



NASA Langley History of In-Space Assembly Assembly of Truss Structures for Space Systems

Presented by

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OVERVIEW

EVA Assembly

- Large Space Structures Construction
 - Truss Components
- LaRC Assembly Studies and Results
 - Early Concepts and Verification
 - Applications

Robotic Assembly

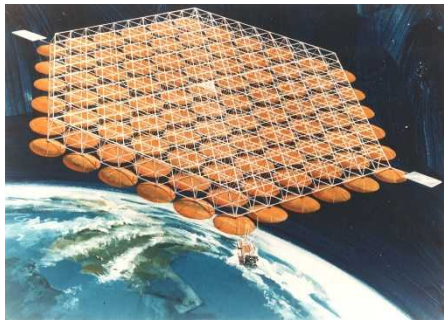
- Reliability

Key Points

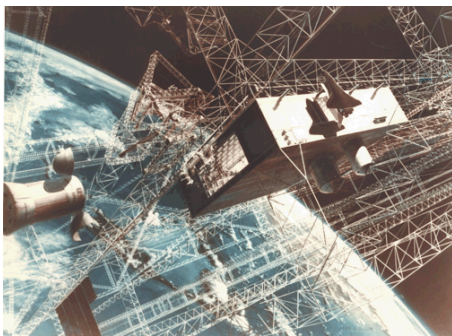
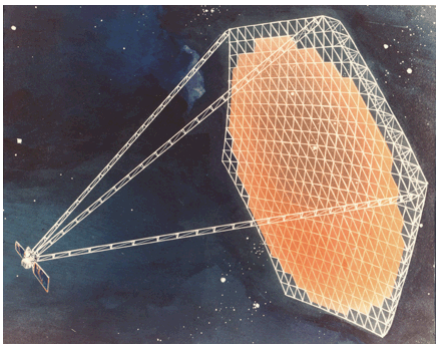
- Predictability of Completed Structures
- Efficiency of Assembly
- Versatility of Structures that can be Formed



CONSTRUCTION OF LARGE SPACE STRUCTURES

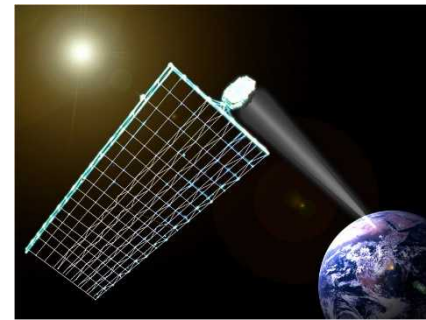


Structures > 100 m

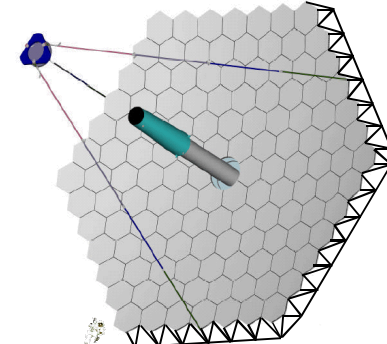


Circa 1970's

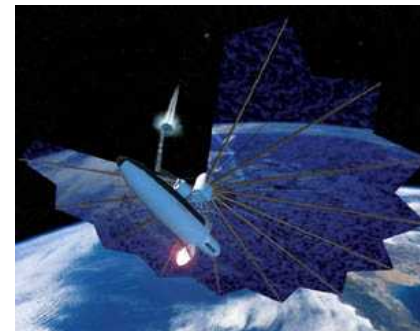
Platforms > km



Telescopes and reflectors > 20 m



Transfer vehicles > 100m



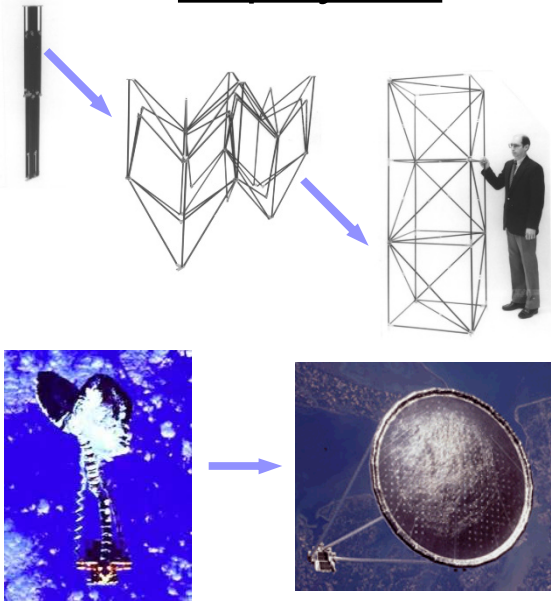
Circa 2040's +

- Need for size has not changed
- Spacecraft too large for launch vehicle volume
- Human presence still available



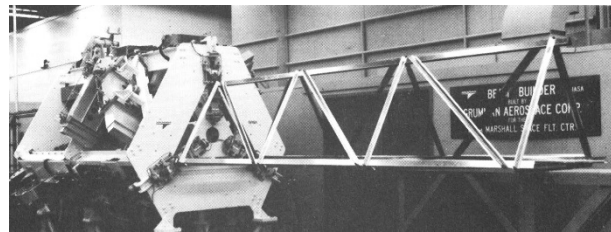
CONSTRUCTION METHODS

Deployable



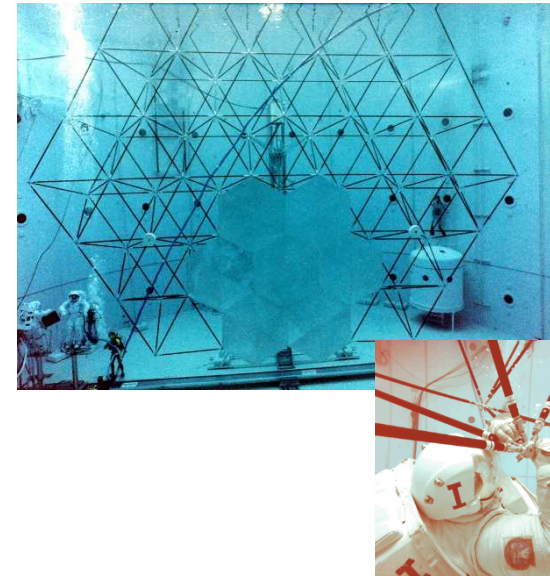
Pre-assembled on Earth,
automatically deployed
on-orbit

Fabrication



In-space fabrication of
structural components from
“raw” materials

Erectable



On-orbit assembly
of components

Key discriminators:

- Launch Volume/Mass
- Reliability
- Cost
- Structural Performance

Erectable Selected: Key Features

- essentially **No Increase in Complexity with Increasing Size**
- Efficient packaging
- Inherently serviceable, expandable, repairable
- Resulting Structures Predictable



COMPONENTS OF ERECTABLE STRUCTURES

Space trusses are comprised of strut members connected at nodes

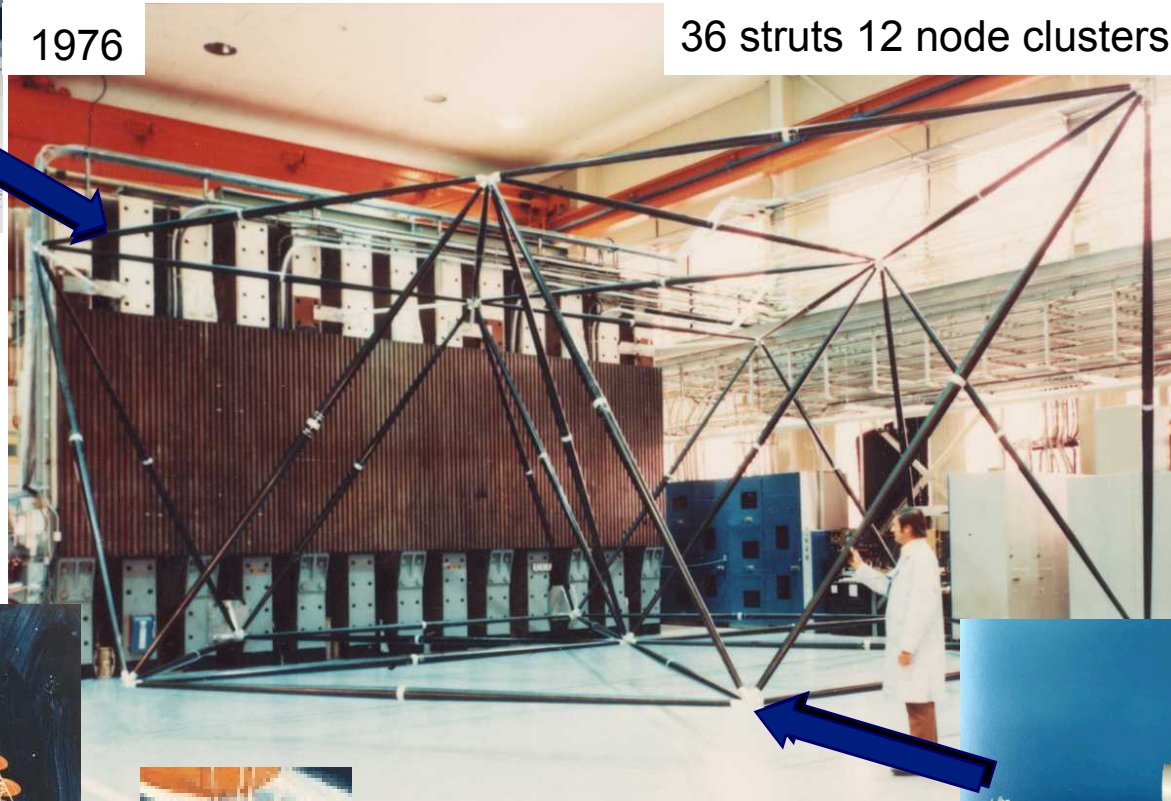
- Efficient packaging
- Structurally simple and predictable



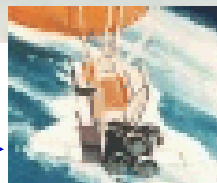
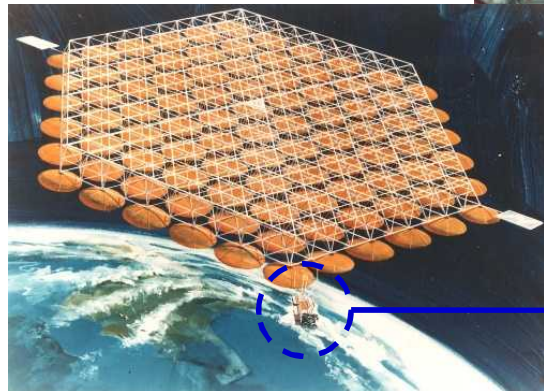
36 struts

Strut Members

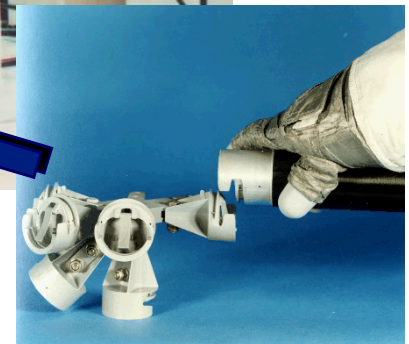
1976



36 struts 12 node clusters



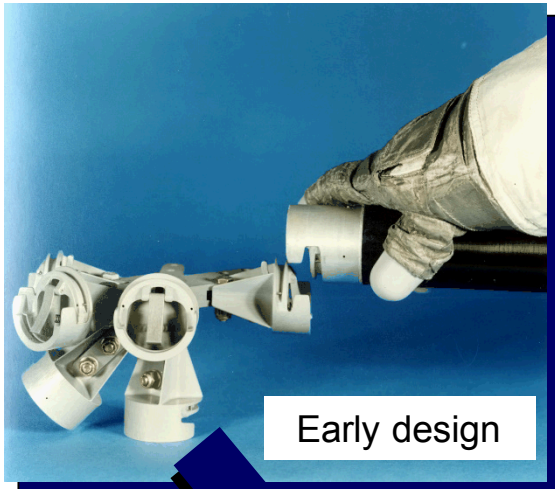
Space Shuttle
(54m, 184ft)



Node and
Connecting Joints



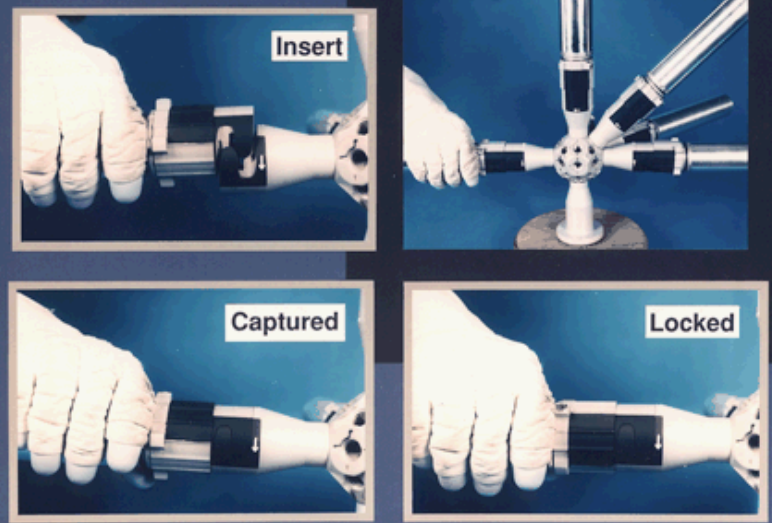
QUICK-ATTACHMENT JOINT DEVELOPED FOR EVA ASSEMBLY



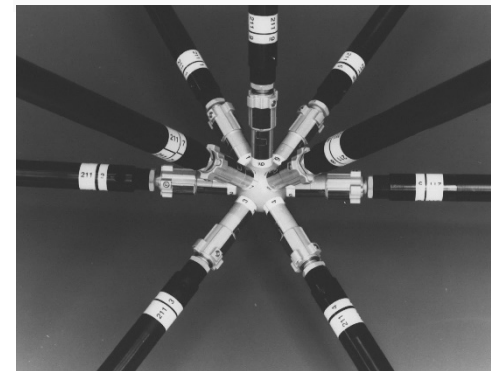
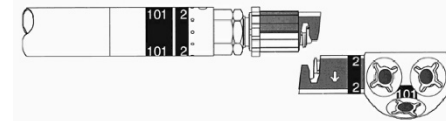
Features Include:

- Side latching, quick-attachment, quick-release
- Easy one-hand operation design, no tools
- Linear, predictable structural behavior
- Easy identification of locking status
- Compatible with robotic assembly

2-inch diameter

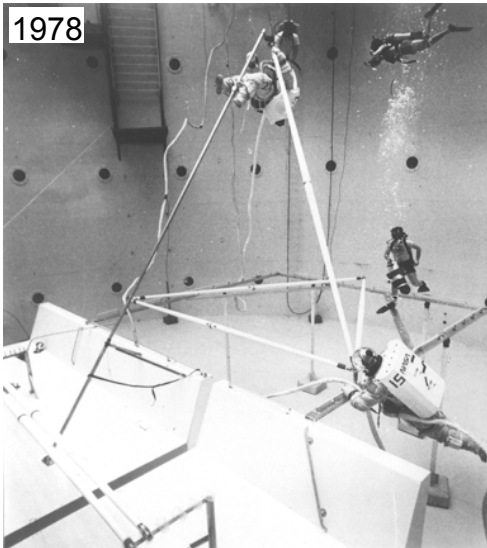


1-inch diameter



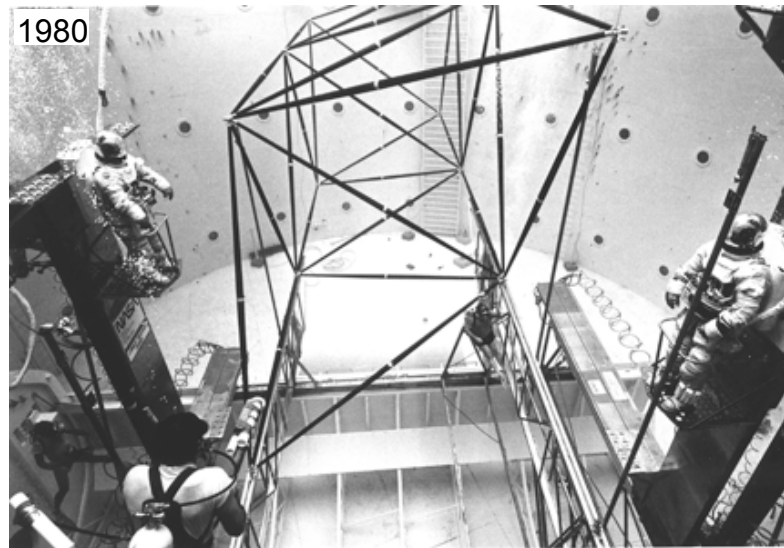


EARLY ASSEMBLY STUDIES



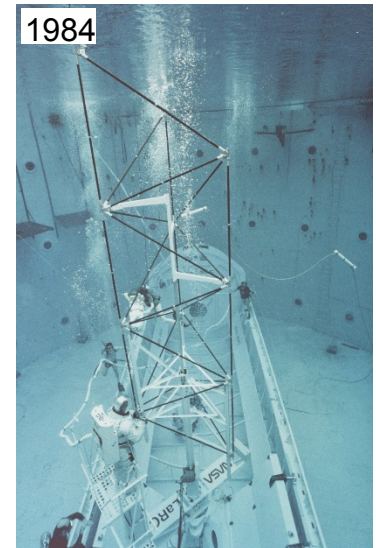
“Unaided” Assembly of
Structural Cell

2 crew, Manual assembly
5 min/strut (manual)
3 min/strut (RMS-assist)



Mobile Work Station Assembly
of Truss Beam

2 crew, mechanized aids
38 sec/strut



Swing-Arm Beam Erector
(SABER) of Truss Beam

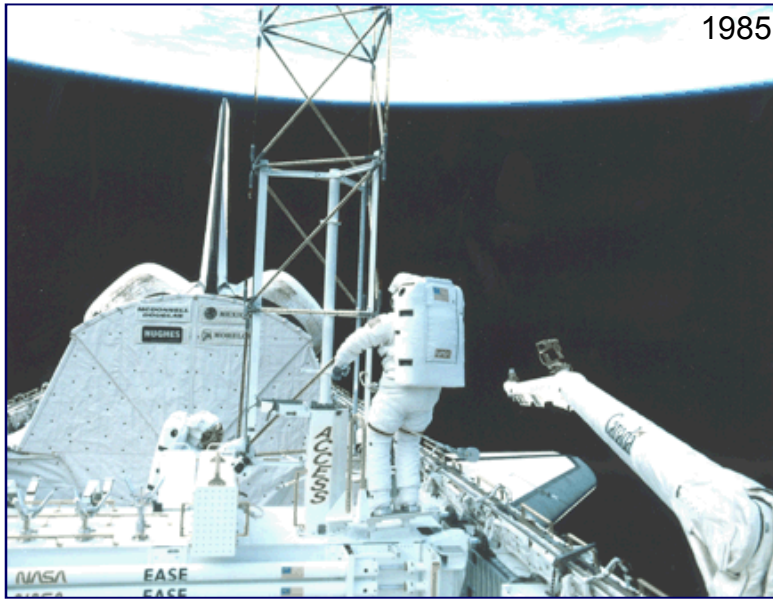
1 crew, mechanized aids
29 sec/strut

Lessons learned:

- Pressure suits restrict crew motions.
- Unrestricted EVA feasible but not practical. Use foot-restraints
- Mechanized translation of astronauts and equipment to work sites, assembly line procedures, and easily assembled parts reduces work load and increases productivity
- 2-inch (5 cm) diameter joint maximum size for handling



FLIGHT VALIDATION OF IN-SPACE ASSEMBLY CONCEPTS



Baseline assembly of 10 bays



Utility line attachment simulation



Truss manipulation



Maintenance and Repair

ACCESS

Assembly Concept for Construction

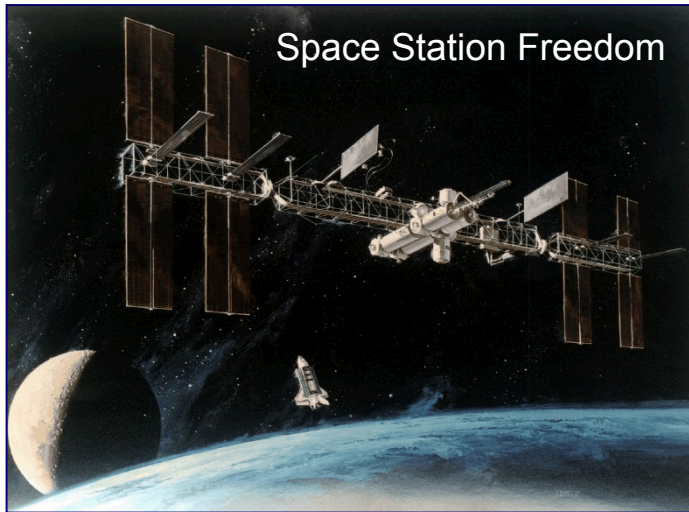
in EVA of Space Structures

2 crew, assembly aids
17 sec/strut

- Demonstrated the ability to assemble a structure on orbit, perform maintenance, and install utilities.
- Demonstrated reliability of simulated 0-g



SPACE STATION FREEDOM ASSEMBLY CONCEPT

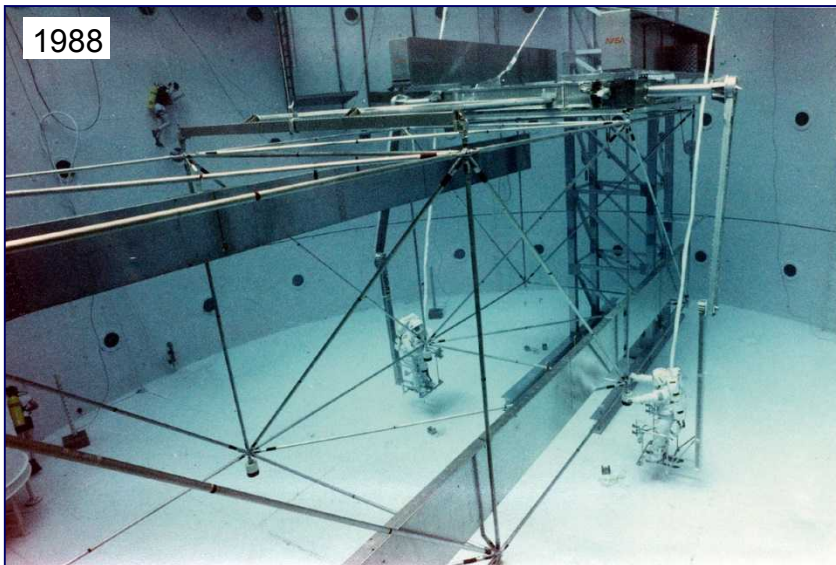


Mobile Transporter Truss Assembly

- 2 person crew
- Mechanized assembly aids
- 25 sec/strut

Demonstrated

- Compatible assembly and payload interfaces minimize effect on assembly time.
- Highly visible joint lock pattern provided easy verification

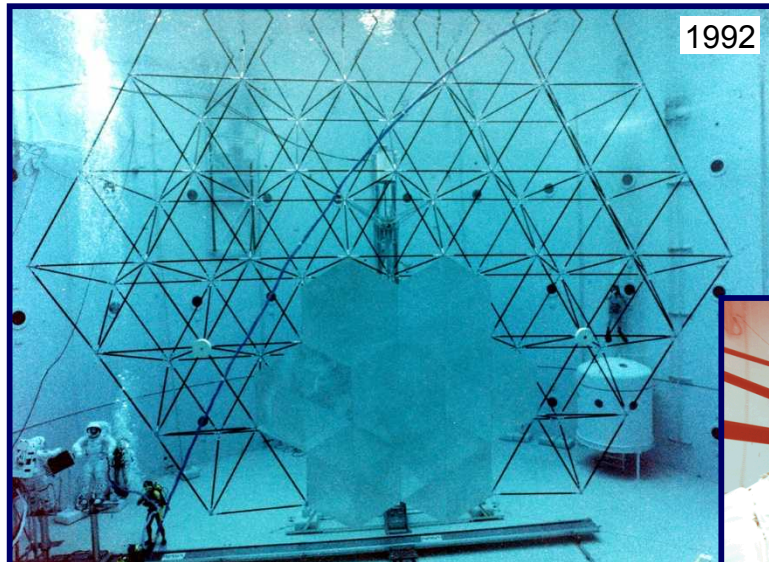
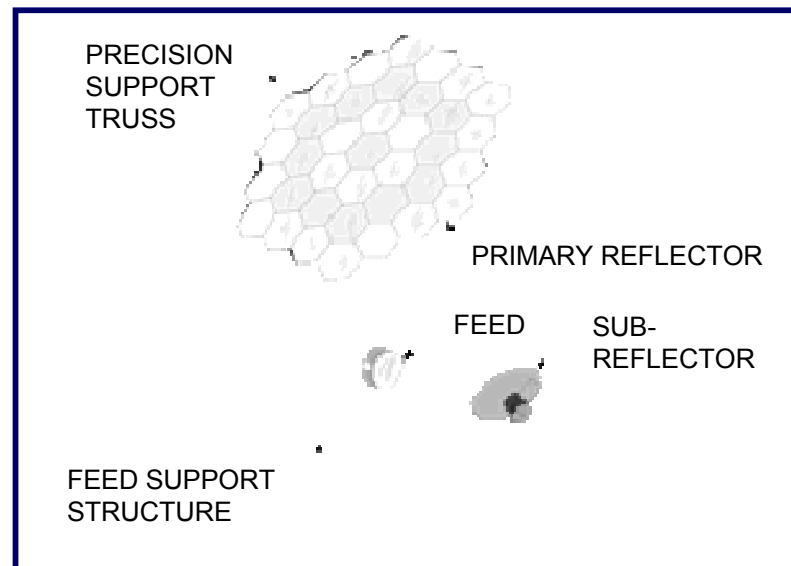




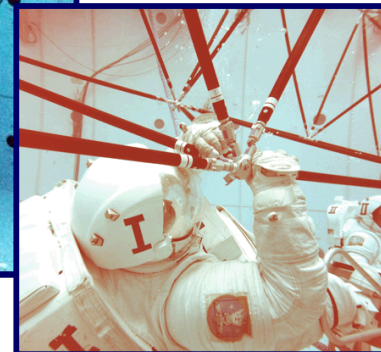
LARGE DIAMETER REFLECTOR ASSEMBLY CONCEPT

- Primary support truss and 7 panels assembled
- Non-axisymmetric reflector, each panel and truss member unique for assembly
- 2 person crew, mechanized assembly aids
- 33 sec/strut, 123 sec/panel

With proper positioning devices, detailed labeling of hardware and pre-planning of assembly sequence, even complex structures having many unique components are assembled in a predictable and reasonable time



315 struts,
84 nodes,
7 reflector panels

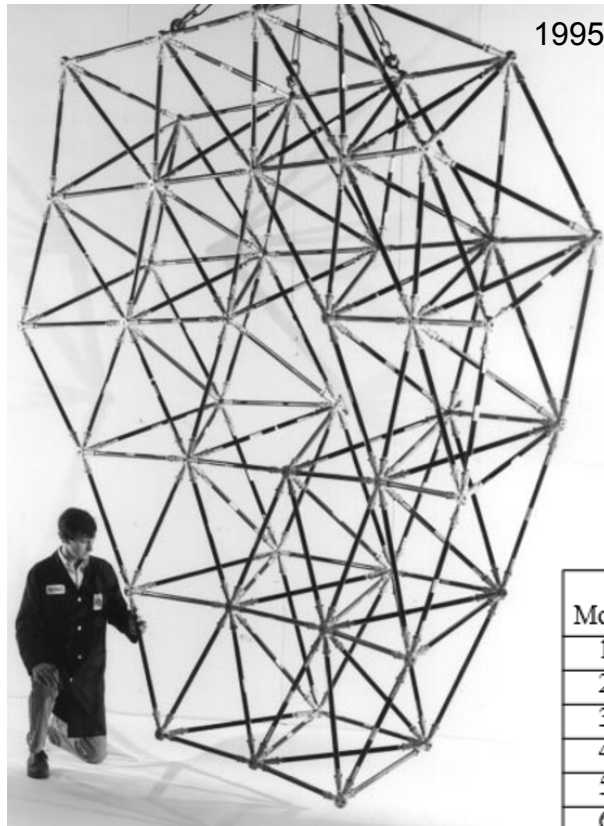


14m-Diameter Offset-Focus Reflector for a Microwave Radiometer



PRECISION SEGMENTED REFLECTOR (PSR) ASSEMBLY CONCEPT

- Primary support truss 45 nodes 150 graphite epoxy struts
- Truss structure surface accuracy of 50-100 microns (~ 0.002 - $0.004''$)
- Center-fed parabolic reflector design with 3 fold symmetry



4m-Diameter



- A prior Predictions
- No tuning

Mode	Analysis frequency, Hz (a)	Test 1 frequency, Hz	Test 1 damping (percent of critical)	MAC (test 1 analysis)	Description
1	35.04	34.5	1.35	0.96	Rocking
2	35.05	35.6	1.19	0.95	Rocking
3	(b)	51.9	1.73	(b)	(b)
4	59.73	57.3	1.45	0.98	Torsion
5	73.31	78.1	1.15	0.98	Umbrella
6	92.26	96.6	0.97	0.83	Saddle
7	92.33	97.3	1.11	0.62	Saddle
8	120.84	123.7	1.01		
9	125.75	129.0	0.89		
10	126.90	130.1	0.84		

^aAnalysis frequencies obtained by using refined analysis model with strut bending

^bNot predicted by finite-element model.

Bush, Harold G., et al. "Design and fabrication of an erectable truss for precision segmented reflector application." *Journal of Spacecraft and Rockets* 28.2 (1991): 251-257.



Robotic Assembly Section Overview

Section Outline

- Automated Assembly
 - Supervised autonomous construction of an 8m 102 element planar truss covered by 12 panels
 - Approach
 - Custom end-effectors** (tools) used by a **standard robot**
 - Truss hardware designed for compatibility with astronaut and robot.
 - Assembly sequence can be **paused** or **reversed** at any point.
- Key Technologies
 - Automated path planning
 - Machine vision guided approaches



Robotic Assembly of Planar 8m Tetrahedral Truss

Structure Characteristics

- 102 Struts Elements
- 12 Simulated Panels
- ~0.14 mm (0.0055 in) rms structure surface error

Assembly Statistics

- 2.5 Minutes Per Strut (no parallel processing)
- 20 Hours for a full Assembly
- 18 Hours for a Disassembly

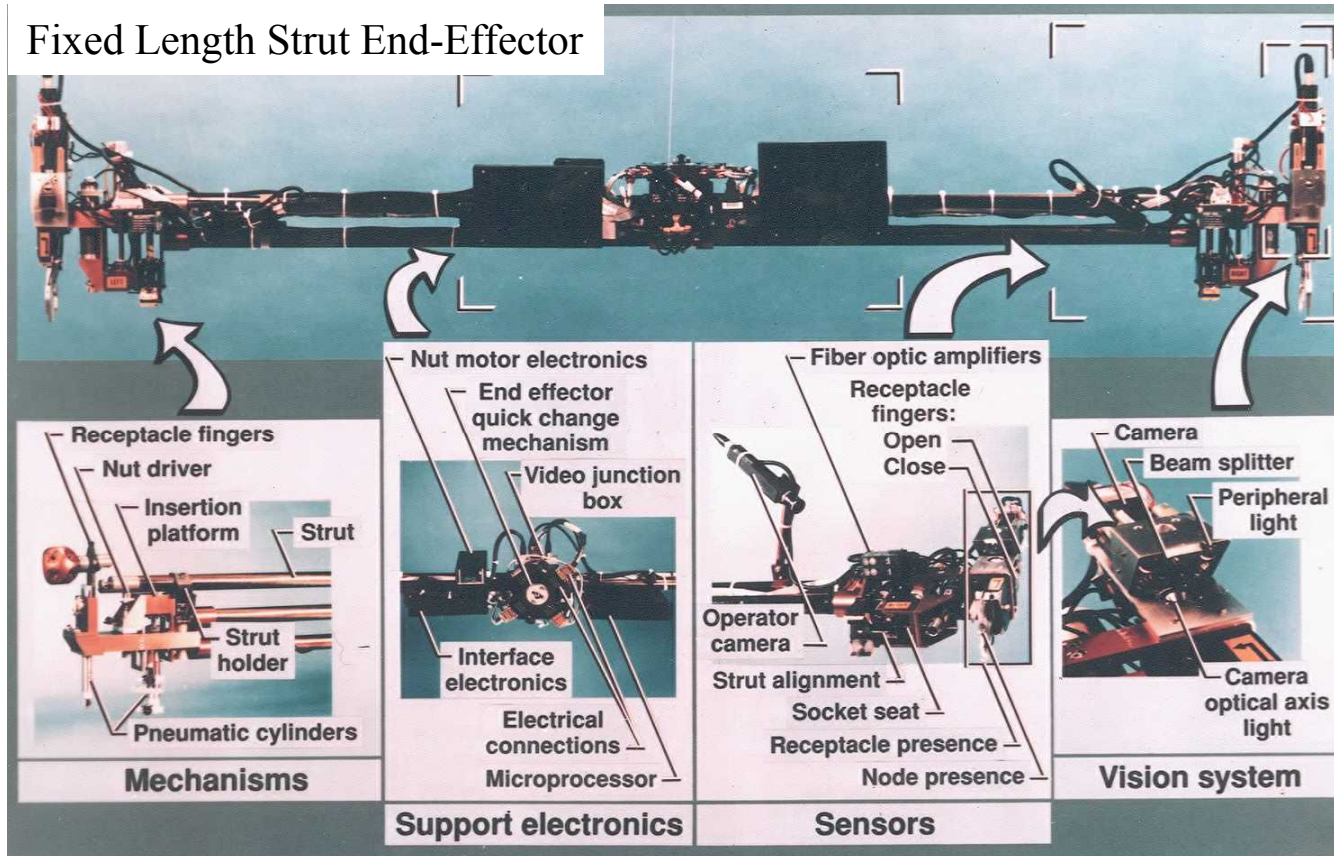


Complete Truss with Panels Autonomously Assembled



Custom End-Effectors and a Standard Robot

Fixed Length Strut End-Effector



All Operations Verified

Only require Power and Communication Signals

Most Operational Intelligence Resides with End-Effector

Fully Autonomous Assembly

Operation can be **Paused**, **Reversed** or **Queried** at anytime



Installing a Truss Element

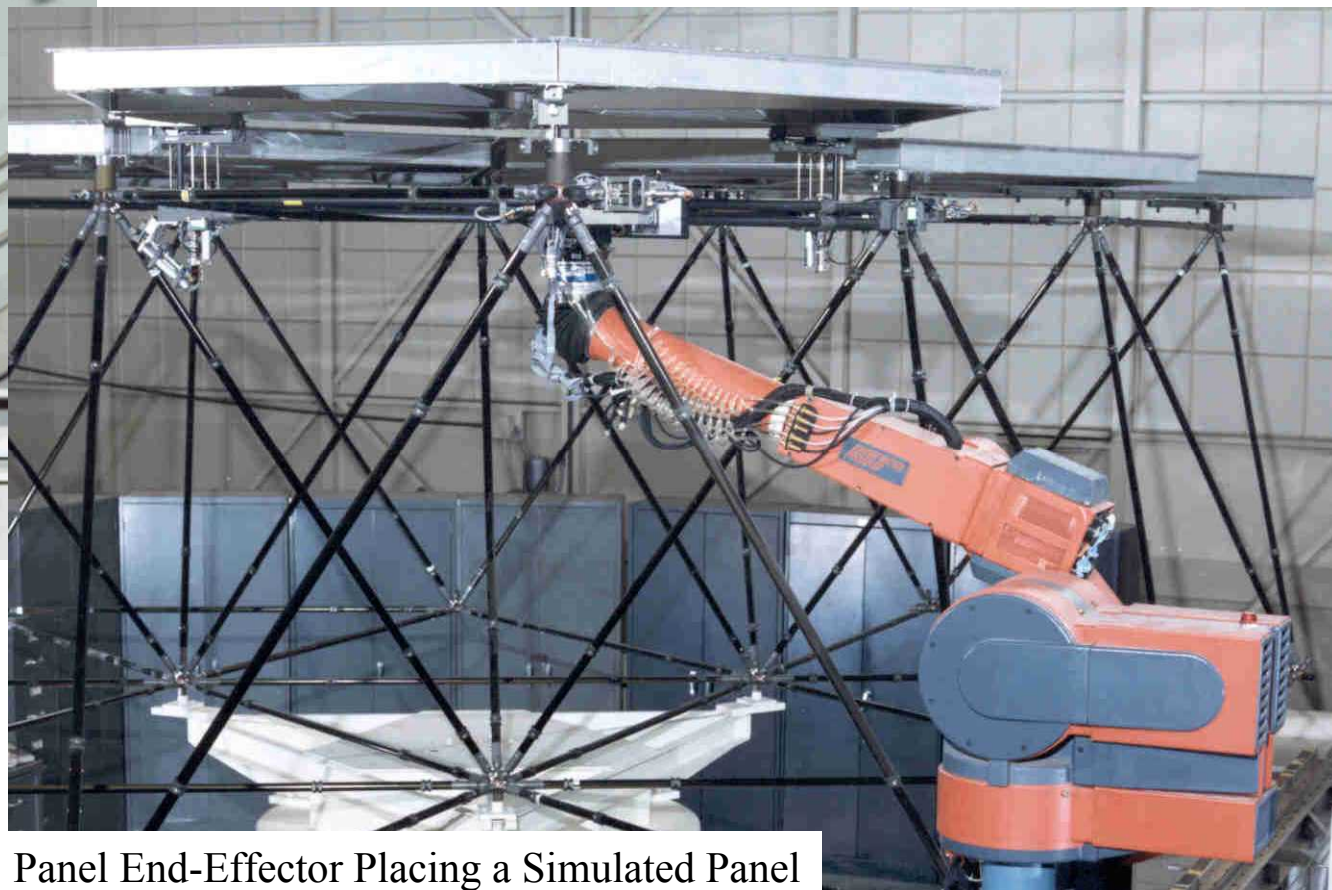
Custom End-Effectors and a Standard Robot

Panel End-Effector



Key Attributes

- Operates from Behind Panel
- Registers itself to Truss Structure
- Clearance with Adjacent Panels Maintained until Panel is Lowered

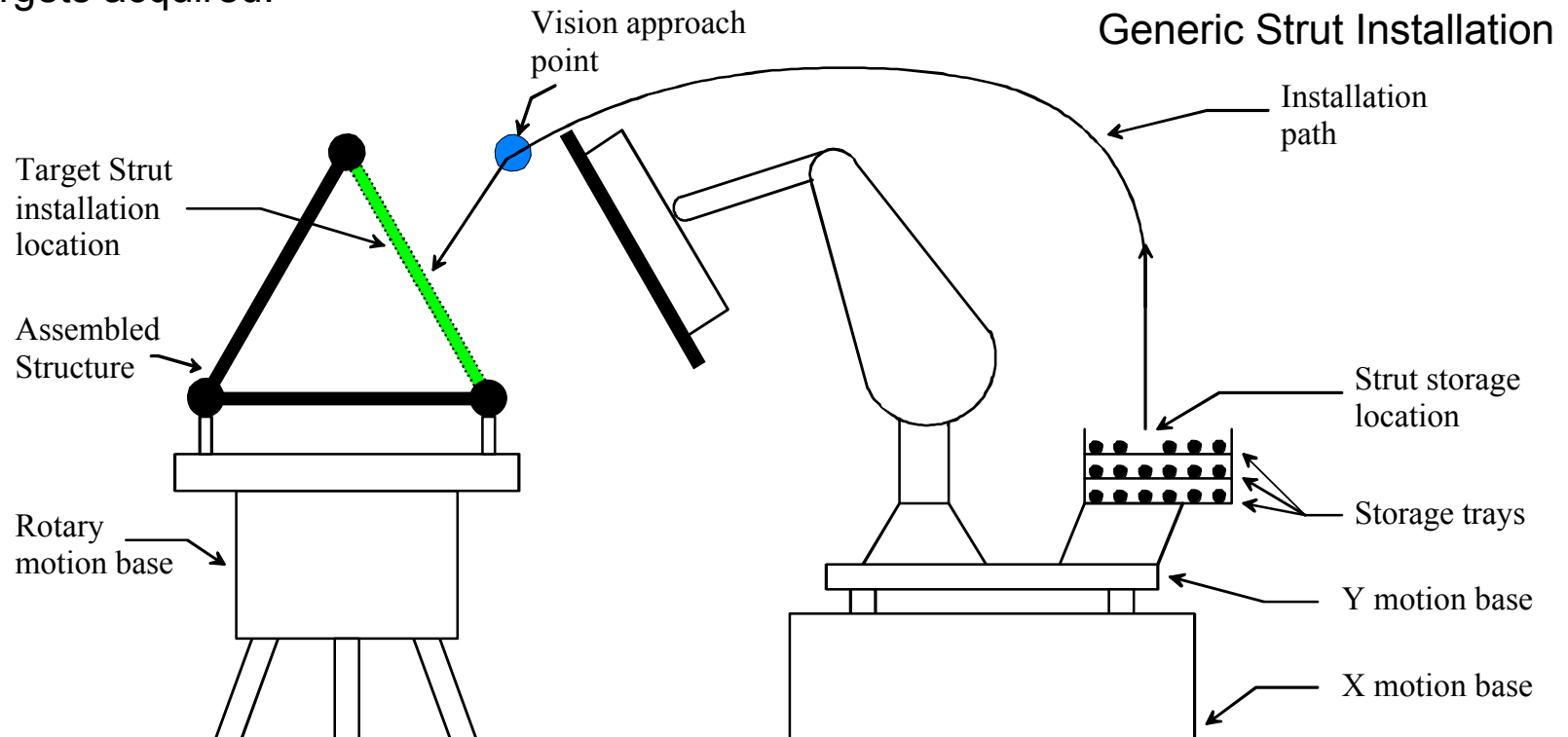


Panel End-Effector Placing a Simulated Panel



6 Degree of Freedom Path Planning of Robot Motions

Collision Free Path Planned from Strut Canister to **Calculated** Installation Location. Path followed to Vision Approach Point (VAP) which is Approx. 20 inches from Installation Location before targets acquired.

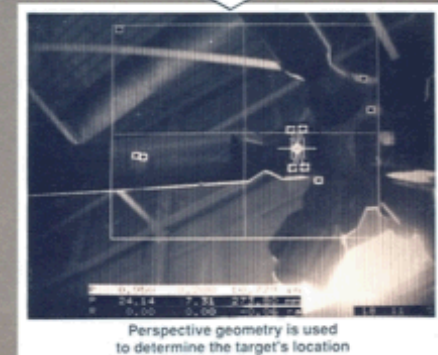
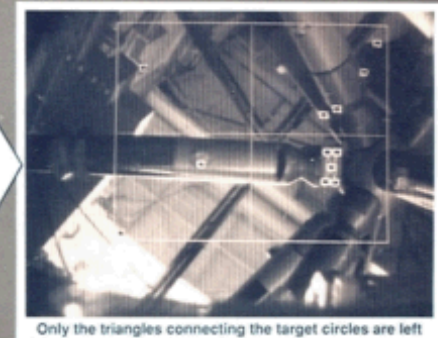
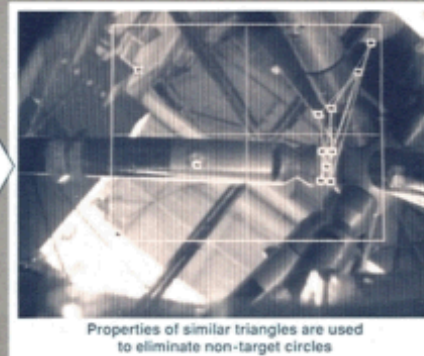
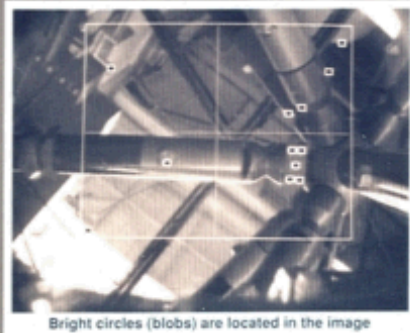


- Enables Assembly of Arbitrary Truss Geometries Independent of Truss Element or overall Structure Size
- Paths Planned and Verified using 3D Graphic Models
- Effects of Modeling Inaccuracies Eliminated by Machine Vision Guided Approach

Machine Vision Approaches

MACHINE VISION FOR ROBOTIC ASSEMBLY

Processing sequence
for locating node receptacle targets



Key Attributes

- Operator can Observe **All** Contact between Robot and Structure
- Passive Targets
- Fully Operational in **Unstructured** Environment
- Enables use of Geometric Path Planner



Closing Comments

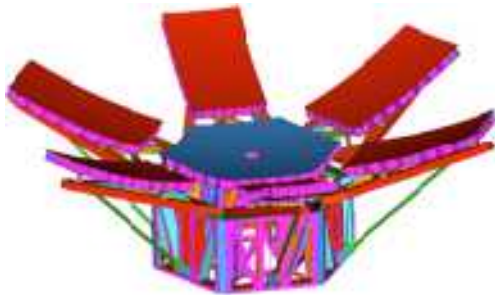
Erectable (In-Space Assembled) Systems

- Efficient Reliable Assembly of Precise Structures
- Predictable Response
- Inherent Serviceability

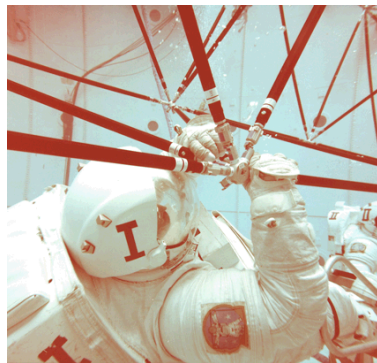
NO ONE TOOL WILL BE A PANACEA FOR ALL MISSIONS

Spacecraft Size

Deployment



Astronaut Assembly



Robotic Assembly



USE ONE OR COMBINATION OF TECHNOLOGIES



Backup

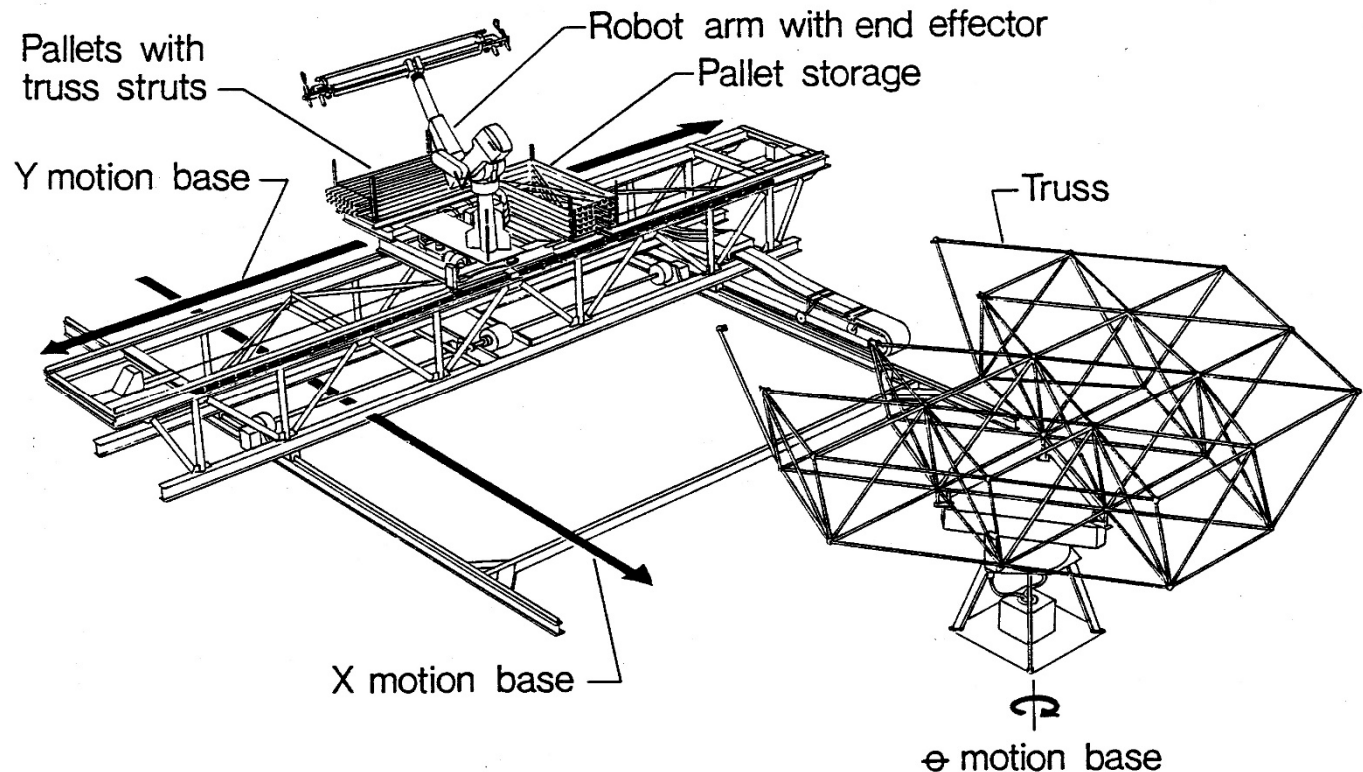


Assembly Facility Overview

Robot and Storage Canisters ride on (x,y) Linear Motion Base

Structure Assembled on Rotary Motion Base

Quick Change used to Interchange End-Effectors

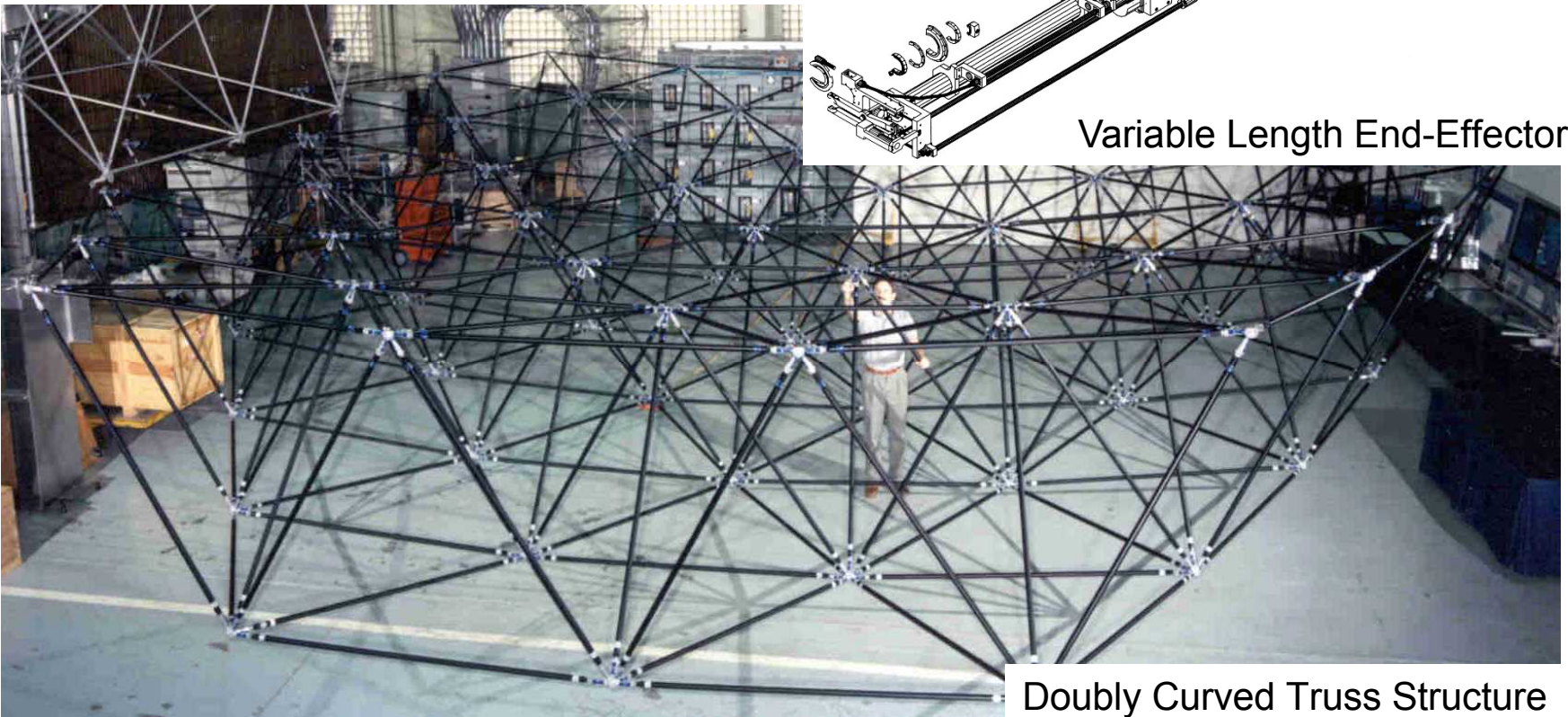
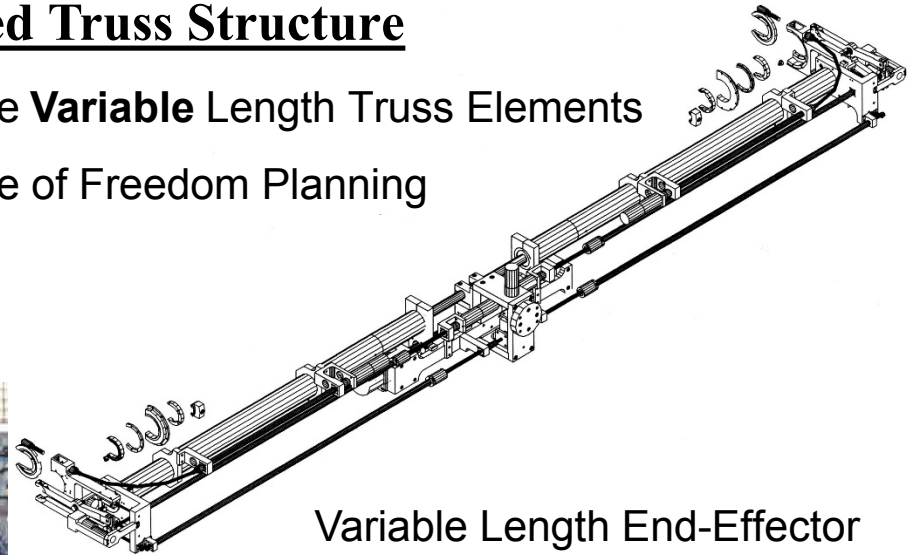




Future Technology Development

Robotic Assembly of Curved Truss Structure

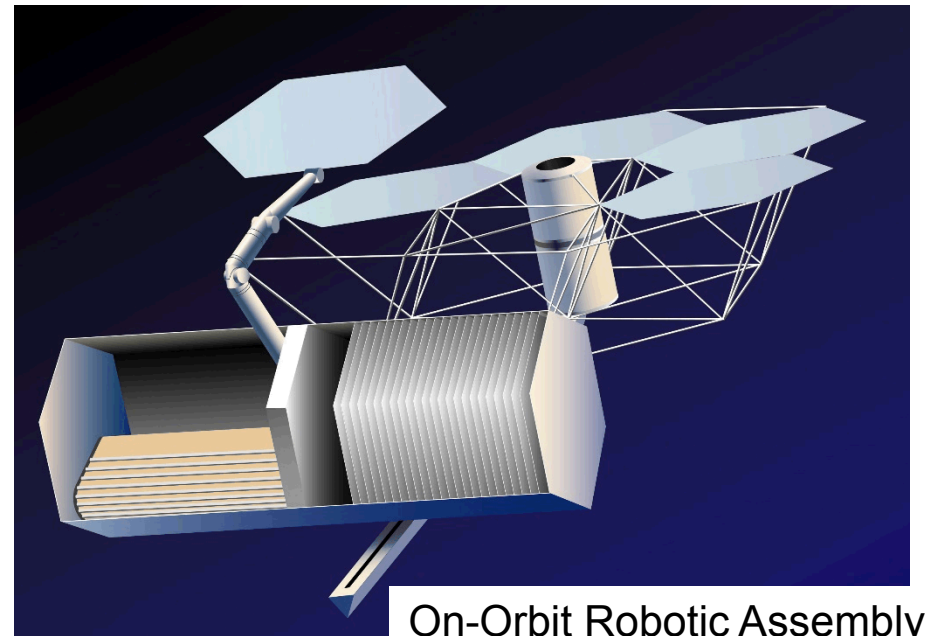
- Develop End-Effector which can accommodate **Variable** Length Truss Elements
- Enhance Path Planner to enable 8 or 9 Degree of Freedom Planning
- Investigate Smaller Machine Vision Targets





Address Integrated System Details

- Modular Connections with integrated subsystems
- Verify Thermal Strain Management, develop near Zero CTE Joints
- Develop Techniques to Support Distributed Wiring/Utilities
- Verify Assembly of Feed Structure and Secondary Mirror
- Continue Investigation of Maintenance/Repair
- Test via Assembly of a **Complete** Telescope



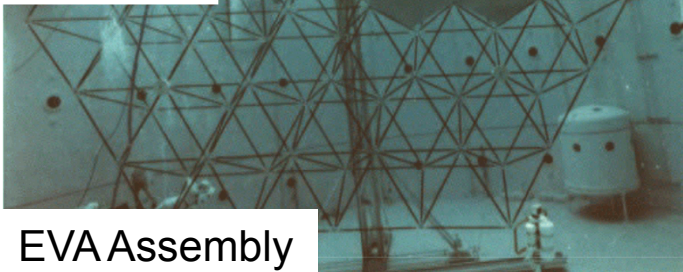
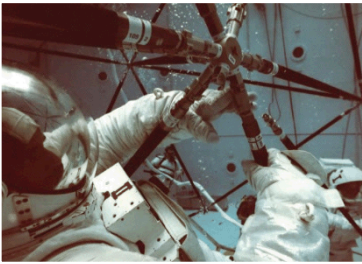
On-Orbit Robotic Assembly



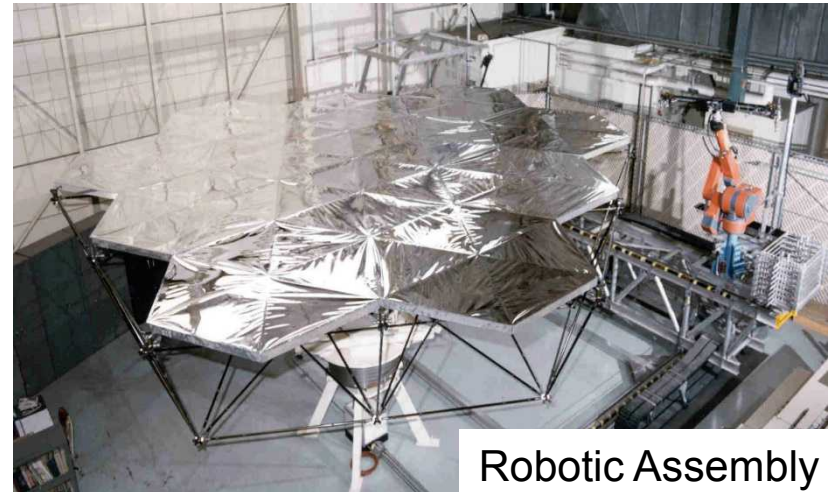
Technology Is Available for 60m Telescopes. Why Wait?

Past NASA investments in hardware and procedures for assembly of large reflectors enables large ($> 30\text{m}$) observatories to be **easily constructed** in the near future.

- In 1992, simulated EVA validated a procedure requiring less than six hours (1 EVA) for assembly of a 14m 36 panel reflector
 - 406 pieces of hardware and a 261-step procedure were validated
- During the early 90's, a 1-g prototype of an Extra-Vehicular Robotic system was developed to build a similar type of reflector (8m diameter, 12-panel)
 - Automated Planning Validated for Planar Structure
 - 120 pieces of hardware and a high-level control architecture were validated



EVA Assembly



Robotic Assembly



CONCLUDING REMARKS

- Large space structures are still being considered for future missions
- LaRC demonstrated simulated and flight 0-g assembly of large space structures using EVA astronauts
 - Mechanized translation of astronauts and equipment to work sites, assembly line procedures, and easily assembled parts reduces work load and increases productivity for EVA in-space construction
 - complex structures having many unique components are assembled in a predictable and reasonable time
- Future missions are candidates for EVA assembly
- An integrated approach of all assembly methods, including EVA is desirable



Robotic Assembly

Assembly is an Alternative Deployment Strategy

Advantages

- essentially **No Increase in Complexity with increasing Size**
- ◆ Ability to Build Large Complex Structures (i.e. > 100 m) with High Precision
- Assembled structures can be Reconfigured
- Efficient Launch Packaging
- Ability to launch Small Units Independently
- ◆ Inherent Expandability
- ◆ Inherent Serviceability/Repairability
- Assembly system is Adaptable and Reusable

Disadvantages

- On-orbit Assembly System Required
- Difficult to Test System until Assembled

