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 Assmbly 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

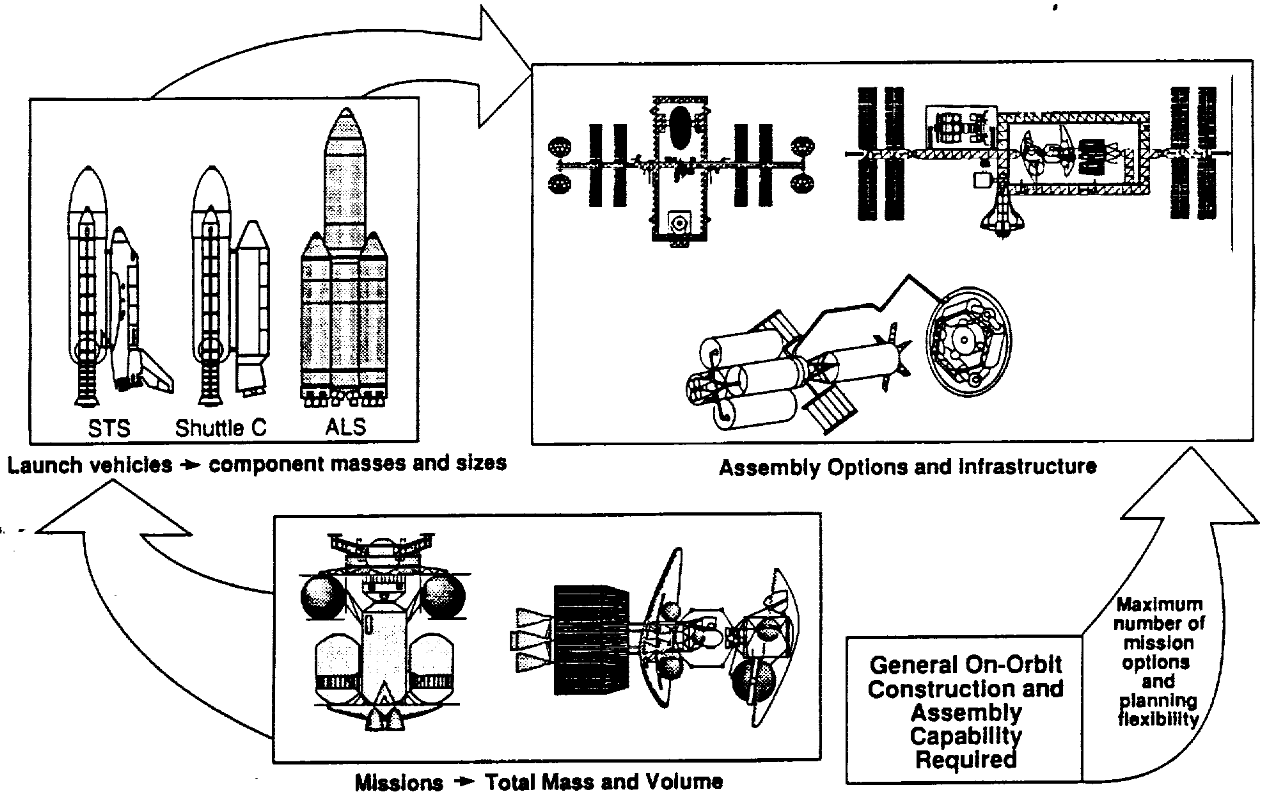
Space crane
- Positioning control
- Passive damping
- Active damping
- Suspension systems

Automated construction

Marshall Spaceflight Center

Automated welding

IN-SPACE ASSEMBLY AND CONSTRUCTION ENHANCES FUTURE MISSIONS PLANNING FLEXIBILITY



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

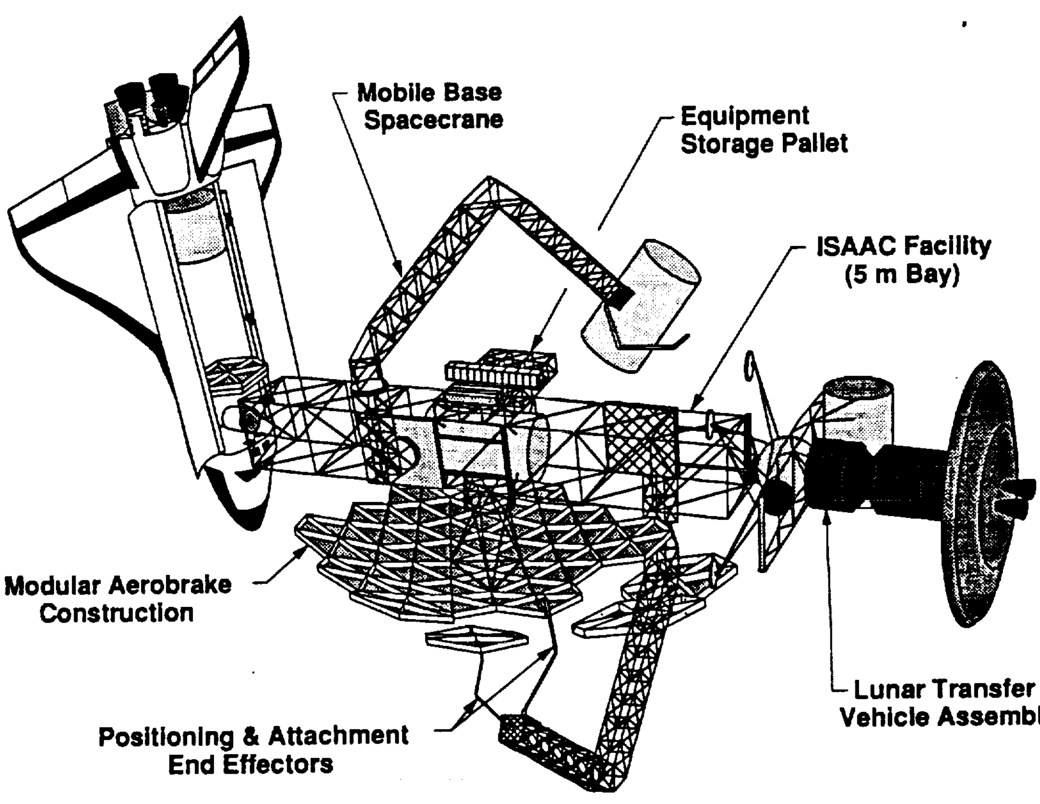
- SPACECRAFT COMPONENT ASSEMBLY
- NTR: BACKBONE TRUSS & RADIATOR CONSTRUCTION, UTILITIES WELDING
- SEP: SOLAR ARRAY CONSTRUCTION

IN-SPACE ASSEMBLY AND 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



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 INFRASTRUCURE FLEXIBILITY.

IN-SPACE ASSEMBLY AND CONSTRUCTION

POSITIONING AND CONSTRUCTION DEVICES PERFORMANCE OBJECTIVES

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

SPACE CRANE

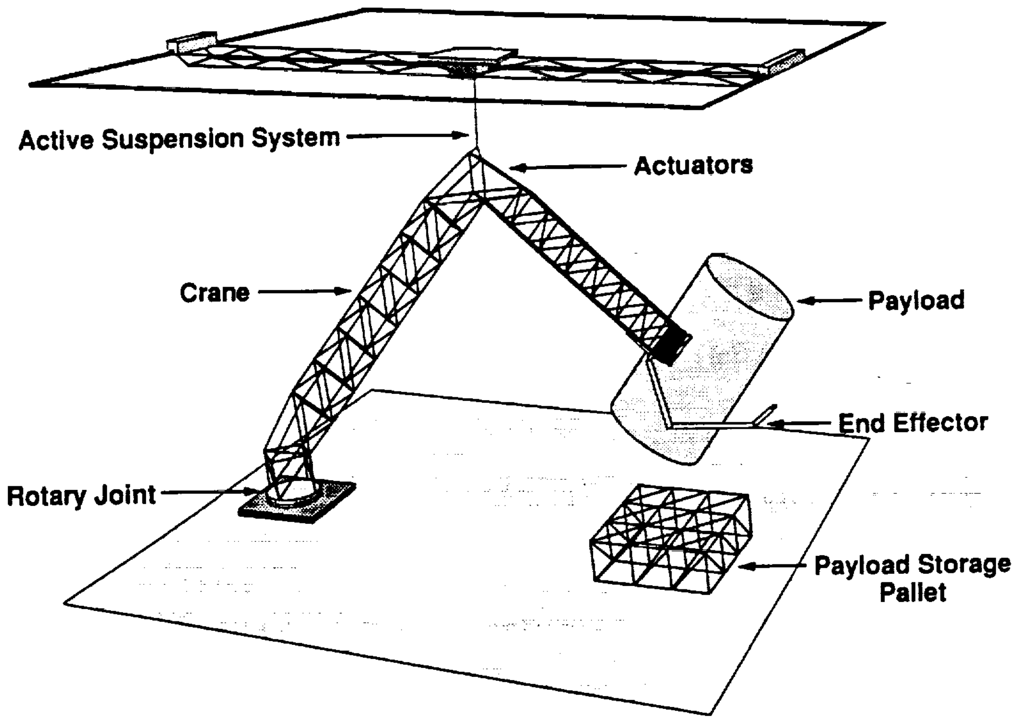
The Capability to Position and Control Spacecraft Components.Precisely and Safely During Assembly Will be Achieved by Developing a Structural Space Crane Type Arm, Having Multiple Articulating Joints for Dexterity, and that can Ultimately be Operated in an Automated Mode

FEATURES

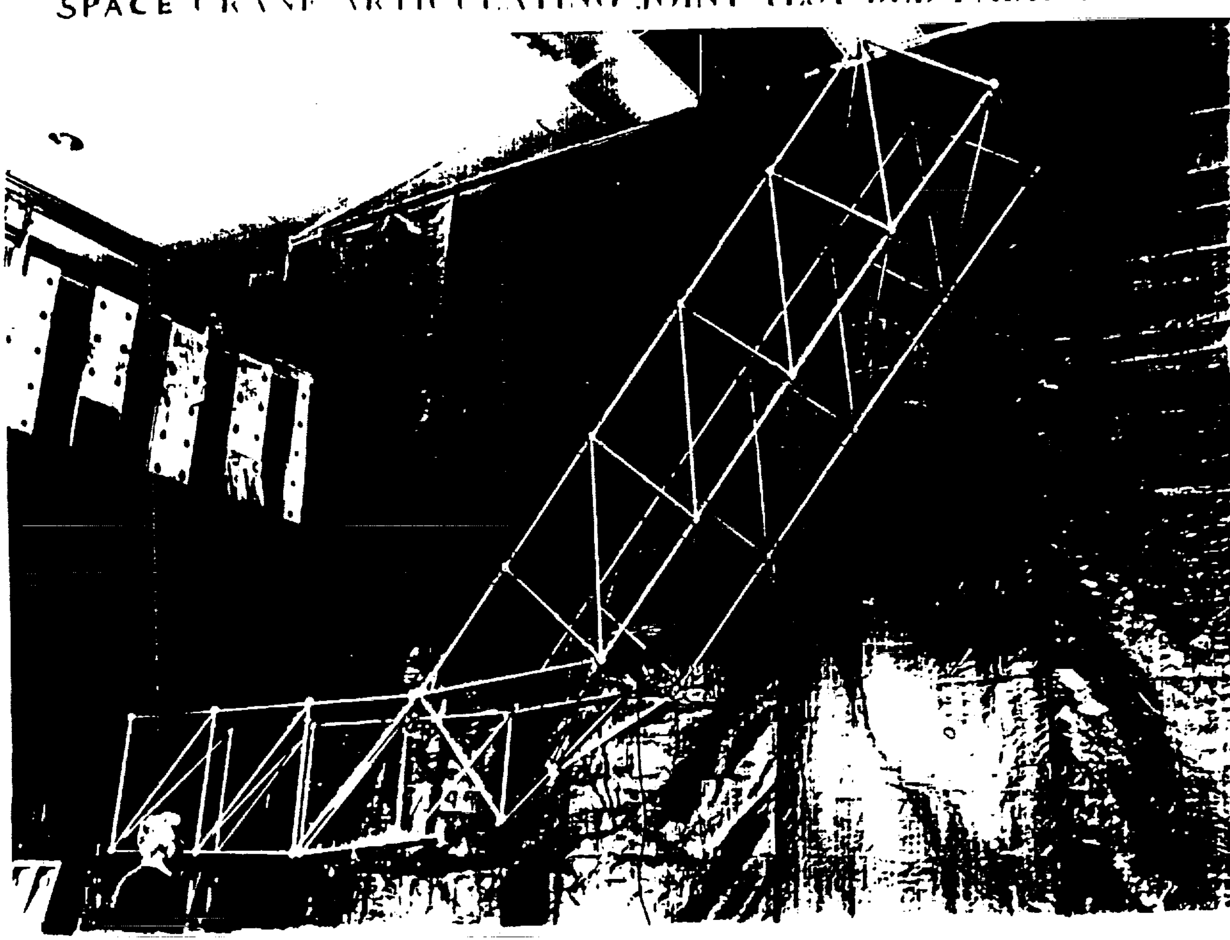
- Strength to Move and Control Large Spacecraft Components Safely
- Passive and Active "Stiffness" to Maintain a Stable and Secure Position
- Highly Controllable Large Angle Motion with Dynamic Control for Stable Trajectories
- Passive and Active Vibration Damping to Achieve Required Precision
- Reconfigurable/Adaptable 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

SPACECRAFT COMPONENT POSITIONING AND ASSEMBLY TEST-BED

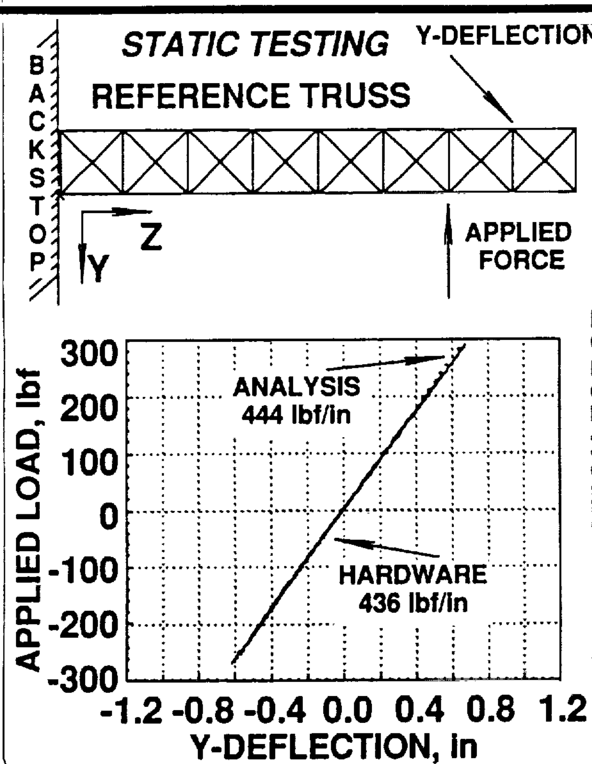


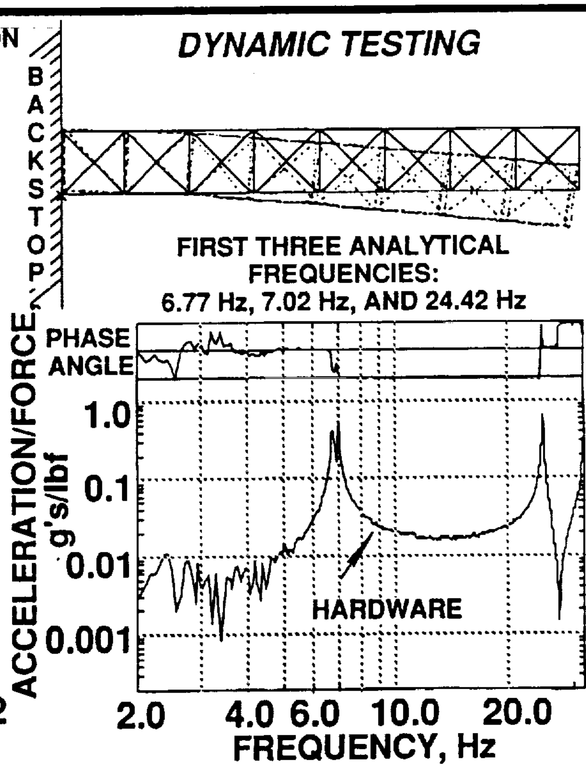
SPACE CRANE ARTICULATING JOINT TEST BED FABRICATED



ERECTABLE TRUSS HARDWARE PREDICTABILITY IS EXCELLENT

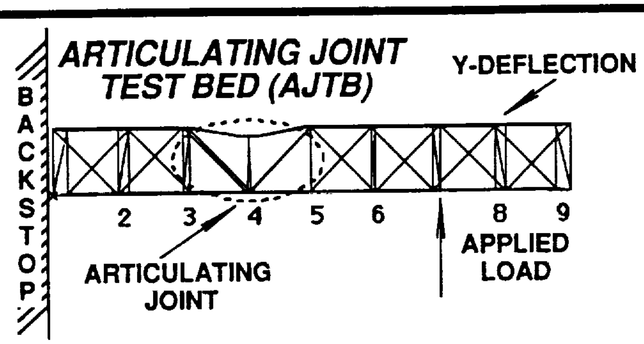
EXPLORATION TECHNOLOGY

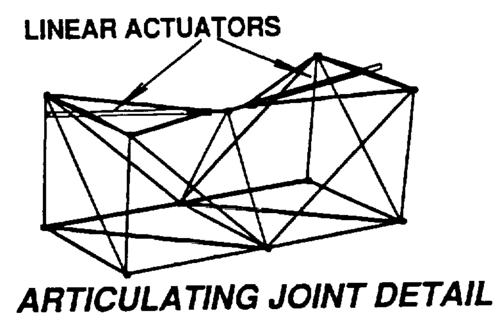


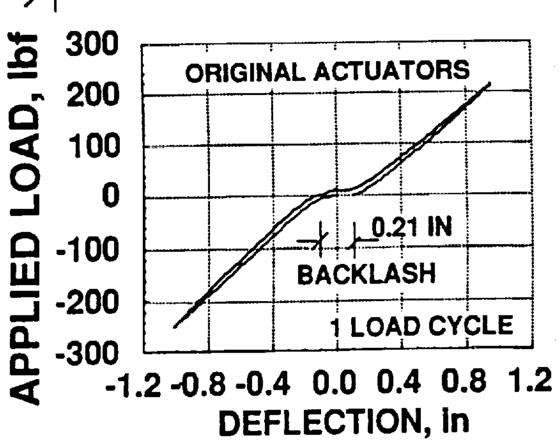


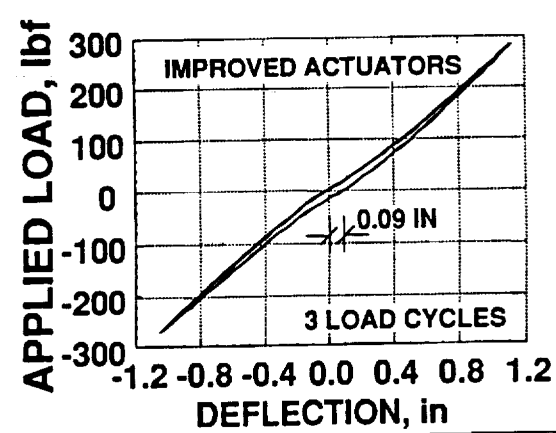
IMPROVED LINEAR ACTUATORS REDUCE TEST BED BACKLASH BY 57 PERCENT

EXPLORATION TECHNOLOGY

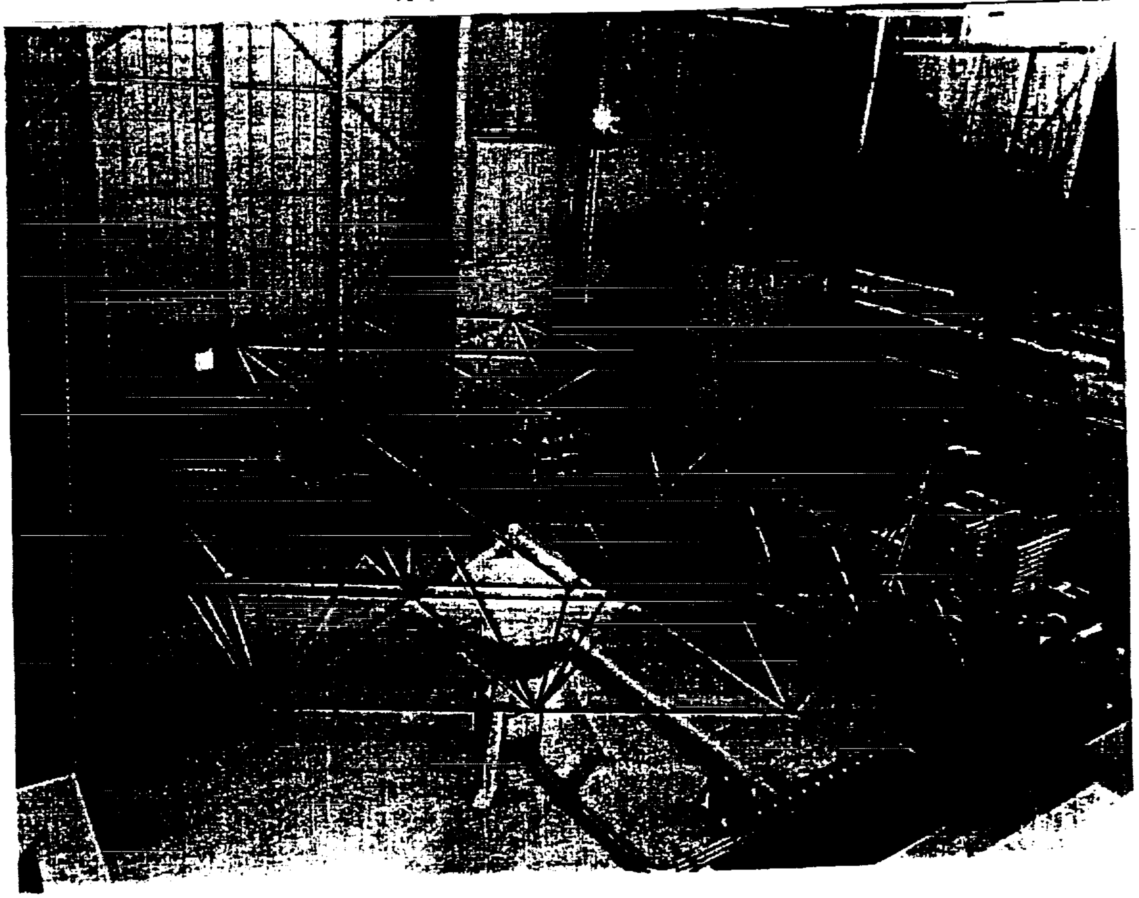




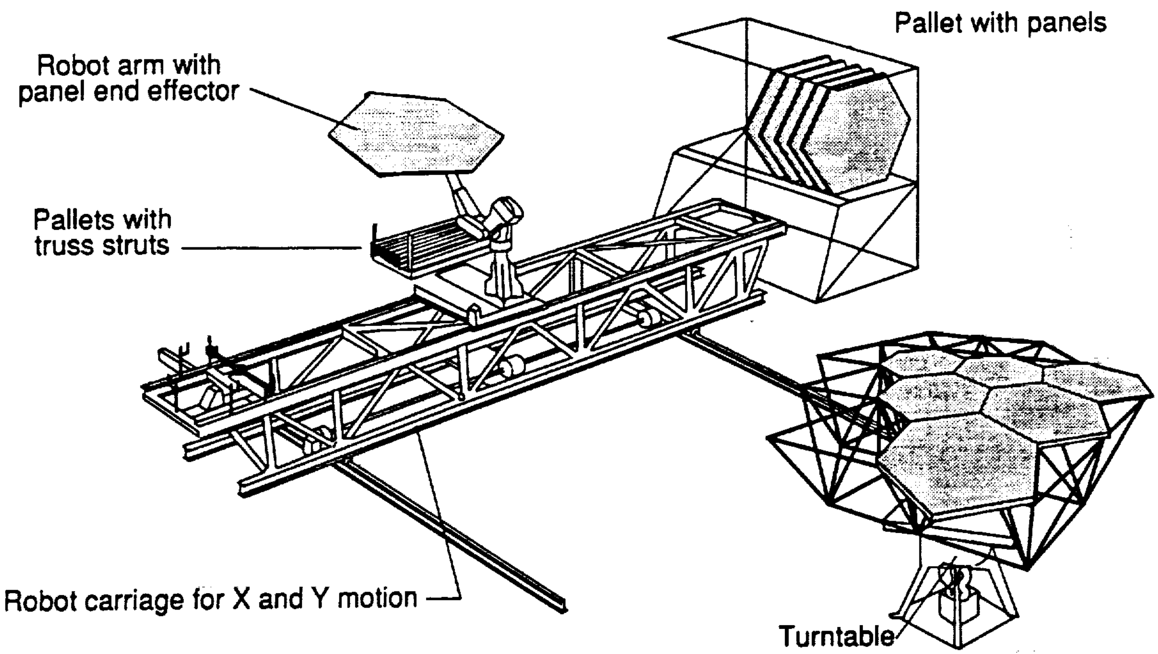




AUTOMATED STRUCTURES ASSEMBLY LABORATORY



AUTOMATED CONSTRUCTION TECHNOLOGY DEVELOPMENT & DEMONSTRATION TEST-BED

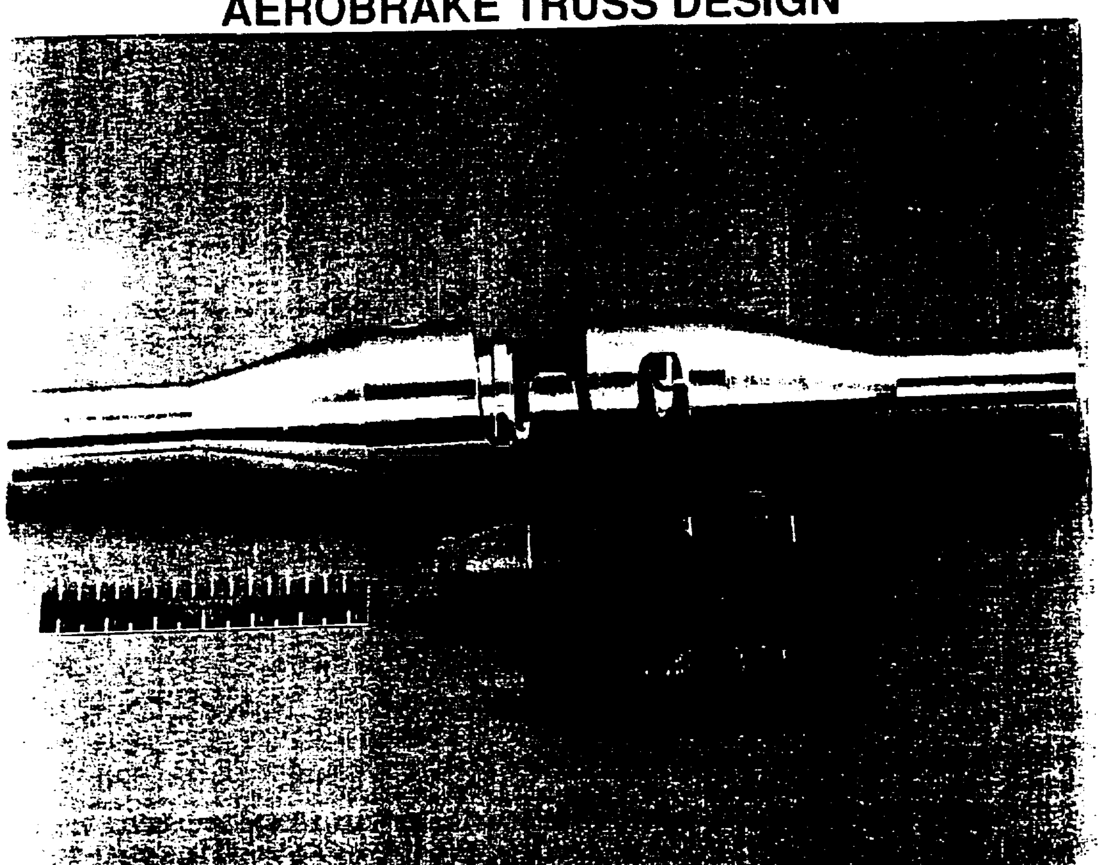


IN-SPACE ASSEMBLY AND CONSTRUCTION

JOINING METHODS PERFORMANCE OBJECTIVES

PERFORMANCE REQUIREMENT	CURRENT S.O.A.	LUNAR	MARS
Strength	2000 lbf (SSF)	Up to 50,000 lbf	Up to 150,000 lbf
Connection time	0.3 min/strut (ACCESS)	0.3 - 5.0 min/strut (mechanical) Welding: TBD	0.3 - 5.0 min/strut (mechanical) Welding: TBD
Durability	> 5years (SSF)	> 5 years	> 10 years
Connection method	Manned EVA (ACCESS, SSF)	Automated/EVA (mix)	Automated/EVA (mix)

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

OPERATIONS TECHNOLOGY: INFRASTRUCTURE OPERATIONS

IN-SPACE ASSEMBLY AND CONSTRUCTION

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

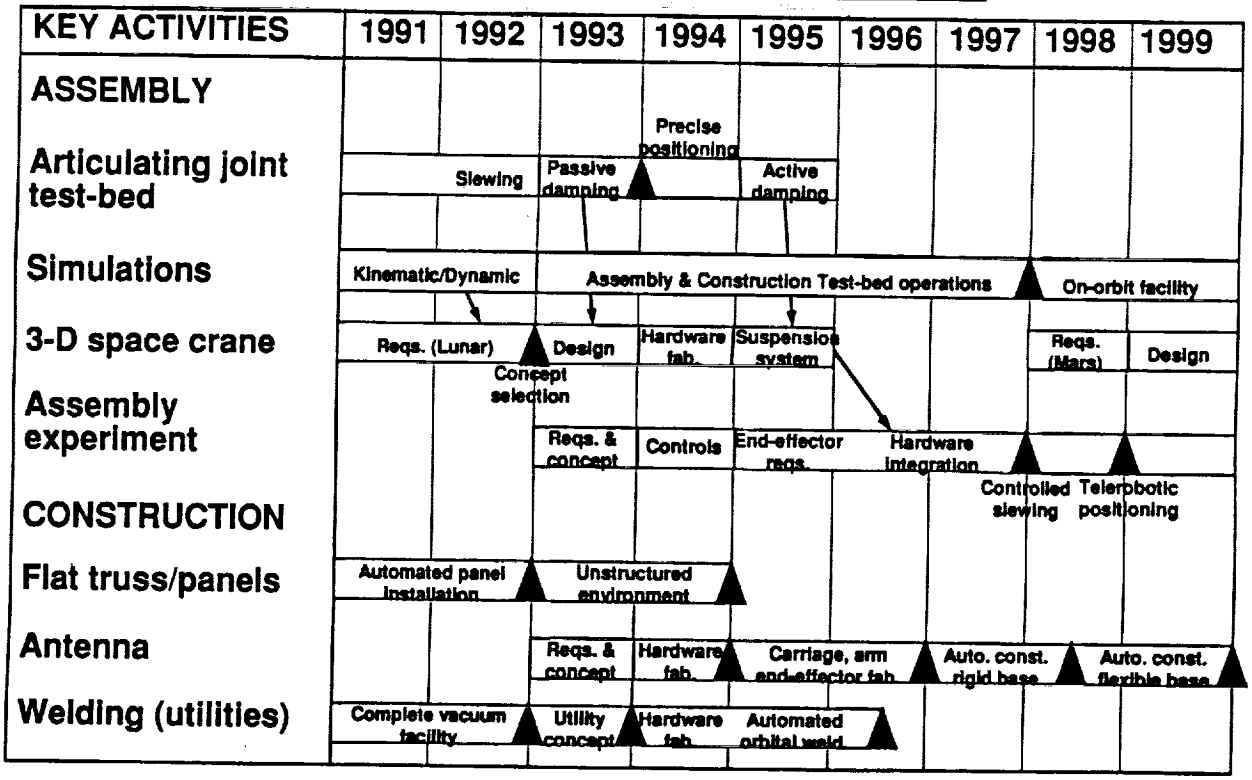
IN-SPACE ASSEMBLY AND CONSTRUCTION

OTHER DEVELOPMENT EFFORTS

- LaRC BASE R&T
  - EVA construction of precision curved truss with panels
  - Automated Structures Assembly Laboratory (ASAL)
- NO OTHERS

IN-SPACE ASSEMBLY AND CONSTRUCTION

ISAAC TECHNOLOGY ROADMAP/SCHEDULE



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