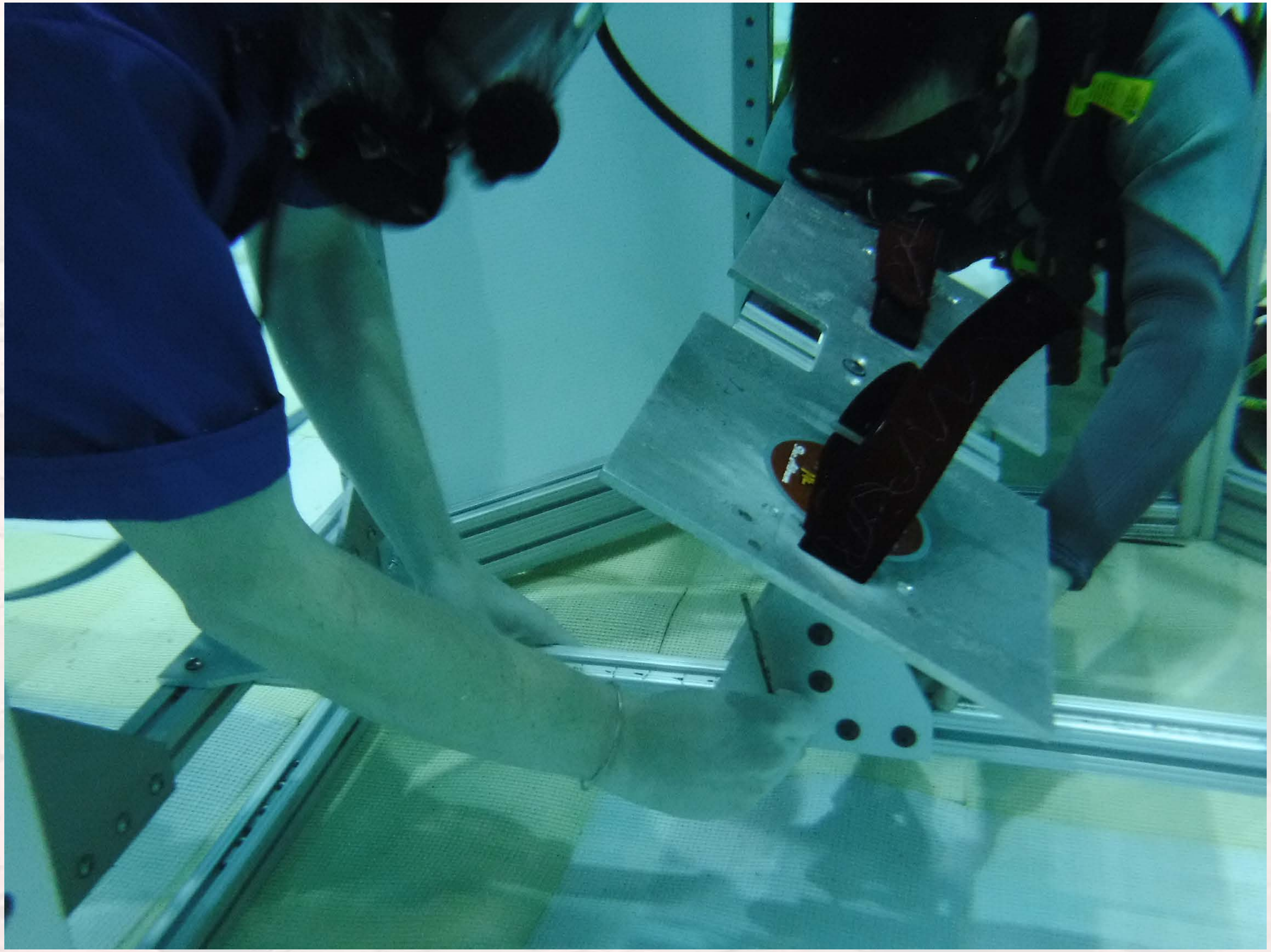
- Four work station positions identified:
  - Head in bubble/arms in suit
  - Head in bubble/arms on sticks
  - Head and arms internal
  - Head in bubble reversed for visual docking
- ENAE 100 team tasked with designing/fabricating/testing 3DOF foot restraints (restricted to sagittal plane)



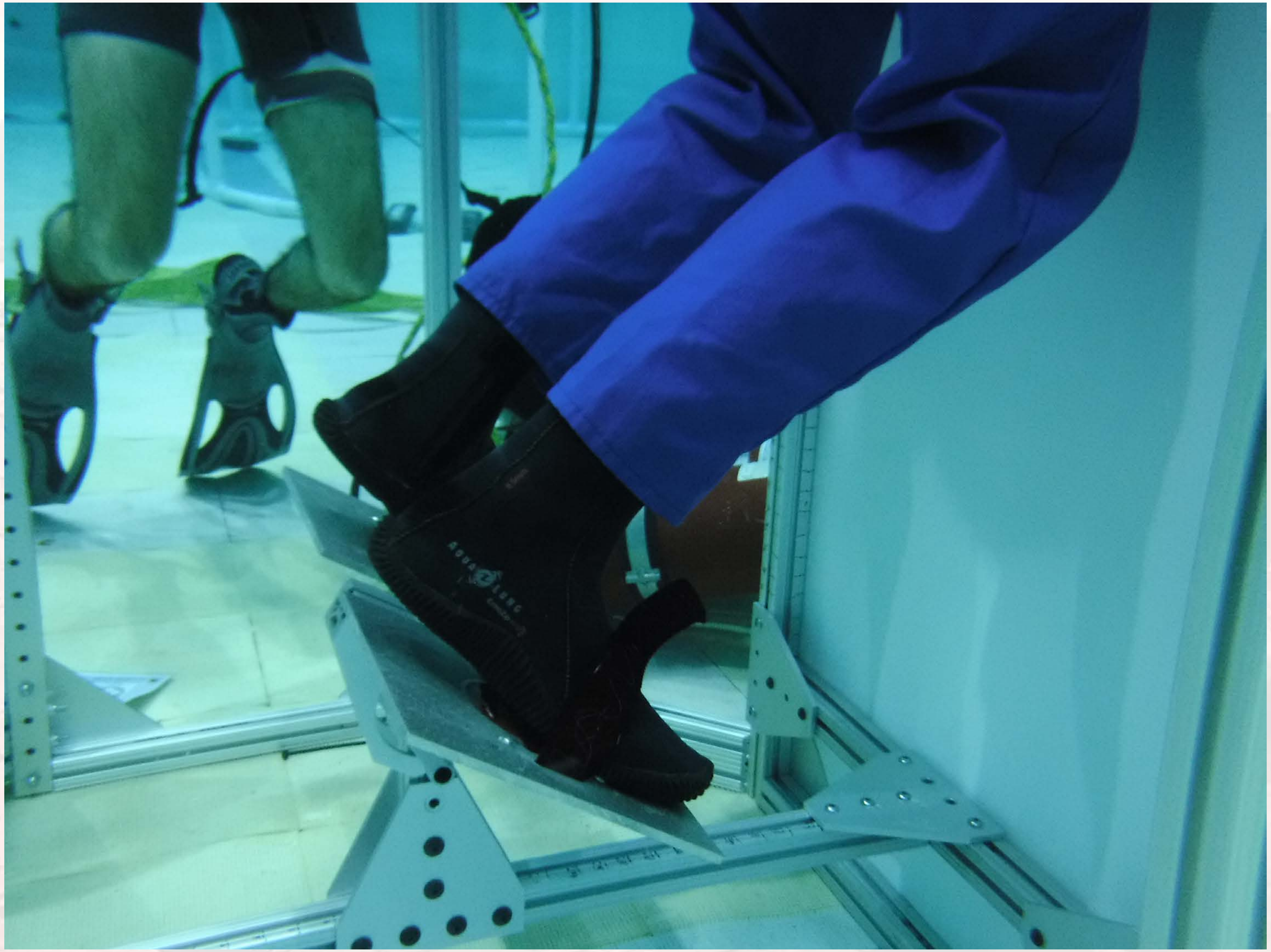
Testing with Handrail Foot Restraints

- Handrails are frequently used as informal foot restraints in ISS
- Initial testing assumed the use of hand rails to capture feet
- Pressure on arches proved to be painful
- Redesigned foot restraint plate to use fabric straps

Cartesian Foot Restraint Mount

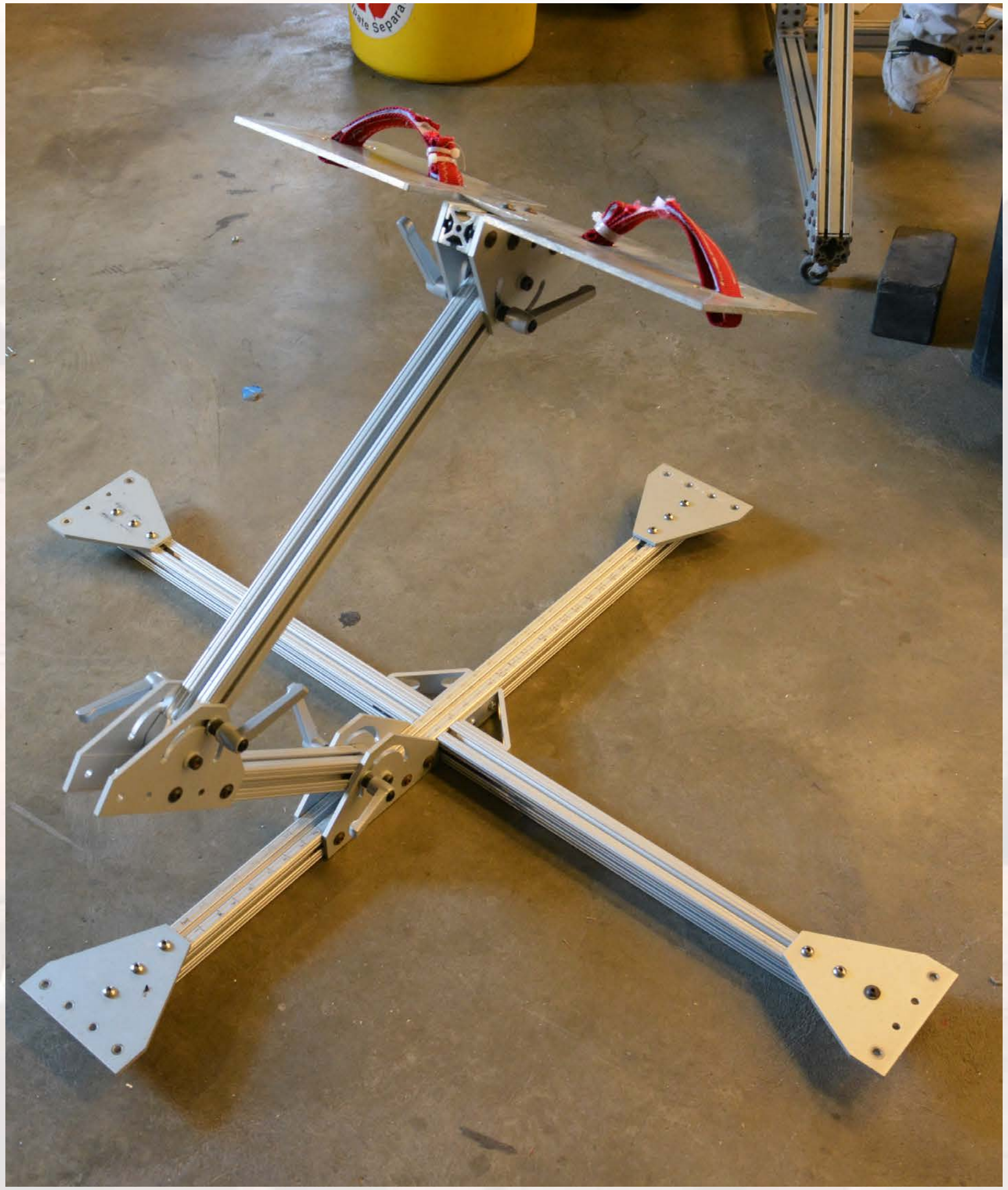


Cartesian Foot Restraints in Use

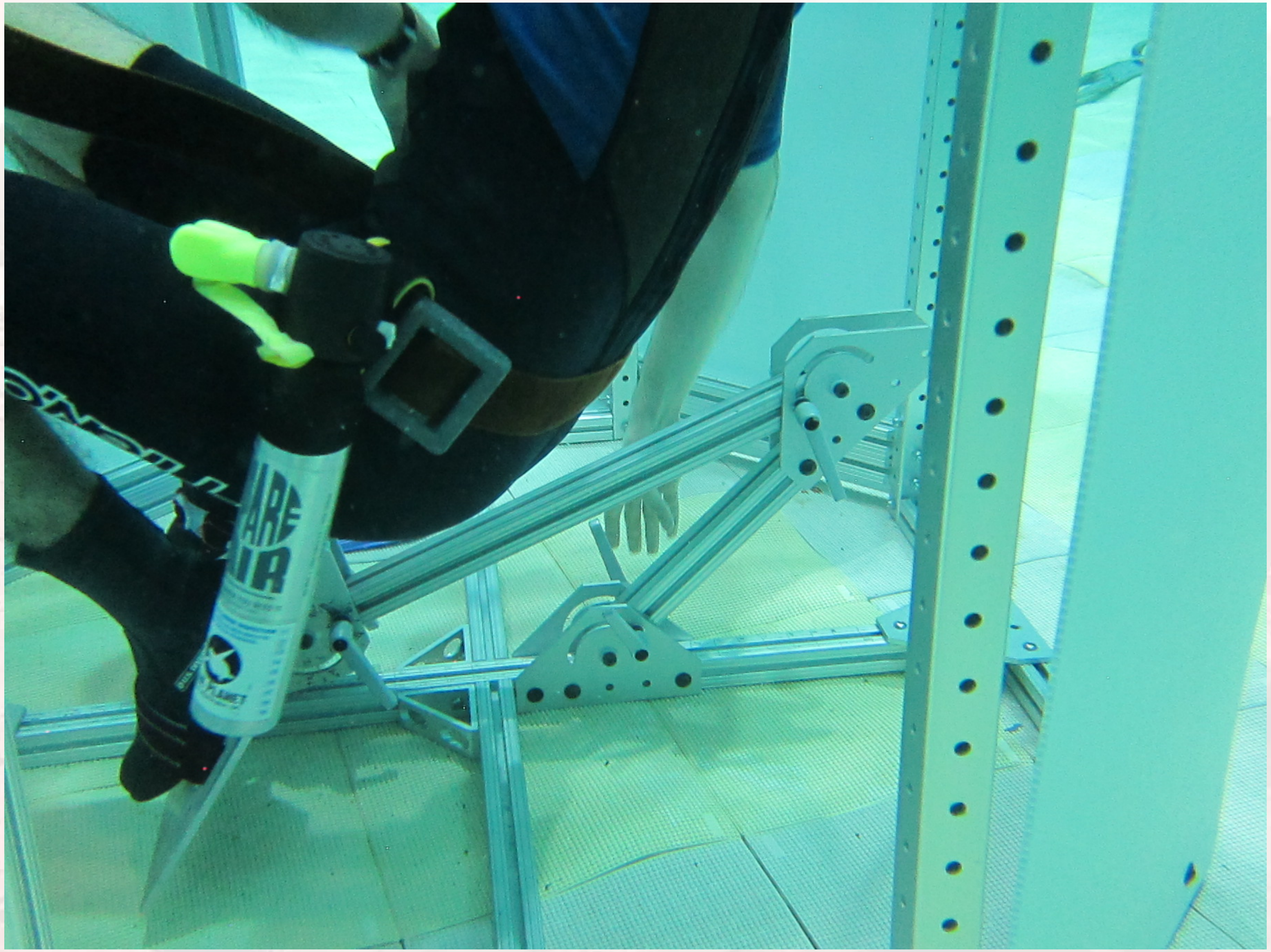


Revised Foot Restraint Design

- Cartesian design involved loosening and tightening many fasteners
- 3 DOF revolute design only requires two locking lever actuations per DOF
- Allows growth to additional DOF

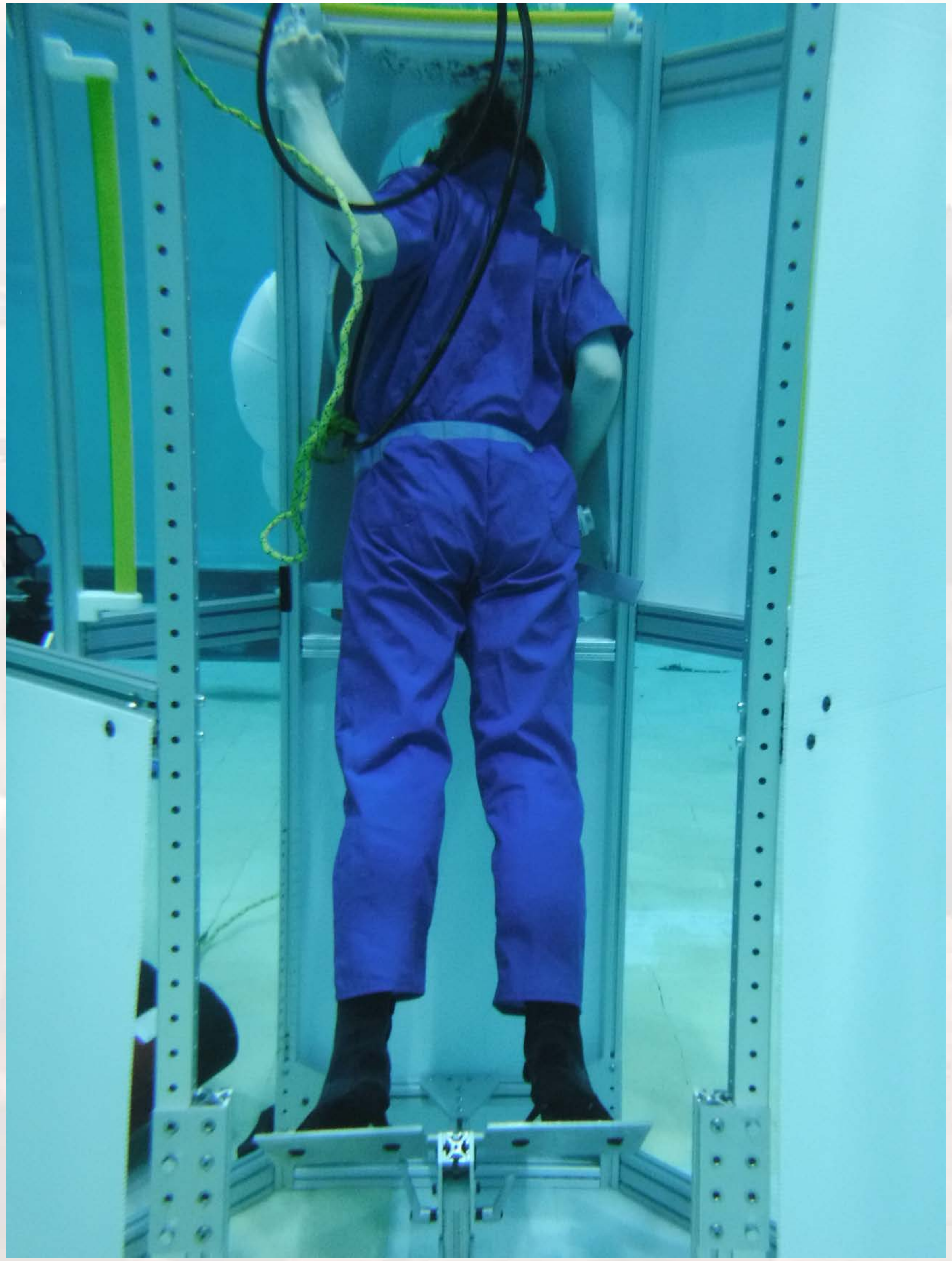


Revised Foot Restraint Testing

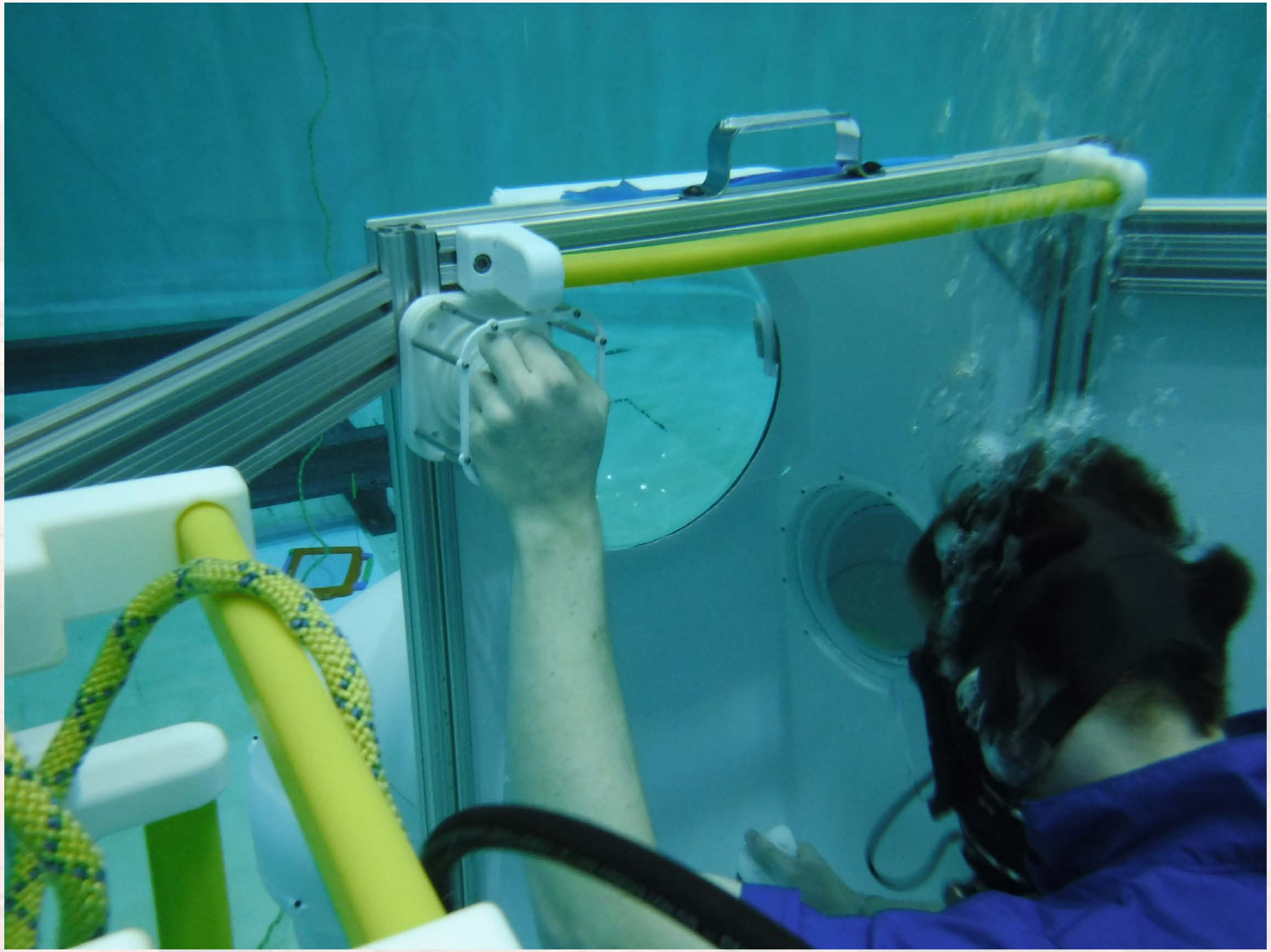


Hand Controller Placement Studies

- Standard 2x3DOF hand controllers for manipulator motion are difficult to place
- Need to have head in helmet bubble requires different body pose than with arms in suit arms
- Considering alternative control devices, continued investigation of siting options

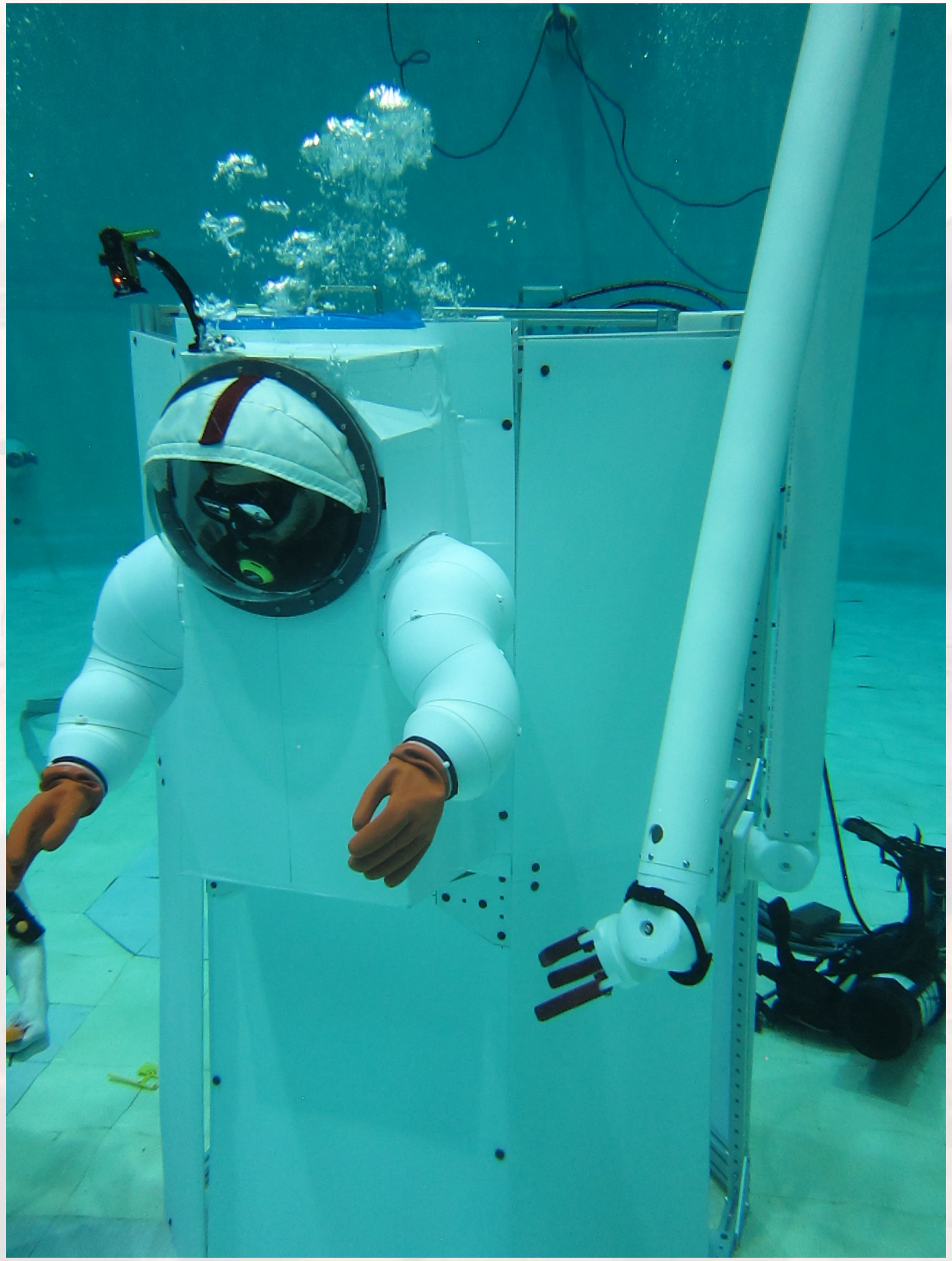


Hand Controller Placement Test

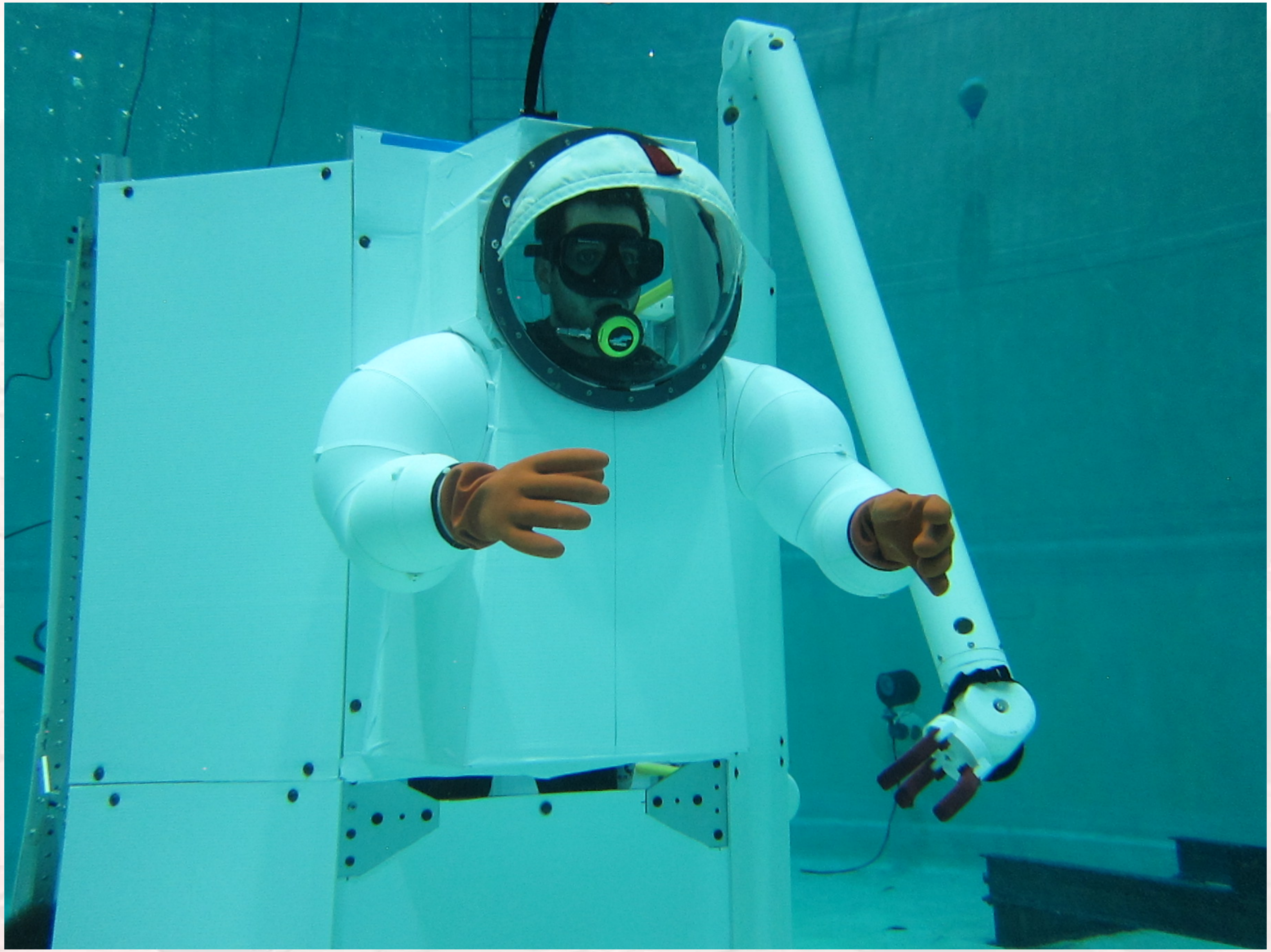


Initial External Manipulator Testing

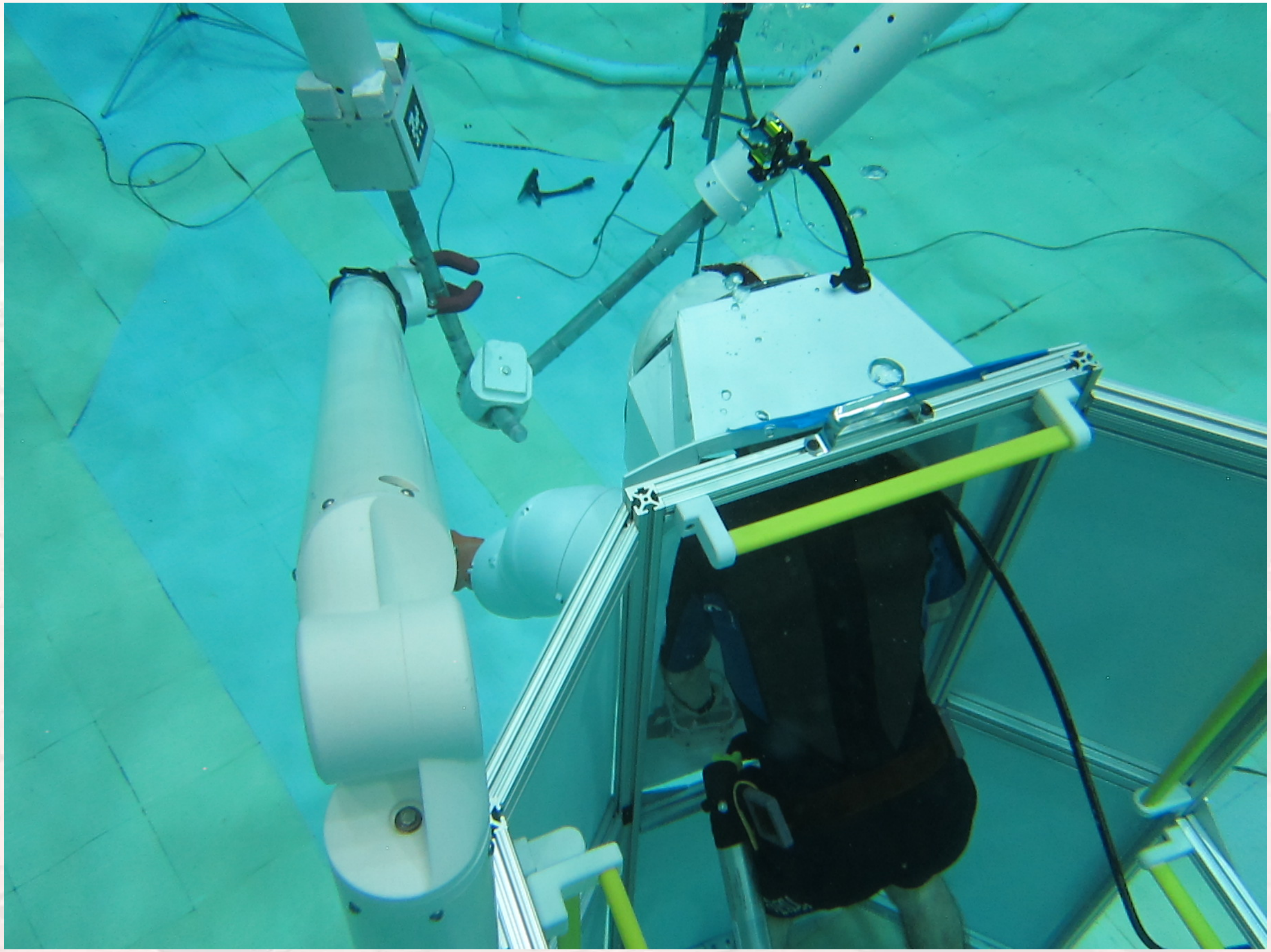
- SUV will eventually include multiple dexterous manipulators
- Fabricated a 4-meter 6DOF posable arm for initial tests of interactions with suit arms
- Will eventually be replaced with existing Ranger-class dexterous manipulators



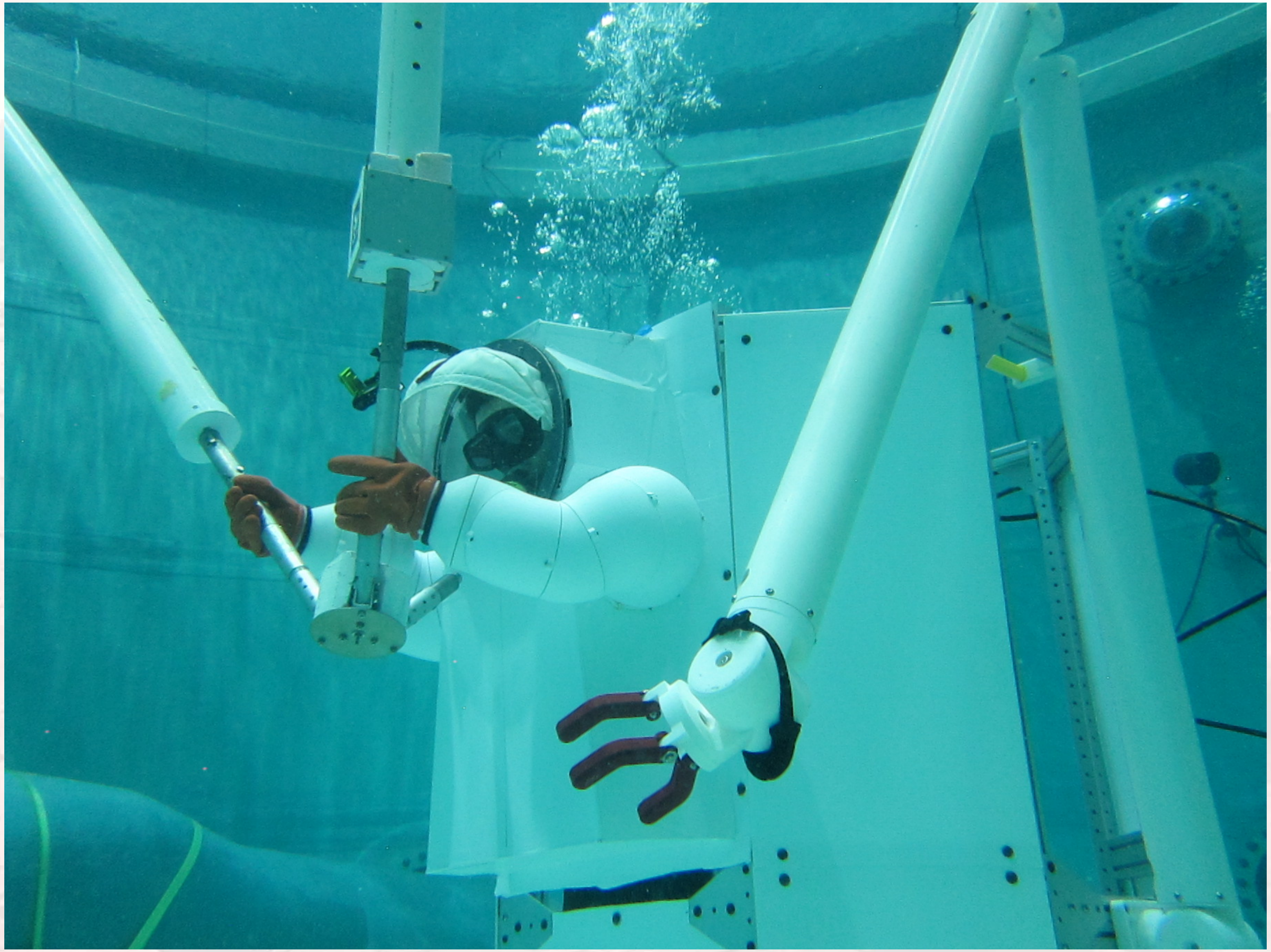
Human/Robot Shared Workspace



Manipulator Holding EASE Assembly



EASE Structure Handed Off to Crew



Current Summary

- SUV research has been limited to available discretionary funding
- Simple tests performed to date have focused on design issues, rather than performance assessments
- Prototyping structure provides easy reconfiguration as design is iterated
- Will need to increase SUV capabilities (e.g., functional manipulators, mobility) to provide meaningful comparison to EVA operations

References

- Kenneth S. Thomas and Harold J. McMann, US Spacesuits - Springer-Verlag, 2006
- Gary L. Harris, The Origins and Technology of the Advanced Extravehicular Space Suit - AAS History Series, Volume 24, American Astronautical Society, 2001