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RESEARCH AND DEVELOPMENT ACTIVITIES AT THE GODDARD SPACE FLIGHT CENTER FOR THE FLIGHT TELEROBOTIC SERVICER PROJECT

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1. Introduction

The Flight Telerobotic Servicer (FTS) is being developed by the Goddard Space Flight Center (GSFC) for performing a variety of assembly, servicing, inspection and maintenance tasks on the Space Station (Figure 1). The Project Office at GSFC has tasked the Engineering Directorate to assemble a robotics research and development program which will support the FTS project. The activities center around support for the Development Test Flight (DTF) on the Space Shuttle and investigations of operational problems associated with the FTS on Space Station Freedom. For the DTF, areas such as control algorithms, safety systems, and end-effectors will be developed. For FTS operations, the emphasis will be to develop a dual-arm bi-lateral force-reflecting teleoperator and use it as an FTS Operational Simulator (FTSOS). The simulator will be used to investigate operational techniques, camera configurations, operator interfacing, orbital replacement unit (ORU) designs, end-effector designs, and training techniques. After a series of test activities, reports will be generated for input to the DTF and FTS designs.

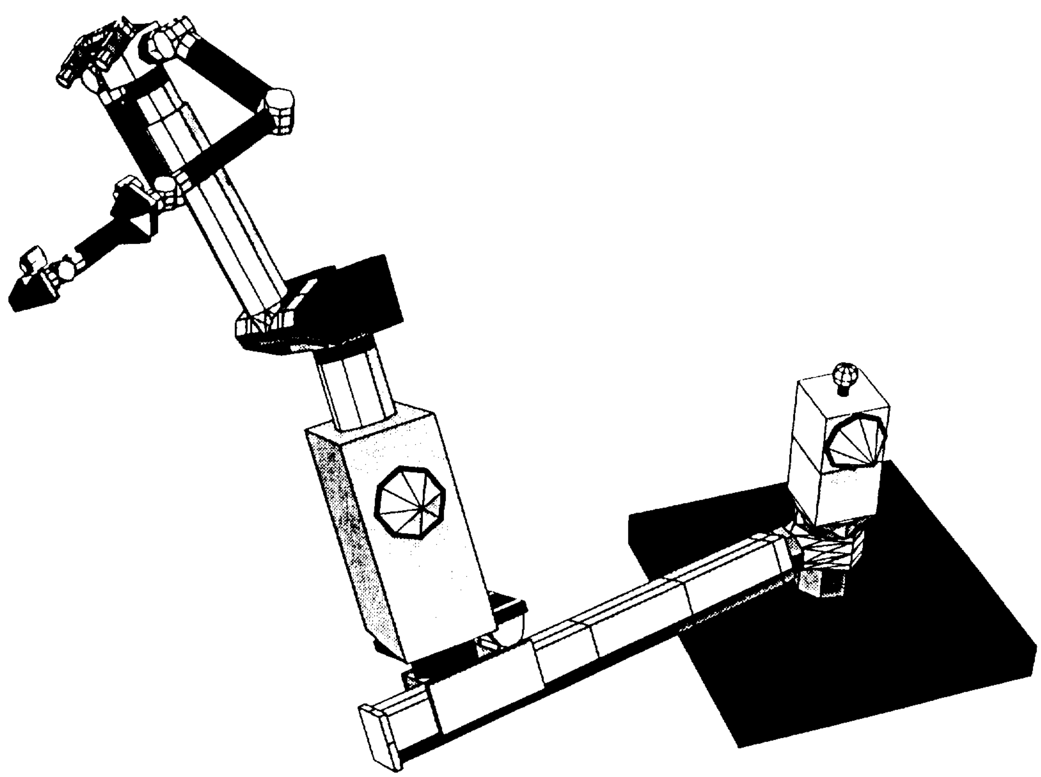

Figure 1. FTS design concept.

2. Facility Description

In support of this effort a robotic facility is being established at GSFC. This facility will be used to develop, test, integrate and evaluate new robotic technologies required to support the FTS Project (Figure 2). It will contain a gantry robot with six degrees of freedom capable of lifting up to 4000 pounds of payload and applying 4000 ft. pounds of torque as well. Suspended from one mast of the gantry will be a set of six degree of freedom industrial arms, which will be used as an FTS Operational Simulator (FTSOS). The other mast will carry a grapple to emulate the Space Station Remote Manipulator System (SSRMS) and will be used primarily to transport payloads to and from the worksite. An operator workstation, installed in a mockup of the STS Aft Flight Deck (AFD) mockup, will permit teleoperation in the constrained environment of the Space Shuttle. This AFD will be designed to be reconfigurable in order to determine the best positioning of hand controllers and displays.

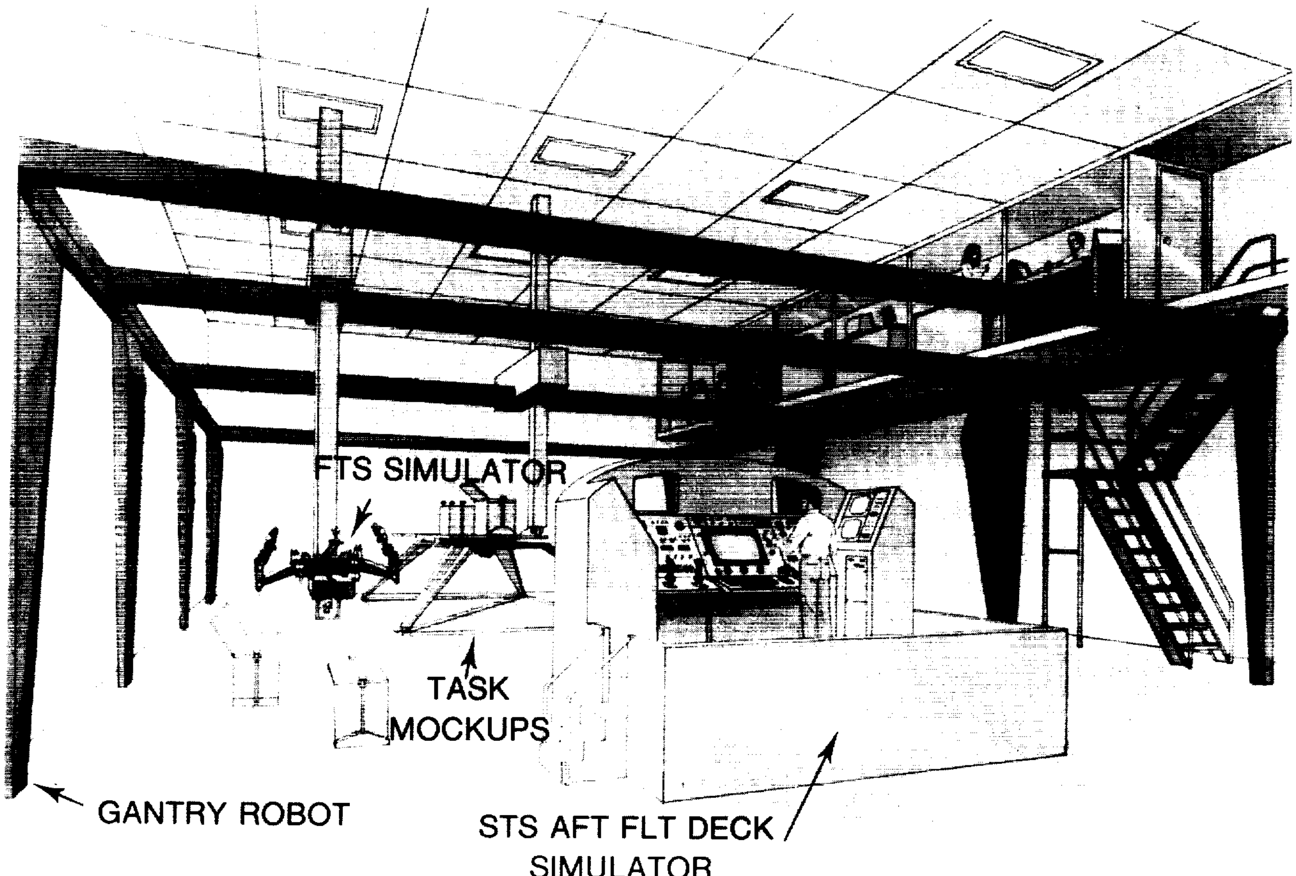

Figure 2. Robot design integration and test facility.

As an adjunct to the facility, a technology is being developed for graphically displaying each move of the robot in performing its tasks. The graphics are being used to determine such things as the robot's reach capability, and check for collision avoidance. The graphic simulator enables the tasks to be defined by breaking down each task into sub-steps from which a "script" can be created. The script allows for the creation of a model representation of the FTS and its relationship to the assembly phase of Space Station. Currently the capability incorporates the inverse kinematics associated with the robot motion. Eventually through research being performed at the University of Iowa [1], dynamic models will be developed and integrated into the system for improved representation.

Working closely with the National Institute of Standards and Technology (NIST), a computer architecture is being established which allows for incremental development and evolution of the telerobotic system leading to greater autonomy. The NASA Standard Reference Model or NASREM [2], has been selected for implementation into the facility. Adopting this architecture, which NIST hopes to standardize, will link the NASA developments to U.S. Industry, making technology transfer possible.

In addition to the gantry and FTS Operational Simulator, a seven degree of freedom industrial manipulator system (Figure 3), will be combined with a six degree mini-master controller to investigate safety and control problems associated with the operation of this complex system [3]. As data is derived from this test bed, it will be made available to the FTS contractor for their use in designing a flight system. As an adjunct to the operational test facility, smaller industrial or research robots are being used for pre-cursor checkout of end-effectors, software development and technologies arriving from other NASA research facilities (Figure 4).

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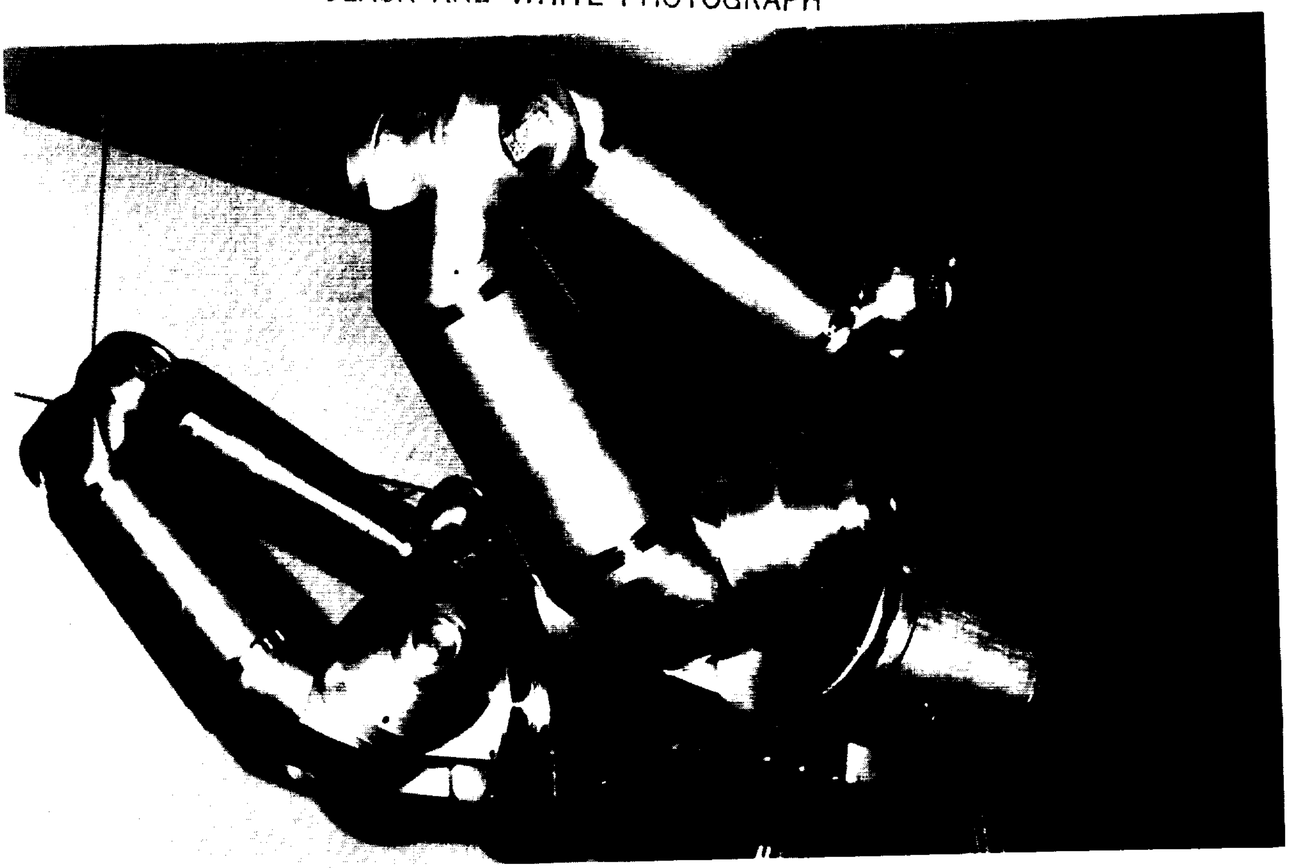

Figure 3. Seven degree of freedom industrial manipulator.

In order to reduce the overall complexity of the robot, that is having to include sophisticated vision recognition systems, dexterous hands, etc. ... the robotic task must be "friendly" in its design. As part of this activity, GSFC is developing structures and mechanisms which will interface with the robot in a known pre-determined manner. Examples of these features are handles which mate with ordinary parallel jaw grippers, singularly actuated orbital replacement units (ORU) and common utility connectors. Figures 5 and 6 show "robot friendly" structural attachments and an ORU with low torque and force "J" hook actuators. Although it is recognized that all tasks cannot be predetermined for the FTS and eventually it will have to operate in a less structured environment, these techniques, when standardized, will make the robot a more cost effective system.

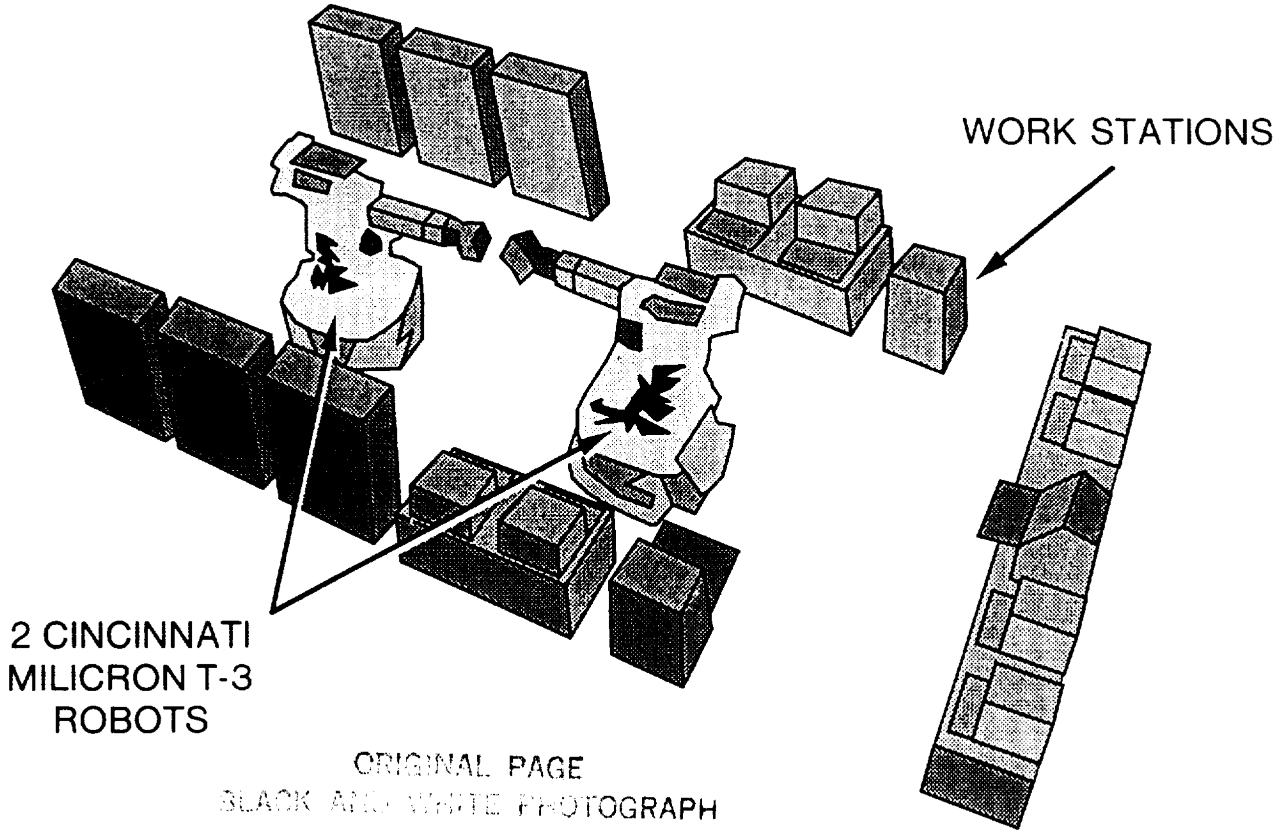

Figure 4. Pre-cursor checkout facility.

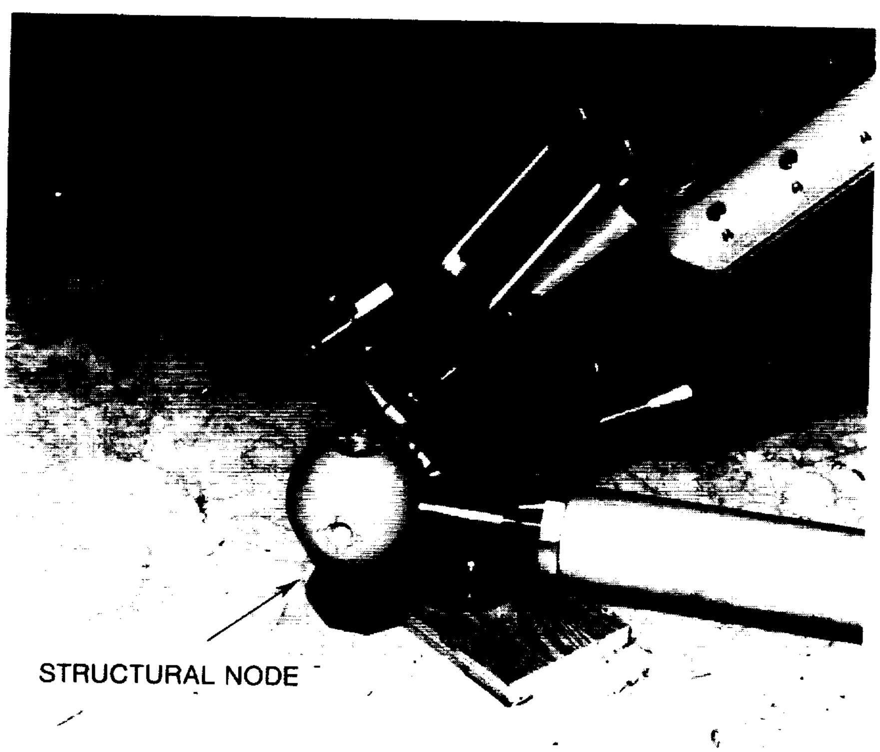

Figure 5. Robot friendly structural attachment.

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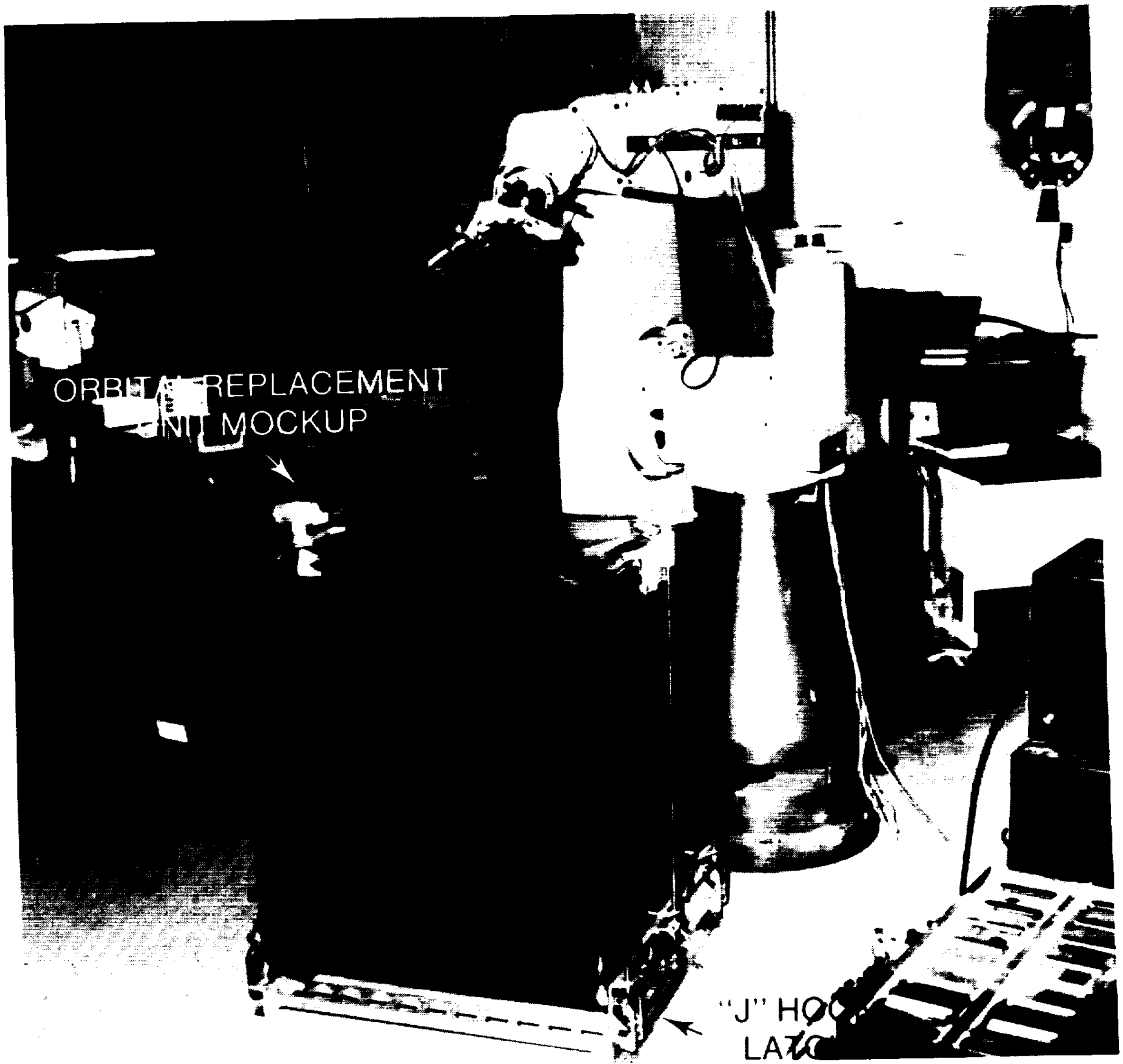

Figure 6. ORU mockup with "J" hook attach mechanisms.

3. Test Program

Each element of the FTS research and development program has been broken down to support specific events in the DTF mission and FTS development (Figure 7). These usually coincide with Preliminary Design Reviews (PDR) or Critical Design Reviews (CDR). In this manner, data accrued from the test program will be available to the FTS design activities in a timely manner. For the first phase, the gantry robot together with two floor mounted PUMA 762 robots, operating through the use of enhanced workstation will:

1. Deploy a Station Interface Adapter (SIA) leg.

2. Attach the SIA to a truss node.

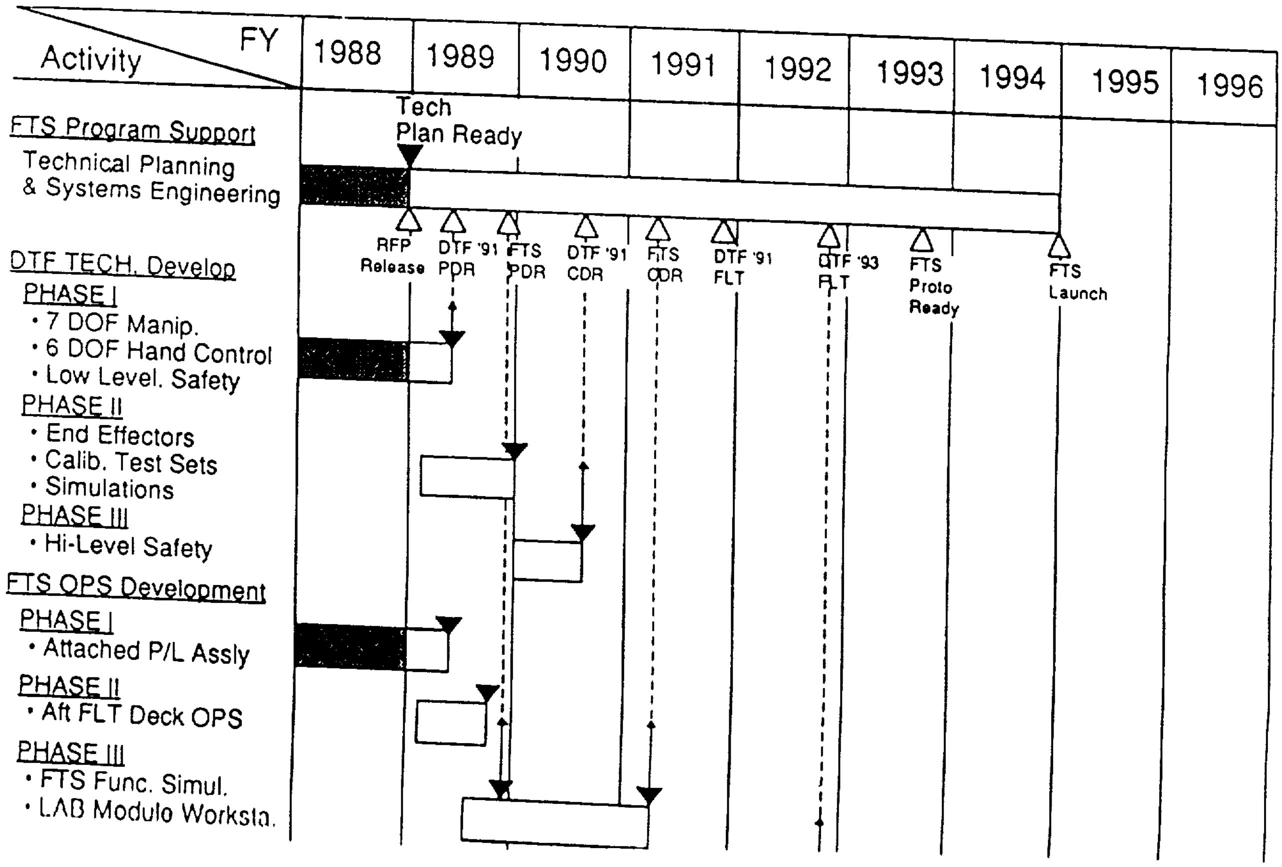

Figure 7. Test program schedule.

3. Perform a Payload Interface Adapter (PIA) actuator closure.

4. Connect a thermal utility connection.

5. Changeout a sub-ORU.

6. Perform a simulated instrument alignment.

For the second phase, a new telerobotic workstation, designed to physically represent the Space Shuttle Aft Flight Deck (AFD) constraints, will be built. The workstation will represent the results of a human engineering study concerning the location of displays and controls. This workstation will be used for future demonstrations. The AFD workstation software will be implemented in ADA.

During the third phase, the dual arm teleoperated manipulator system will become the FTS operational simulator (FTSOS). The FTS operational simulator will have kinematically identical 6-DOF masters and slaves. The teleoperator system will be integrated onto the gantry. A new task mockup representative of the Space Station Electrical Power System (EPS) radiator panel assembly will be built. The activity will consist of inserting the radiator panels into a mockup heat exchanger using the FTSOS system and AFD workstation.

For the DTF technology, seven degree of freedom dual-arm telerobotic controls and a safety testbed will be developed. The testbed will investigate the ADA language, mini-masters, control techniques, end-effector designs, system safety, and dynamic simulations.

During the initial phase, the equipment necessary to build the seven degree of freedom dual-arm manipulator testbed system will be implemented for force-feedback teleoperation. Safety algorithms will be developed and integrated into the testbed using expert systems where applicable. The dual-arm system, with its control algorithms and safety system imbedded into the NASREM architecture, will be used to investigate tele-operator issues.

For the second phase, end-effectors will be developed and integrated. A calibration task set based on the expected DTF mission will be used for determining end-to-end performance of the hand controller and manipulator system.

4. Future Activities

As the characteristics of the FTS become better understood and its capabilities to perform useful tasks have been demonstrated, the test program will be broadened to include assembly of large Space Station attached payloads, servicing of scientific instruments on earth observation platforms, and the investigation of rendezvous and docking techniques. These activities will be consolidated in an extension of the current facility (Figure 8) planned to be completed in FY 93. Also housed in this extension will be a full sized mockup of a Space Station node and cupola FTS workstation for operational simulation.

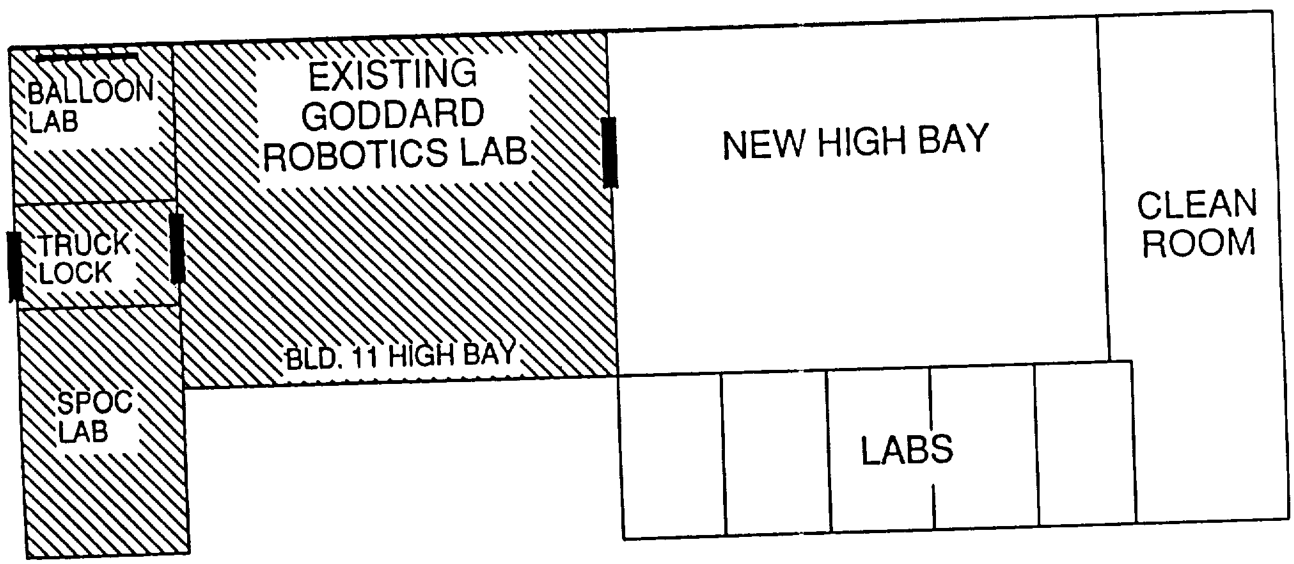

Figure 8. Extension planned to current robotic facility.

5. References

1. Harry Yae, Sung Soo Kim, Edward J. Haug, Warren Seering, Kamala Sundaran, Bruce Thompson, Harold P. Frisch, and Richard Schnurr, "Test and Validation for Robot Arm Dynamics Simulation," *Proceedings of the 1989 NASA Conference on Space Robotics*, Pasadena, CA, January 31-February 2, 1989.

2. Ronald Lumia, "The FTS: From Functional Architecture to Computer Architecture," *Proceedings of the 1989 NASA Conference on Space Robotics*, Pasadena, CA, January 31-February 2, 1989.

3. Gary E. Mosier, Maureen E. O'Brien, and Richard G. Schnurr, "Development of a Robotics Technology Testbed for the Flight Telerobotics Servicer Project," *Proceedings of the 1989 NASA Conference on Space Robotics*, Pasadena, CA, January 31-February 2, 1989.