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AUTOMATED ASSEMBLY OF LARGE SPACE STRUCTURES

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PROGRAM RESEARCH OBJECTIVE

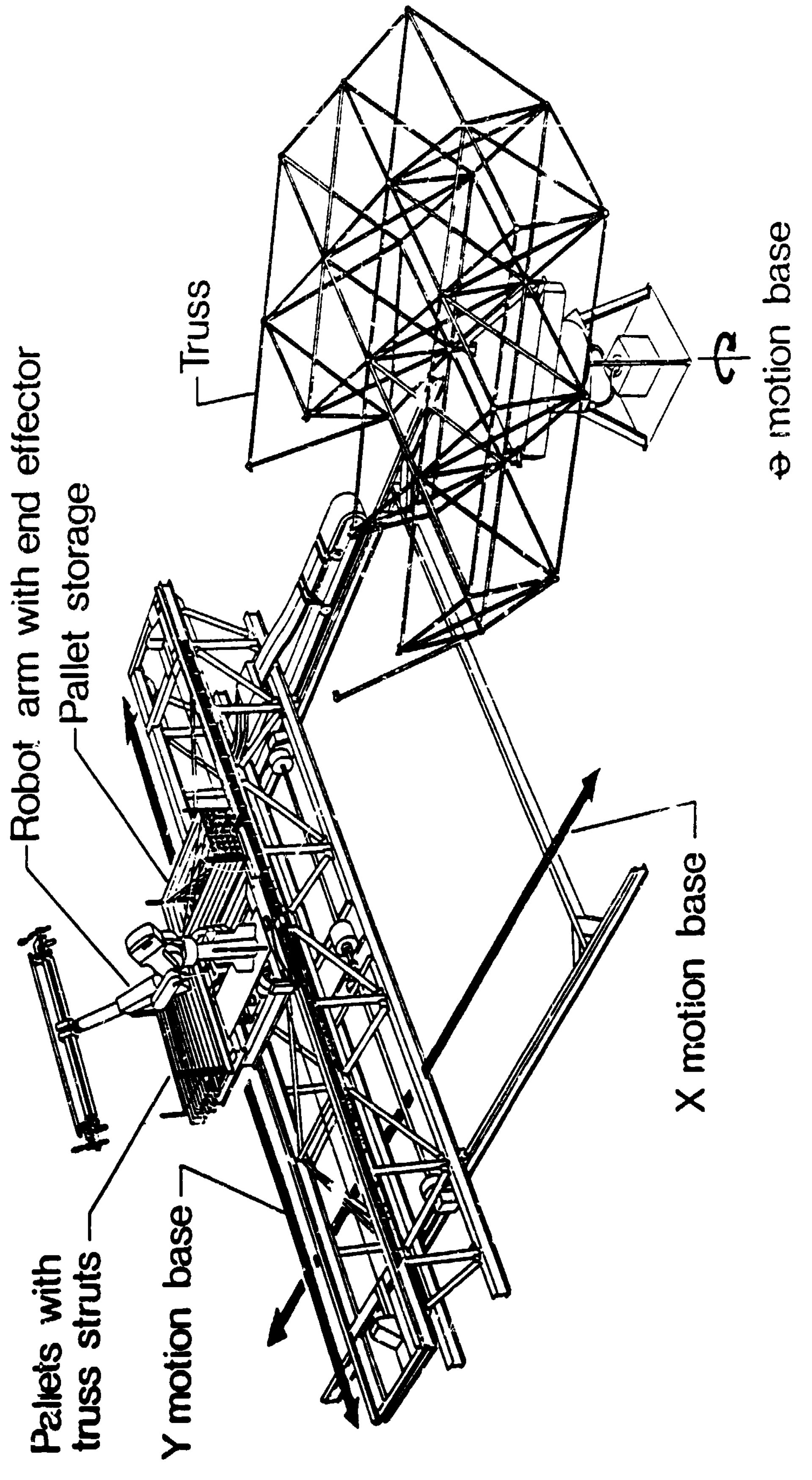
DEVELOP TECHNOLOGY AND DEMONSTRATE THE POTENTIAL FOR AUTOMATED INSPACE ASSEMBLY OF LARGE ERECTABLE STRUCTURES

APPROACH

MERGE EXPERIENCE IN STRUCTURAL ASSEMBLY AND ROBOTICS AT LARC INTO AN INTERDISCIPLINARY PROGRAM WITH FOCUSED EFFORT ON AUTOMATED ASSEMBLY OF A GENERIC STRUCTURAL CONFIGURATION WITH A STANDARD CELL AND BUILD INTO THE SYSTEM THE CAPABILITY TO DO EXPANDED RESEARCH WITH COMPLEX CONFIGURATIONS

Future space missions such as submillimeter astronomical telescopes and aerobrakes for Mars landers are likely to require support trusses to provide a stiff structure to position and support a large segmented panel surface. The support structure for these missions will involve the assembly of thousands of members and the potential demands on astronauts work time and the potential hazards associated with EVA operations make it imperative to examine alternate techniques for routine structural assembly operations. Therefore, an interdisciplinary program was recently initiated at the Langley Research Center to evaluate the potential for automated in-space assembly. The experience in structural joint design developed over the past several years, was joined with robotics technology to form an interdisciplinary research team to evaluate automated assembly of a regular tetrahedral truss. This truss was selected because it has been proposed as the backbone structure for a number of future missions and it has a simple geometrical configuration that is developed around a standard unit cell. Also the truss construction can be easily expanded to very large systems by simple repetitive operations.

Features of the assembly facility are shown in this sketch. A commercially available robot arm is mounted on a carriage system to position the robot in an X-Y reference frame. The truss is assembled on a rotating motion base near the end of the X carriage system. The struts used in the construction of the truss are stored in pallets that are mounted immediately behind and within easy reach of the robot arm. As the pallets are emptied they are moved to a pallet storage rack. This facility was designed around the use of existing components and fabricated from traditional structural shapes so that the research program could be initiated quickly and the system could be modified as experience dictates. This facility is intended to be a research development tool as opposed to a brass-board space flight system.



Pallets with truss struts
Y motion base
Robot arm with end effector
Pallet storage
Truss
θ motion base
X motion base

A photograph of some of the facility components are shown in this figure. The truss has tubular strut members that are 2 meters long and 2.6 cm in diameter. There are 102 struts in the completed truss configuration, however, the facility is of adequate size to enlarge the test truss to 252 members. The strut tubes are graphite/epoxy with a wall thickness of 2.03 mm (0.080 in). They were fabricated on a mandrel from unidirectional prepreg which was preplied at +/- 10 deg before being rolled on the tool. The truss joints are aluminum and they were designed to provide structural preload and linear load deflection response through the connection interface.

The rotating motion base and the X and Y carriages are motor driven and have sensors to position the respective components at operator defined locations. All of these drive systems use cables wrapped around drum pulleys to minimize system backlash and freeplay. The motion base systems were stiffness designed so that deflections introduced from unbalanced assembly or from forces applied by the robot arm would not adversely affect construction operations.

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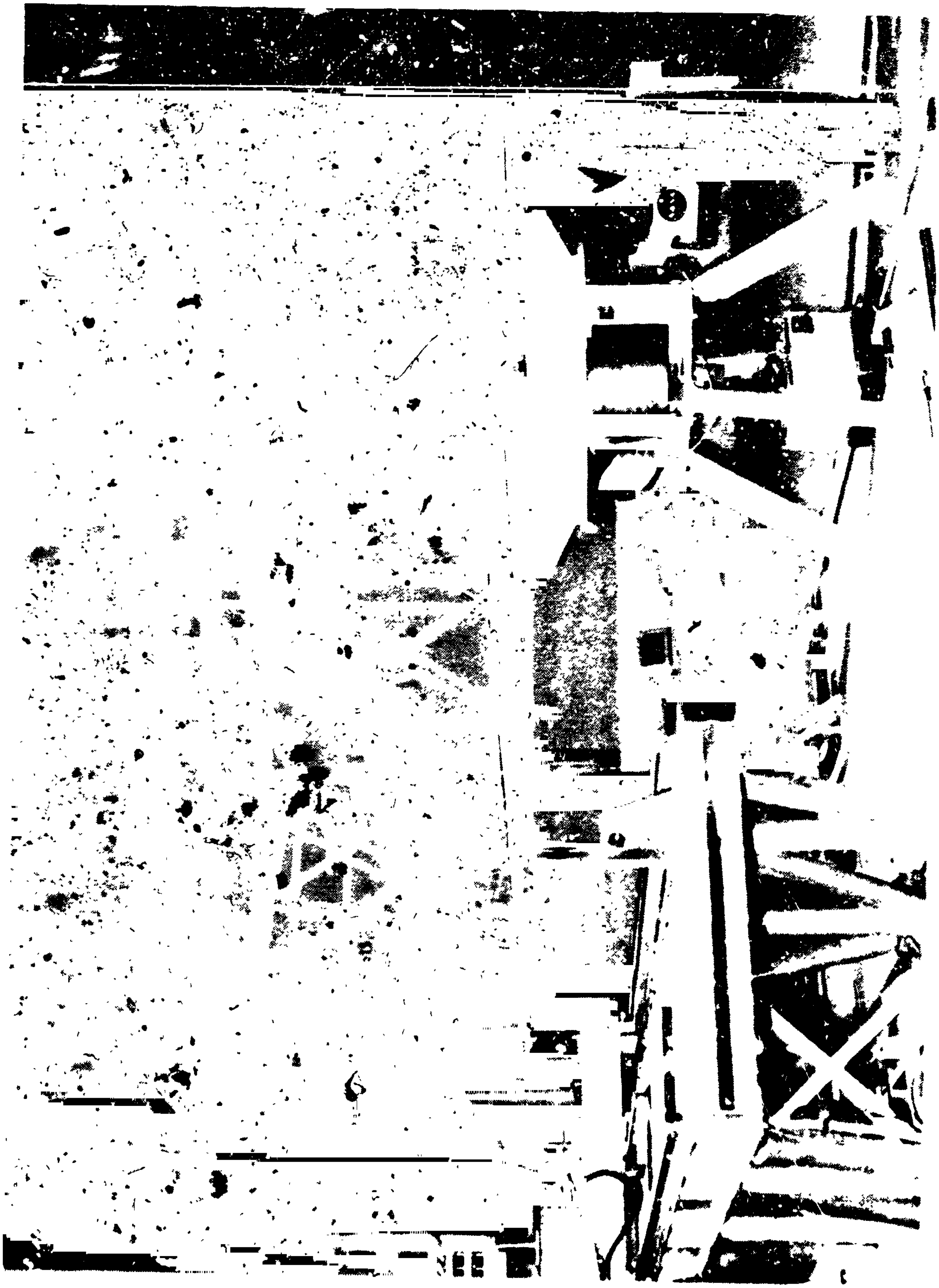
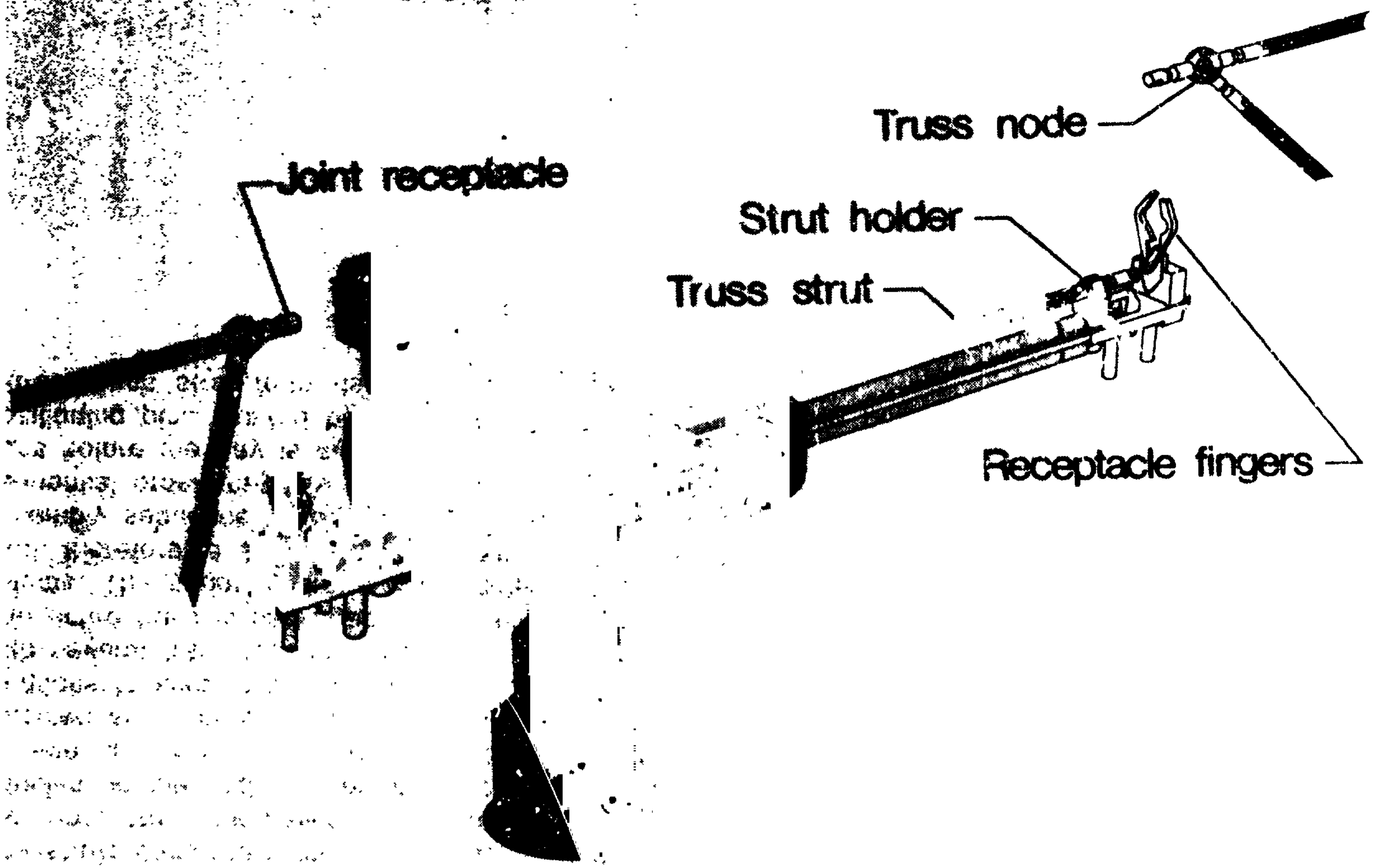
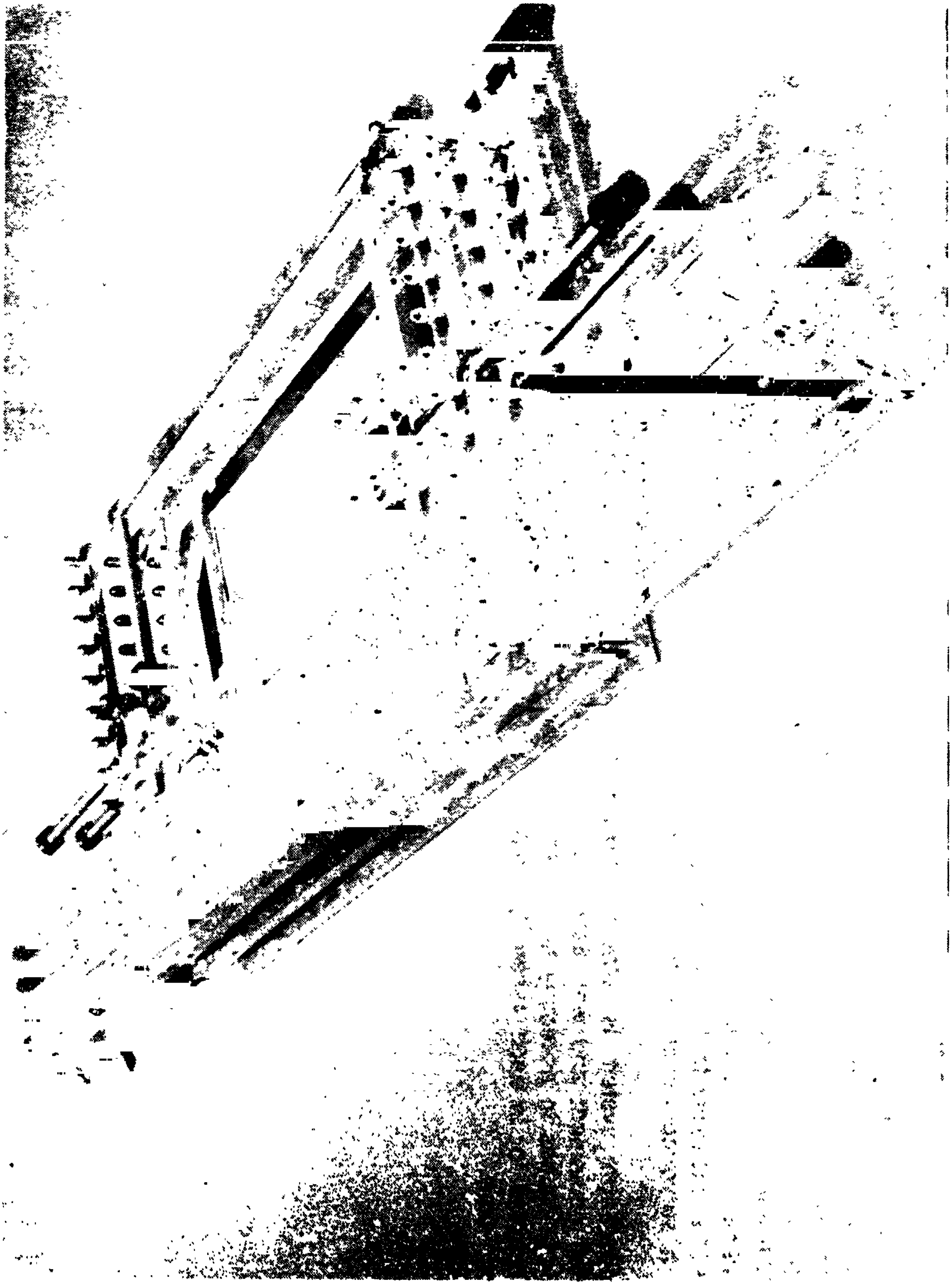


The end-effector is a specially designed tool that is dedicated to the task of grasping the struts in the pallets, holding the strut as the arm moves into position, grasping joint receptacles on the nodes, inserting the strut into the nodes, locking the joint, and then releasing the member. The fingers on each end of the end-effector grasp the joint receptacle and are seated in the groove when closed. These fingers are designed to capture the receptacle at any location within a 2.5 cm diameter by 1.5 cm long cylindrical envelope, and will move the nodes of members that are connected together as a frame into the correct position for strut insertion. This feature compensates for misalignment caused by gravity or bowing of the strut graphite tubes. It also secures all components so that drag or small misalignments will not restrict the insertion operation. Having grasped the receptacle, the end-effector inserts the strut in the joint and a motor powered nut driver locks the strut in place. The total operation of the joint and the end-effector were designed as a coordinated unit, as opposed to designing one component such as the joint and then designing an end-effector.to make it operate. The end-effector is designed to permit operation either with a node preattached to the strut, or to insert a strut into nodes already assembled on the truss.

ROBOT END EFFECTOR



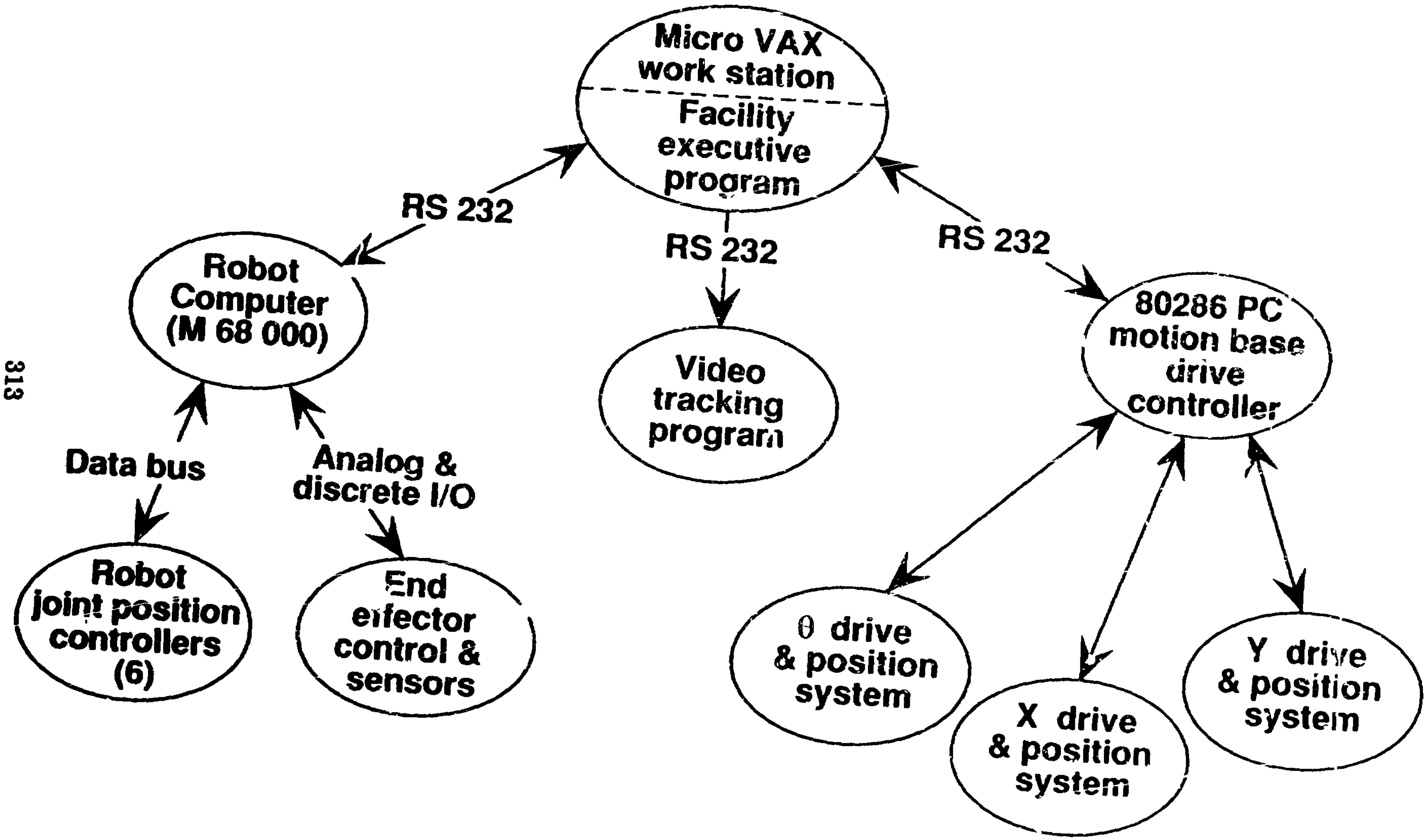
The struts comprising the truss structure are mounted in pallets that are held in a rack behind the robot arm. The pallets are structural frames fabricated from aluminum angle. Each pallet has handles on the ends to permit the strut holder on the end-effector to move it to the pallet storage rack. Each pallet will hold up to 13 struts and the nodes are preattached to one end of selected struts before assembly begins. The struts are placed in the pallets at preselected locations to accommodate efficient packaging. The complete truss can be packaged in 9 trays with several tray locations unused to accommodate selective placement of nodes in the pallets. The entire truss is packaged in an envelope which is less than 1.4% of the fully erected truss volume. The nodes interfere with each other if they are placed closer together than every fourth strut, therefore, a special arrangement of the nodes had to be devised and coordinated with the assembly sequence. The struts are not necessarily selected for insertion in the truss in the sequential order they are arranged in the pallets. However, all struts in a tray are inserted in the truss before the tray is moved to the storage rack. Spring loaded pin plungers in the side of the positioning pins located between struts hold the struts in the pallet and a force is required to extract each strut from its storage location.



Several computers are used to monitor and control the operations of the assembly facility. The function of these various computers is illustrated in the figure. The system is controlled by an executive program executed by a microVAX workstation. The executive program communicates with the other computers, a Motorola 68000 based unit and an 80286 based PC, by transmitting ASCII code through RS232 lines. Output commands are transmitted from both of these lower level systems directly to stepper drive motors and encoder position sensors. The robot computer also has the capability to handle analog and discrete input and output signals and is, therefore, used as a servo controller for the end-effector.

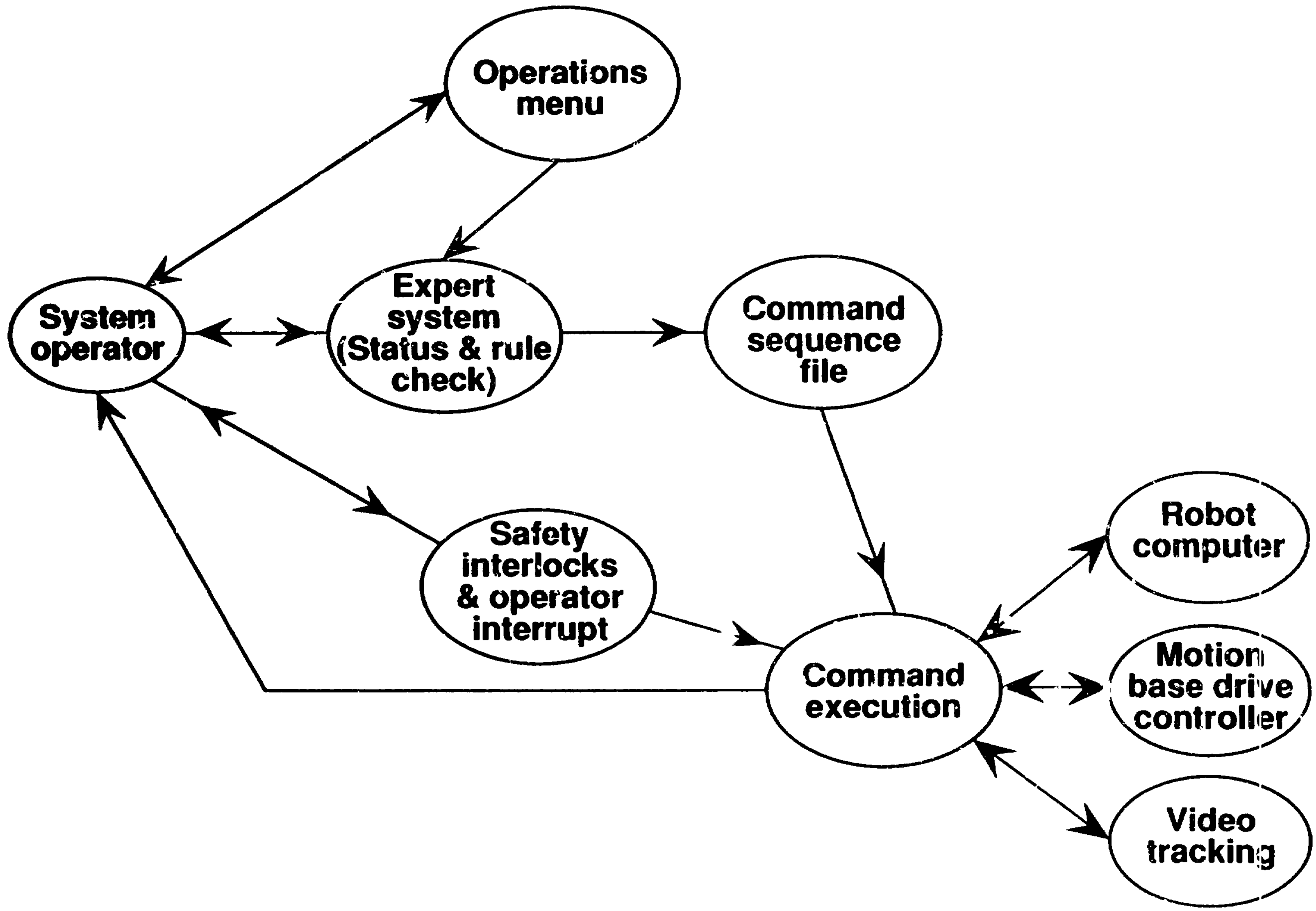
This control system is relatively slow and unsophisticated, however, it incorporates all off-the-shelf equipment and was assembled rapidly so that operational testing could begin without delay. Pauses in assembly time associated with the transfer of program commands can be accounted for in each assembly operation. Parallel system operation may be incorporated at a later time.

FACILITY COMPUTER CONTROL SYSTEM



The assembly facility executive program operates from the microVAX workstation and the operation is shown schematically in the figure. The system operator selects the desired assembly function from a menu of preprogrammed operations. The selected menu function is directed to the expert system which stores in memory the preceding operation and determines what changes in the current hardware configuration are required to perform the new menu selection. The hardware configuration status includes the truss struts and their location, the state of the end-effector, and the position of the motion bases. If the selected operation can be performed, the system notifies the operator and checks the facility safety interlocks. The expert system then generates the command sequence file required to perform the selected menu function and the commands are directed to the appropriate sublevel computer in sequential order. As the commands are executed the operator is notified by the executive program. The operator monitors the operations as they occur by a video surveillance system. If a failure occurs the operator has a menu from which to select corrective options and he will be permitted to override some noncritical fault indicators. All anticipated and experimentally defined failures are being incorporated into the operator menus. Those not listed can only be performed by directly accessing the appropriate sublevel computer.

COMPUTER EXECUTIVE PROGRAM



The research development plan for automated assembly of large space structures is shown in the figure. The program outline proceeds from fairly simple pick and place operations where robots are traditionally applied in terrestrial applications to complex operations for which sensors and controls play a major role. The initial assembly uses operator "taught" paths and defined locations that require the high level of repeatability built into the control system of most robot arms. By having redundant degrees of freedom in the assembly motion base system the entire 102 member truss structure can be assembled by "teaching" the paths and positions of approximately 12% of the members. Also the current end-effector is a special purpose tool for assembling trusses of this size. Expanded operations will focus on the design of end-effectors which can perform the assembly of curved trusses where many different length members are required and the same end-effector can be used to attach payloads during truss assembly. Finally, any mechanism that operates at a remote and inaccessible location where collision can cause considerable damage will require a complex 3D graphics simulation with path planners and sensor guidance.

Automated Assembly of Large Space Structures

Project Development

"Dumb" assembly of planar truss using taught points & dedicated robot positions

Expanded truss assembly with payloads, panels, sensor guidance and graphics simulation

Curved truss structure, system dynamics and coordinated motion

"Smart" assembly of complex integrated system with sensor guidance and collision avoidance path planner

To support the logical progression of the research program a number of activities listed on the accompany chart are planned for near term development. Some of these activities, such as attachment of panels, will expand the system capabilities while others, like the path planner and sensor guidance, will significantly increase reliability. These activities will benefit many proposed missions which require in-space assembly. This focused program provides as excellent opportunity to develop a much needed technology base.

Automated Assembly of Large Space Structures

Current System Development Plans

Panels and Payloads For Attachment To Truss

Evaluate Suitability Of System For Assembly Of SS Solar Dynamic Reflector

Develop Path Planner For First Level End Effector Positioning

Incorporate Sensors For Intermediate End Effector Positioning

Develop Graphics Simulation Of System To Predict & Monitor Operations

Incorporate Microprocessor Into End Effector Operation

Many useful technical observations in automated assembly have been developed from the limited research conducted to date. Several of these are highlighted on the accompanying chart. The motion base hardware and truss structure were stiffness designed so that gravity induced deflections would not adversely affect assembly operations, especially since only minimal sensor feedback and no sensor guidance was incorporated. The passive guidance features designed into the truss joints and end-effector work well to direct entry of the struts into the correct assembly and capture position.

It was anticipated during the hardware design phase that the combination of arm positioning accuracy, motion base positioning accuracy and strut passive guidance features would be adequate for all assembly operations. However, it became clear very early in the test assembly phase that small positioning errors cause large loads due to the high stiffness of both the truss and the motion base support system. Therefore a force/torque load cell was inserted between the robot arm and the end-effector and final positioning of the end-effector is accomplished by repositioning the robot arm to null out the measured loads and moments. Final positioning of the robot reduces the loads to under 0.8 lbs and the moments to under 5 in-lbs.

During the planning phase it was also anticipated that assembly of the truss joints could be accomplished by simply using the robot arm to push the strut joint directly into the receptacle on the node, rather than capturing the receptacle and having the end-effector insert the strut. Tests conducted to date have shown that the use of the arm to push the strut into place simply would not have worked because small misalignments and friction will push the receptacle aside. Additional discussions on these and other findings will be included in planned publications.

Automated Assembly of Large Space Structures

Program Findings

Precision and Stiffness Of Truss & Carriage System Adequate For "Dumb" Assembly Operations.

Passive Guidance Designed Into System Necessary & Adequate To Correct Positioning Errors.

Force/Torque Load Cell Necessary For Correction Of Cumulative Error.

Insertion Of Strut Into Captured Receptacle Provides Positive Assembly Technique.

Robotic Structural Assembly Must Be Under Computer Control. Difficult For System Operator To Remember All Operations Required For Assembly Of Even Simple Structure.

Preliminary Results Indicate Assembly Times Of 2-5 Minutes/ Strut With Current Operation. Faster Times Achievable With Coordinated Motion & End Effector Microprocessor.

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The large number of struts necessary for the support trusses required for future space missions such as submillimeter astronomical antennas and the Mars aerobrake make it imperative to examine alternate techniques for structural assembly. Due to the repeatability of the members in these trusses, automation using a robot arm for the structural assembly is a natural extension of the traditional pick and place operations for which robots are used in terrestrial applications. The current research also provides a focused effort to expand the capabilities of this automated operation to develop other space assembly methods. However, automation should be considered during the concept development and hardware design phase of a proposed operation and not as a retrofit after the program is well underway.

Automated Assembly of Large Space Structures

Conclusions

Structural Assembly Provides Outstanding Focus For Space Automation-Fundamentally A Pick And Place Task.

No Major Problems Have Been Encountered That Would Indicate Automated Structural Assembly Is Not A Viable Option For In-Space Construction.

Automation Should be Considered In Initial Design And Not As A Retrofit Operation.

Thermal Control System

Level III

Subsystem Presentation

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