**IN-SPACE ASSEMBLY AND CONSTRUCTION TECHNOLOGY PROJECT SUMMARY**

**INFRASTRUCTURE OPERATIONS AREA OF THE OPERATIONS TECHNOLOGY PROGRAM**

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration
Washington, D.C. 20546

**OPERATIONS TECHNOLOGY INFRASTRUCTURE OPERATIONS**

### In-Space Assembly and Construction

#### OBJECTIVES
- Programmatic

  Develop and Demonstrate an In-Space Assembly and Construction Capability for Large and/or Massive Spacecraft

#### RESOURCES
- 1991 $0.3M
- 1992 $0.0M
- 1993 $2.0M
- 1994 $4.0M
- 1995 $7.0M
- 1996 $8.0M

### SCHEDULE
- 1993 Automated panel installation on truss
  Complete welding vacuum facility
- 1994 Demonstrate precise 2-D crane positioning
- 1995 Demonstrate automated "orbital" welding
- 1997 Controlled slewing of 3-D space crane
- 1998 Precise positioning of large component
- 1999 Automated construction of curved antenna

#### PARTICIPANTS
- **Langley Research Center**
  - Space crane
  - Positioning control
  - Passive damping
  - Active damping
  - Suspension systems
  - Automated construction
- **Marshall Spaceflight Center**
  - Automated welding
IN-SPACE ASSEMBLY AND CONSTRUCTION ENHANCES FUTURE MISSIONS PLANNING FLEXIBILITY

Launch vehicles ➔ component masses and sizes

Assembly Options and Infrastructure

Operations Technology: Infrastructure Operations

In-space Assembly and Construction

Technology Needs

The in-space assembly and construction technology program will support the need to build, on orbit, the full range of spacecraft required for the missions to and from planet Earth, including:

Earth-Orbiting Platforms
- Earth Observation System (Platforms)
- Precision Radiometer & Antennae
- Evolutionary Space Station

Lunar Transfer Vehicles
- Aerobrake Construction
- Spacecraft Component Assembly

Mars Transfer Vehicles
- Spacecraft Component Assembly
- NTR: Backbone Truss & Radiator Construction, Utilities Welding
- SEP: Solar Array Construction
TECHNOLOGY CHALLENGES/APPROACH

- TECHNOLOGY DEVELOPMENT CHALLENGES:
  - REDUCE LIMITATIONS ON SPACE VEHICLE SIZES AND CONFIGURATIONS IMPOSED BY LIMITED ETO LAUNCH CAPABILITY AND/OR ON-ORBIT OPERATIONS REQUIREMENTS

- SPECIFIC CHALLENGES INCLUDE:
  - ACCURATELY POSITION LARGE SPACECRAFT COMPONENTS
  - ASSEMBLY TWO OR MORE LARGE COMPONENTS TO FORM SPACECRAFT
  - CONSTRUCT DISCRETE SINGLE-POINT JOINTS
  - CONSTRUCT DISCRETE MULTI-POINT JOINTS
  - CONSTRUCT CONTINUOUS "LINE" JOINTS
  - AUTOMATE ASSEMBLY AND CONSTRUCTION OPERATIONS
  - ANALYZE AND SIMULATE ALL ASSEMBLY AND CONSTRUCTION OPERATIONS

- TECHNOLOGY DEVELOPMENT APPROACH
  - SURVEY MISSIONS FOR ISAAC NEEDS AND REQUIREMENTS
  - DEFINE FUNDAMENTAL GENERIC CAPABILITIES NEEDED
  - DEFINE FOCUS PROBLEMS AND ASSOCIATED EXPERIMENTS
  - DEVELOPE METHODS AND HARDWARE FOR ACCOMPLISHING ISAAC PROCESSES
  - PERFORM EXPERIMENTS WHICH VALIDATE ISAAC METHODS

IN-SPACE ASSEMBLY AND CONSTRUCTION
FACILITY CONCEPT

[Diagram showing various components and processes related to in-space assembly and construction operations, including mobile base, spacecrane, equipment storage pallet, ISAAC facility, modular aerobrake construction, positioning & attachment end effectors, and lunar transfer vehicle assembly.]
STATE-OF-THE-ART ASSESSMENT

- GENERAL ASSESSMENT: EXTENSIVE NEUTRAL BUOYANCY EXPERIENCE IN SIMULATED ZERO-G CONSTRUCTION OF LARGE SPACE TRUSSES. VERY GOOD CORRELATION WITH FLIGHT DATA (ACCESS). NO EXPERIENCE IN THE AREAS OF ON-ORBIT ASSEMBLY (AUTOMATED) OR AUTOMATED (TELERobotic) CONSTRUCTION

- DETAILED ASSESSMENT:
  - NO VALIDATED DESIGN-FOR-CONSTRUCTION METHODS
  - NO SYSTEM EXISTS FOR RAPIDLY & PRECISELY POSITIONING LARGE/MASSIVE SPACECRAFT COMPONENTS (FOR ASSEMBLY)
  - CONCEPTS EXIST FOR LIGHTLY MECHANICAL LOADED JOINTS (ACCESS, SSF), HOWEVER, NO CONCEPTS EXIST FOR HEAVILY LOADED JOINTS
  - LIMITED EXPERIENCE WITH ZERO-G WELDING (SKYLAB, SOVIET UNION), HOWEVER, NO EXPERIENCE WITH AUTOMATED ZERO-G VACUUM WELDING FOR CONSTRUCTION OR ASSEMBLY APPLICATIONS ON ORBIT

OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS
IN-SPACE ASSEMBLY AND CONSTRUCTION

STATE-OF-THE-ART ASSESSMENT (CONCLUDED):

- AUTOMATED CONSTRUCTION OF A LIGHTLY LOADED TRUSS IN A HIGHLY STRUCTURED ENVIRONMENT WITH NO ON-ORBIT EFFECTS INCLUDED (ASAL). NO EXPERIENCE WITH AUTOMATED ASSEMBLY OR CONSTRUCTION IN AN UNSTRUCTURED ENVIRONMENT INCLUDING PATH PLANNING, COLLISION AVOIDANCE, AND FACILITY INFRASTRUCTURE FLEXIBILITY.
OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS
IN-SPACE ASSEMBLY AND CONSTRUCTION

POSITIONING AND CONSTRUCTION DEVICES PERFORMANCE OBJECTIVES

<table>
<thead>
<tr>
<th>PERFORMANCE REQUIREMENT</th>
<th>CURRENT S.O.A. (RMS)</th>
<th>LUNAR</th>
<th>MARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manipulator Reach</td>
<td>15 m</td>
<td>30 m</td>
<td>100 m</td>
</tr>
<tr>
<td>Component Mass</td>
<td>14,500 kg (ret.)</td>
<td>75,000 kg</td>
<td>150,000 kg</td>
</tr>
<tr>
<td></td>
<td>30,000 kg (dep.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Placement Accuracy</td>
<td>± 2 inches</td>
<td>± 1 inch</td>
<td>± 1 inch</td>
</tr>
<tr>
<td>Tip Force</td>
<td>15 lbf</td>
<td>50 lbf</td>
<td>150 lbf</td>
</tr>
<tr>
<td>Damping</td>
<td>&lt; .5%</td>
<td>&gt; 5.0% (5 modes)</td>
<td>&gt; 5.0% (5 modes)</td>
</tr>
<tr>
<td>Max. tip velocity</td>
<td>0.2 ft/sec</td>
<td>0.4 ft/sec</td>
<td>0.6 ft/sec</td>
</tr>
<tr>
<td>(14,500 kg, 2 ft. stop)</td>
<td>After each flight</td>
<td>&gt; 1 year</td>
<td>&gt; 1 year</td>
</tr>
<tr>
<td>Maintenance Interval</td>
<td>Highly structured</td>
<td>Unstructured path planning</td>
<td>Unstructured path planning</td>
</tr>
<tr>
<td>environment</td>
<td>taught points</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation</td>
<td>Teleoperated</td>
<td>Telerobotic</td>
<td>Telerobotic</td>
</tr>
</tbody>
</table>

SPACE CRANE

The Capability to Position and Control Spacecraft Components Precisely and Safely During Assembly Will be Achieved by Developing a Structural Space Crane Type Arm, Having Multiple Articulating Joints for Dexterity, and that can Ultimately be Operated in an Automated Mode

FEATURES

- Strength to Move and Control Large Spacecraft Components Safely
- Passive and Active "Stiffness" to Maintain a Stable and Secure Position
- Highly Controllable Large Angle Motion with Dynamic Control for Stable Trajectories
- Passive and Active Vibration Damping to Achieve Required Precision
- Reconfigurable/Adaptable Geometry to Reduce the Amount of Required On-Orbit Infrastructure
- Scaleability (Larger or Smaller Sizes) for a Variety of Applications
- Robustness and Reuseability for Long Life
SPACECRAFT COMPONENT POSITIONING AND ASSEMBLY TEST-BED

Active Suspension System

Actuators

Crane

Payload

End Effector

Rotary Joint

Payload Storage Pallet

SPACE CRANE ARTICULATING JOINT TEST BED FABRICATED
Erectable Truss Hardware
Predictability is excellent

Static Testing
- Reference Truss
- Applied Force
- Y-Deflection

Dynamic Testing
- First three analytical frequencies: 6.77 Hz, 7.02 Hz, and 24.42 Hz
- Phase analysis
- Acceleration/force
- Hardware

Improved linear actuators
Reduce test bed backlash by 57 percent

Articulating joint
Test bed (AJTB)
- Applied load
- Y-Deflection

Linear actuators
- Articulating joint detail

Applied load, lb
- Original actuators
- 0.21 in
- Backlash
- 1 load cycle

Applied load, lb
- Improved actuators
- 0.09 in
- 3 load cycles

Deflection, in
AUTOMATED STRUCTURES ASSEMBLY LABORATORY

AUTOMATED CONSTRUCTION TECHNOLOGY DEVELOPMENT & DEMONSTRATION TEST-BED

Robot arm with panel end effector

Pallets with truss struts

Robot carriage for X and Y motion

Pallet with panels

Turntable
## Joining Methods Performance Objectives

<table>
<thead>
<tr>
<th>Performance Requirement</th>
<th>Current S.O.A.</th>
<th>Lunar</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>2000 lbf (SSF)</td>
<td>Up to 50,000 lbf</td>
<td>Up to 150,000 lbf</td>
</tr>
<tr>
<td>Connection time</td>
<td>0.3 min/strut (ACCESS)</td>
<td>0.3 - 5.0 min/strut (mechanical)</td>
<td>0.3 - 5.0 min/strut (mechanical)</td>
</tr>
<tr>
<td></td>
<td>Welding: TBD</td>
<td>Welding: TBD</td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>&gt; 5 years (SSF)</td>
<td>&gt; 5 years</td>
<td>&gt; 10 years</td>
</tr>
<tr>
<td>Connection method</td>
<td>Manned EVA (ACCESS, SSF)</td>
<td>Automated/EVA (mix)</td>
<td>Automated/EVA (mix)</td>
</tr>
</tbody>
</table>

Erectable joint family available for efficient aerobrake truss design.
WELDED JOINTS - CLASSIFICATION
(Basic Advantages)

• TUBULAR STRUT
  - High Strength, Low Mass
  - Low Dimensional Accuracy Requirements
  - Simple Welding Mechanism

• PIPES/DUCTS
  - Hermetic Seal
  - Simple Welding Mechanism

• SKIN/TANK
  - Hermetic Seal

• SEMI-MONOCOQUE STRUCTURES
  - High Strength, Low Mass
  - Low Dimensional Accuracy Requirements

• REPAIR/CONTINGENCY (Manual)
  - Flexibility

OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS
IN-SPACE ASSEMBLY AND CONSTRUCTION

CURRENT PROGRAM: ACCOMPLISHMENTS

ACCOMPLISHMENTS

• Load/displacement testing of 1st and 2nd generation space crane linear actuators completed

• Space crane maximum allowable tip velocity established using strut buckling loads

• 1st. generation heavily loaded 4-inch diameter erectable aerobrake joint developed

• Automated construction of the complete 102-member flat tetrahedral truss structure successfully completed

• Vacuum plasma welding experiments conducted

• Aerobrake hexagonal heatshield panel construction tests completed
CURRENT PROGRAM: FY 91/92 PLANS

FY 91/92 PLANS (FUNDING FOR FY 92 = $0)

• Perform space crane kinematic and dynamic simulations
• Upgrade space crane articulating joint test hardware and perform dynamic tests
• Redesign heavily-loaded erectable joints and perform static tension failure tests
• Demonstrate automated installation of flat antenna panels onto flat truss
• Complete welding vacuum manipulation facility

OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS
IN-SPACE ASSEMBLY AND CONSTRUCTION

OTHER DEVELOPMENT EFFORTS

• LaRC BASE R&T
  • EVA construction of precision curved truss with panels
  • Automated Structures Assembly Laboratory (ASAL)

• NO OTHERS
CONCLUDING REMARKS

- Design-for-Construction/Assembly Must be Emphasized From the Very Beginning of the Spacecraft Design Process

- Having a Basic Generic Set of In-Space Assembly and Construction Capabilities Available Will
  - Give Mission Planners and Spacecraft Designers a Great Deal of Flexibility
  - Minimize the Amount of In-Space Infrastructure and Resources Required to Build Spacecraft on Orbit

- Spacecraft Design Costs can be Reduced by Using Available and Developed ISAAC Capabilities, Methods, and Hardware