**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

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**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

**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

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

**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

Missions ® Total Mass and Volume

General On-Orbit Construction and Assembly Capability Required

Maximum number of mission options and planning flexibility

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
• AEROSHADE CONSTRUCTION
• SPACECRAFT COMPONENT ASSEMBLY

MARS TRANSFER VEHICLES
• SPACECRAFT COMPONENT ASSEMBLY
• NTR: BACKBONE TRUSS & RADIATOR CONSTRUCTION, UTILITIES WELDING
• SEP: SOLAR ARRAY CONSTRUCTION
IN-SPACE ASSEMBLY AND CONSTRUCTION

TECHNOLOGY CHALLENGES/APPRAOCH

• 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
OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS
IN-SPACE ASSEMBLY AND CONSTRUCTION

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

DETAILED 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.
### 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>
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<tr>
<td>Component Mass</td>
<td>14,500 kg (ret.) 30,000 kg (dep.)</td>
<td>75,000 kg 150,000 kg</td>
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<tr>
<td>Placement Accuracy</td>
<td>± 2 inches</td>
<td>± 1 inch</td>
<td>± 1 inch</td>
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<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>Maintenance Interval</td>
<td>After each flight</td>
<td>&gt; 1 year</td>
<td>&gt; 1 year</td>
</tr>
<tr>
<td>Required environment</td>
<td>Highly structured taught points</td>
<td>Unstructured path planning</td>
<td>Unstructured path planning</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

\[ NASA \]

MS9-5
SPACECRAFT COMPONENT POSITIONING
AND ASSEMBLY TEST-BED

Active Suspension System → Actuators
Crane → Payload
Rotary Joint → End Effector
Payload Storage Pallet

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

Static Testing Y-Deflection
Reference Truss

Dynamic Testing

First three analytical frequencies:
6.77 Hz, 7.02 Hz, and 24.42 Hz

Improved Linear Actuators
Reduce test bed backlash by 57 percent

Articulating Joint Test Bed (AJTB)

Articulating Joint Detail

Improved actuators

Original actuators

0.21 in backslash

1 load cycle

0.09 in

3 load cycles
AUTOMATED STRUCTURES ASSEMBLY LABORATORY

AUTOMATED CONSTRUCTION TECHNOLOGY DEVELOPMENT & DEMONSTRATION TEST-BED

Robot arm with panel end effector
Pallet with panels
Pallets with truss struts
Robot carriage for X and Y motion
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>
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<tr>
<td>Connection time</td>
<td>0.3 min/strut (ACCESS)</td>
<td>0.3 - 5.0 min/strut (mechanical) Welding: TBD</td>
<td>0.3 - 5.0 min/strut (mechanical) Welding: TBD</td>
</tr>
<tr>
<td>Durability</td>
<td>&gt; 5 years (SSF)</td>
<td>&gt; 5 years</td>
<td>&gt; 10 years</td>
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<tr>
<td>Connection method</td>
<td>Manned EVA (ACCESS, SSF)</td>
<td>Automated/EVA (mix)</td>
<td>Automated/EVA (mix)</td>
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</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

OTHER DEVELOPMENT EFFORTS

- LaRC BASE R&T
  - EVA construction of precision curved truss with panels
  - Automated Structures Assembly Laboratory (ASAL)
- NO OTHERS
### ISAAC TECHNOLOGY ROADMAP/SCHEDULE

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<td><strong>ASSEMBLY</strong></td>
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<tr>
<td>Articulating joint test-bed</td>
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<tr>
<td>Simulations</td>
<td>Kinematics/Dynamics</td>
<td>Assembly &amp; Construction Test-bed operations</td>
<td>On-orbit facility</td>
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<td>3-D space crane</td>
<td>Reqs. (Lunar)</td>
<td>Design</td>
<td>Hardware fab</td>
<td>Suspension system</td>
<td>Req. (Mars)</td>
<td>Design</td>
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<tr>
<td>Assembly experiment</td>
<td>Reqs. &amp; concept</td>
<td>Controls</td>
<td>End-effector reqs</td>
<td>Hardware integration</td>
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<tr>
<td><strong>CONSTRUCTION</strong></td>
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<tr>
<td>Flat truss/panels</td>
<td>Automated panel installation</td>
<td>Unstructured environment</td>
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<tr>
<td>Antenna</td>
<td>Reqs. &amp; concept</td>
<td>Hardware fab</td>
<td>Carriage, arm and effector fab</td>
<td>Auto. const. rigid base</td>
<td>Auto. const. flexible base</td>
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<tr>
<td>Welding (utilities)</td>
<td>Complete vacuum facility</td>
<td>Utility concept</td>
<td>Hardware fab</td>
<td>Automated orbital weld</td>
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### 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