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DEXTEROUS END EFFECTOR FLIGHT DEMONSTRATION

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Abstract

The Dexterous End Effector Flight Experiment is a flight demonstration of newly developed equipment and methods which make for more dexterous manipulation of robotic arms.

The following concepts are to be demonstrated:

The Force Torque Sensor is a six axis load cell located at the end of the RMS which displays load data to the operator on the orbiter CCTV monitor.

TRAC is a target system which provides six axis positional information to the operator. It has the characteristic of having high sensitivity to attitude misalignment while being flat.

AUTO-TRAC is a variation of TRAC in which a computer analyzes a target, displays translational and attitude misalignment information, and provides cues to the operator for corrective inputs.

The Magnetic End Effector is a fault tolerant end effector which grapples payloads using magnetic attraction.

The Carrier Latch Assembly is a fault tolerant payload carrier, which uses mechanical latches and/or magnetic attraction to hold small payloads during launch/landing and to release payloads as desired.

The flight experiment goals and objectives are explained. The experiment equipment is described, and the tasks to be performed during the demonstration are discussed.

DEXTEROUS END EFFECTOR FLIGHT DEMONSTRATION

1.0 INTRODUCTION

The DEE project is a flight technology demonstration. IT is managed by the Automation and Robotics Division of the NASA Johnson Space Center (JSC). The project, with its precursors, began in 1985 as an effort to develop a force torque sensor (FTS) for the Shuttle Remote Manipulator System (RMS). It is currently a flight demonstration with four new technology products to display, and with the additional objective of collecting RMS performance data. DEE is manifested to fly on STS-62 in February of 1994. After a brief overview of the project goals and background, this paper will focus on the flight experiment.

1.1 PROJECT GOALS

The goals of the DEE project are to demonstrate new technology, to gain experience with the hardware and software developed, and to evaluate the benefit to the operator/RMS in performing space operations. The new concepts and hardware are: (1) Force Torque Sensor (FTS); (2) Magnetic End Effector (MEE); (3) Target and Reflective Alignment Concept (TRAC) which can be used manually or automatically; and (4) carrier latch assembly (CLA).

1.2 PROJECT BACKGROUND

The magnetic end effector (MEE) was conceived and developed at JSC. Since the first tests of the MEE/FTS prototype in September 1987, the DEE project has operated frequently at the Manipulator Development Facility (MDF). The Targeting and Reflective Alignment Concept (TRAC) system was developed shortly after the MEE prototype was first used and has been employed in almost all of the MDF operations with the MEE and FTS. Each time a new procedure was developed or a new feature was added to the MEE or to the TRAC system, the change was checked out and demonstrated. These demonstrations have been used to prove new capabilities of the tools, as well as to familiarize interested people with the work being done.

1.3 OBJECTIVES OF THE FLIGHT EXPERIMENT

The detail objectives of the flight experiment are to demonstrate and evaluate the benefits to RMS operators and the task capability of the following:

(a) Use of the Force Torque Sensor to minimize loads on the RMS,
(b) RMS Constrained Control Resolution with the FTS output used for load control,
(c) Generic constrained motion tasks with RMS,
(d) RMS Unconstrained Control Resolution using TRAC for measurements,
(e) Magnetic End Effector enhanced grappling ability and fault tolerance,
(f) Determine capture envelope of the Magnetic End Effector,
(g) TRAC flat mirror target system for improved alignment ability,
(h) Performance data base for RMS,
(i) Force torque sensor using laptop computer with TRAC display,
(j) Electronic cross hairs on orbiter CCTV monitor
(k) AUTO-TRAC computer generated alignment cues
(l) The value of right angle TV camera,
(m) The use of a fault tolerant latch assembly (secondary release capability not required),
(n) Collect arm control data for analysis,
(o) Dynamics of RMS structure and joint drives,
(p) RMS control hypothesis and control logic,

2.0 GENERAL DESCRIPTION OF THE FLIGHT EXPERIMENT

2.1 OVERVIEW

The demonstration will be described from a systems approach, as to the physical arrangement, and from an operations viewpoint.

The DEE is intended to demonstrate five new technologies: the FTS, the MEE, the TRAC, AUTO-TRAC, and the CLA. In the demonstration of these five systems all 16 of the objectives listed above will be accomplished.

In addition to the five technologies there is a support structure and a system of generic tasks which support the demonstration of the five main systems.

The equipment for the five technologies are physically integrated. and/or split up by the hardware arrangement.

2.1.1 SYSTEM LEVEL DESCRIPTION

2.1.1.1 FORCE TORQUE SENSOR

The FTS is a load cell which provides six-axis force data to the RMS operator. The FTS is in two parts. The Data Collection Assembly (DCA) is in the payload bay (on the MAT), and the Display Electronics Assembly (DEA) is in the aft flight deck (AFD). These are connected by the RMS special purpose end effector (SPEE) cable.

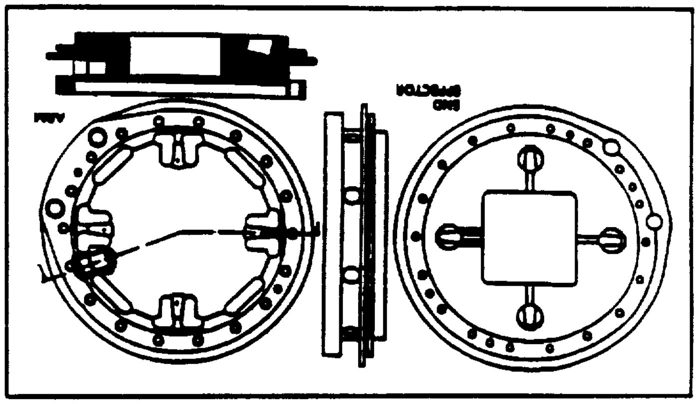

Figure 1 - Data Collection Assembly

The DCA (see figure 1) provides power to 32 strain gages, and, on command from the DEA, it collects the bridge outputs, digitizes the outputs, resolves the outputs into six axis loads (in engineering units), serializes the data into an RS422 bus format and transmits the data to the DEA.

The DEA consists of the SC-1D computer and the video graphics generator (VGG). The DEA performs scaling and point of resolution translations on the signals from the DCA and converts the data into a video display which is viewed on the orbiter CCTV monitor. The monitor display of the VGG output is shown in figure 2. The DEA also receives commands for scale and point of resolution from the Payload General Support Computer (PGSC) and outputs data to the PGSC for recording on floppy disks.

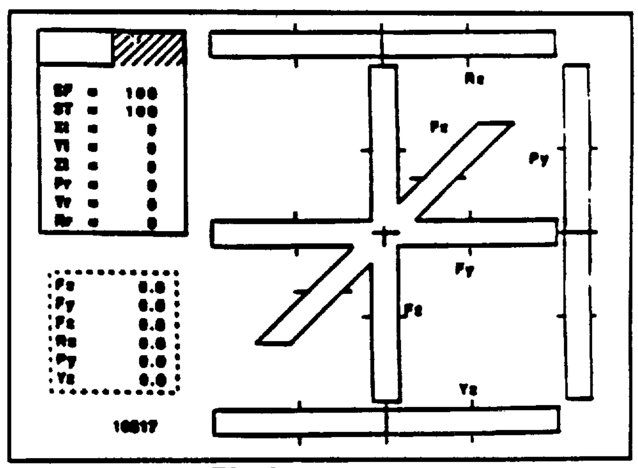

Figure 2 - FTS Display

2.1.1.2 MAGNETIC END EFFECTOR

The MEE is a system which provides for two fault tolerant grappling of payloads by magnetic attraction. A structural housing contains the various MEE components (see figure 3). The primary components are two magnet assemblies, two TV cameras, backup batteries, and the alignment pins. In addition, there are switches, indicators, camera lights, control circuit boards, and a TV interface device. The MEE produces a magnetic attractive force of 3200 pounds.

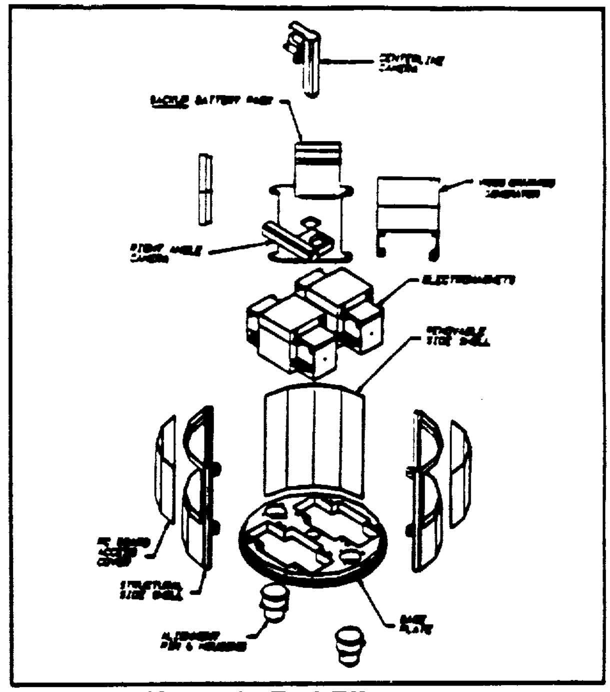

Figure 3 - Magnetic End Effector

2.1.1.2.1 ELECTROMAGNETS.

The two magnets are U-shaped, with three separate coils on each. One is a high powered pull-in coil which produces an appreciable attractive force with a large air gap, and which is automatically switched off by the preload indication system after grapple has been achieved. The other two are holding coils and are identical, with each producing sufficient magnetization to saturate the core and thus develop the full rated holding performance of the MEE. One of the holding coils on each magnet is connected to separate controls and power sources, while the other two holding coils (one on each magnet) are connected to a third power source for two fault tolerant operation. The magnets are arranged with the pole faces within a 7.0-in. square footprint; they are independently mounted on a spring suspension systems in such a way that the poles move slightly toward the grapple fixture during the grappling process. This motion is detected by optical switches as an indication of preload. The use of the springs does not reduce the attractive force, but rather ensures that a preload exists across the grapple interface.

2.1.1.2.2 TV Cameras

Two TV cameras are mounted in the MEE. One is on the MEE centerline and the other normal to the centerline. The cameras are used only for targeting; thus they are preset to a fixed focus distance, and the lens apertures are also preset. Supplementary incandescent lighting is provided for the centerline camera during close targeting. Only one camera output can be utilized at a time.

2.1.1.2.3 Battery Backup

A failure of the RMS exists whereby the electrical connector at the EFGF can become disconnected, thus disconnecting the MEE from all Shuttle power and from all controls. The MEE must not release a grappled payload because of this failure. To accommodate this possible situation, the MEE is equipped with two 18-volt battery backup systems, each of which powers one of the magnet holding coils. The MEE can therefore survive loss of connection and still be one fault tolerant for inadvertent release of a grappled payload.

2.1.1.2.4 ALIGNMENT PINS

The MEE is designed with two spring-loaded alignment pins which ensure accurate alignment and provide increased capability for shear and torsion loads. Optical switches detect the fully out position of the pins.

2.1.1.3 TARGETING AND REFLECTIVE ALIGNMENT CONCEPT

The TRAC system uses a TV camera viewing its own image in a mirror target to achieve alignment in all six axes. TRAC consists of a TV camera, a TV monitor with alignment marks, and a mirror target with cross hairs (see figure 4). Mirror targets are located on objects to be grappled and areas to be targeted. The system can be utilized with the centerline camera, the right-angle camera, or the RMS wrist camera.

In use the target is aligned in all six axes when the reflected image of the camera is centered on the mirror cross hairs, both are centered on the monitor, and the camera image size matches the alignment marks. Translation errors are indicated by the cross hairs appearing off the monitor center and by the size of the camera image being too large or too small. Attitude errors are indicated by the camera image being misaligned to the cross hairs and by the rotational misalignment of the cross hairs to the monitor. The attitude cues are thus separate from the translation cues, and this fact improves operator performance.

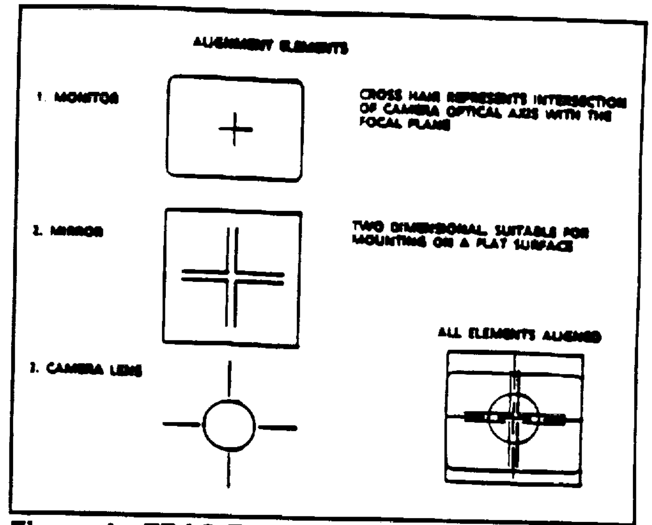

Figure 4 - TRAC Tagreting

2.1.1.4 AUTO-TRAC

AUTO-TRAC is an advanced development of TRAC in which the TV image is processed by a computer to generate alignment errors or operator cues. For AUTO-TRAC five retro-reflectors are mounted on the target mirror (on the middle of each side and on one corner), and an array of light emitting diodes (LED's) are mounted close to the camera lens. Thus when the LED's are emitting and the TV camera is aligned with the target the camera image includes the five retro-reflectors with the direct mirror reflection of the LED's in the center of the pattern. The LED's are made to flash so that in some video frames the LED's are off, but in other frames one or more LED's are on. A frame of video with the LED's off is processed with an adjacent frame of video with an LED on to produce a pseudo-frame of video in which only the LED reflections are present. The processing eliminates the effect of ambient light and simplifies the scene. The pseudo-frame is analyzed for alignment errors.

Control of which LED in the array is on in a given frame allows the direct mirror reflection to be differentiated from the retro-reflector images. Pitch and yaw errors are derived from the amount and direction that the mirror reflection of the LED's is off center relative to the retro-reflector pattern. Roll error is derived from the rotation of the retro-reflector pattern in the video image. Translation errors are derived from conventional stadiametric methods. Singularity ambiguities present in systems using only stadiametric methods are therefore eliminated.

AUTO-TRAC uses a TV camera mounted in the payload bay near the keel and a target mounted on the MAT.

2.1.1.5 CARRIER LATCH ASSEMBLY

The CLA is a small payload carrier which is designed to release a payload to the RMS during on orbit operations. It uses a combination of electro-magnetic holding and electro-mechanical latch pawls to meet the requirements of safety and mission success. The magnets have redundant features identical to those described above for the MEE, except there are no batteries.

In operation, the payload is held mechanically by two sets of independent latch pawls during launch and landing. When release is required, the payload is first grappled magnetically which unloads the mechanical latch pawls. The mechanical latches are then driven open by redundant drive mechanisms, motors, and controls. Indicators are provided for each critical function. The payload can then be safely grappled by the RMS because there are three ways to interrupt electrical power to each set of magnets.

Stowage of the payload back into the CLA follows the reverse sequence.

2.1.2 HARDWARE DESCRIPTION

The DEE equipment is located in three areas, 1) a computer mounted in the (AFD), 2) a targeting camera mounted on a frame in the payload bay, and 3) a longeron-mounted Experiment Stowage and Activities Plate (see figure 5) (a portion of which is released when grappled by the RMS using the Special Purpose End Effector (SPEE)).

The DEE does not affect the standard configuration of the RMS or any other payload using the RMS.

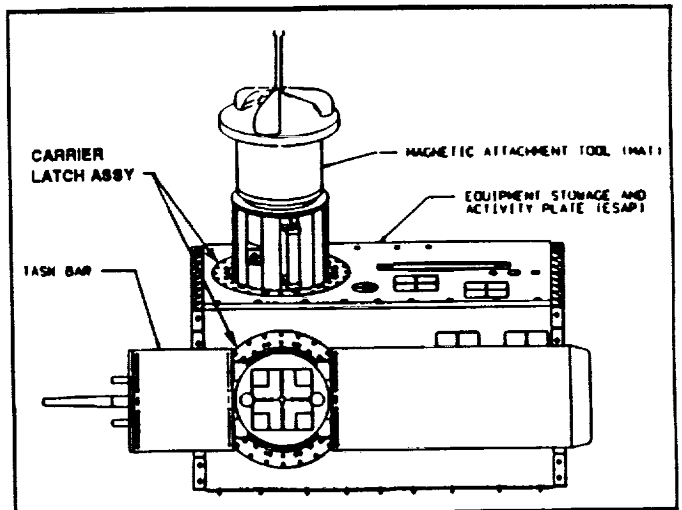

Figure 5 - ESAP In Launch Configuration

2.1.2.1 AFT FLIGHT DECK INSTALLATION

The installation in the AFD consists of parts of the DEA, one-half of a standard switch panel, interconnecting cables, and some standard Orbiter equipment.

2.1.2.1.1 DISPLAY ELECTRONICS ASSEMBLY

The DEA is installed in position L11-Outboard. It provides three switch/circuit breakers and connectors for video and an RS232 port on its front panel.

2.1.2.1.2 STANDARD SWITCH PANEL

The SSP (one-half) provides all of the switches for control of DEE.

2.1.2.2 PAYLOAD BAY TARGETING CAMERA

The targeting camera is a modified commercial TV camera which is equipped with an array of LED's around the lens. It is mounted with a video converter on a small housing on the frame at x=807 and between y=24 and y=34. The converter also provides regulated power and controls the flashing of the LED's. The camera is connected to the standard orbiter keel camera cable.

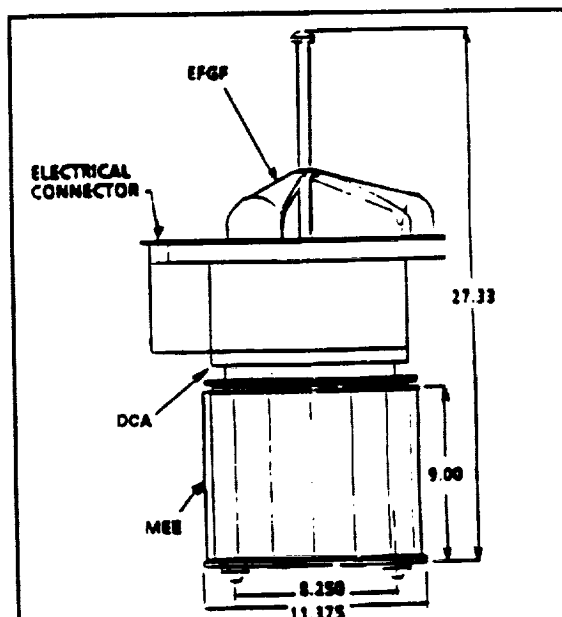

Figure 6 - Magnetic Attachment Tool

2.1.2.3 EXPERIMENT STOWAGE AND ACTIVITY PLATE (ESAP)

The ESAP (figure 5) is the structure which is mounted on a Goddard Get Away Special (GAS) Beam and which supports the MAT and Task Bar during launch and landing via two CLA's. In addition, it provides four sockets and seven TRAC targets, which are used in carrying out the experiment operations. The MAT and Task Bar are released to the RMS during demonstration operations.

2.1.2.3.1 MAGNETIC ATTACHMENT TOOL (MAT)

The MAT (see figure 6) is the assembly which is grappled by the RMS for experiment operation. It is mounted in the top CLA on the ESAP during launch and landing (see figure 1). The magnetic attachment tool is made up of the MEE, the DCA, and the electrical flight grapple fixture (EFGF). There is also an adaptor between the FTS and the EFGF. The MEE and the DCA hardware are adequately described under 2.1.1.1 and 2.1.1.2.

2.1.2.3.1.1 ELECTRICAL FLIGHT GRAPPLE FIXTURE

The EFGF is a piece of standard STS-provided equipment. For this flight experiment it will be modified by removing a portion of the abutment plate to improve visibility around the EFGF when the TRAC system is used with the RMS wrist TV camera.

2.1.2.3.2 TASK BAR

The task bar, a short panel structure as shown in figure 7, is the device which the MEE magnetically grapples and manipulates during the task operations. One end of the task bar simulates a generic panel, and the other end simulates a module servicing tool (MST).

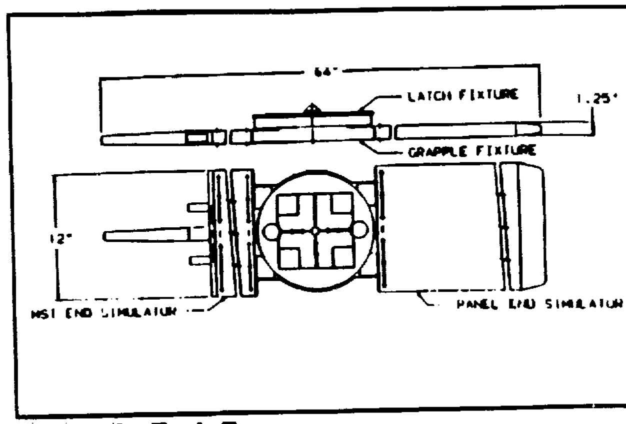

Figure 7 - Task Bar

3.0 EXPERIMENT OPERATION

The task operations for the flight experiment include the following:

a. RMS control resolution tasks
b. Generic constrained motion tasks
c. Magnetic hold down task
d. AUTO-TRAC task

3.1 INITIAL HARDWARE CHECKOUT

The RMS is powered up and uncradled, and the RMS is placed in the vicinity of the MAT. The CLA electromagnets are then energized, and upon holding verification, the mechanical latches are released. The RMS operator then aligns the SEE with the MAT and grapples the MAT. MAT operational capability is now verified. The CLA electro-magnets are turned off and the RMS moves the MAT away from the ESAP. Once the RMS is configured, the experiment tasks begin.

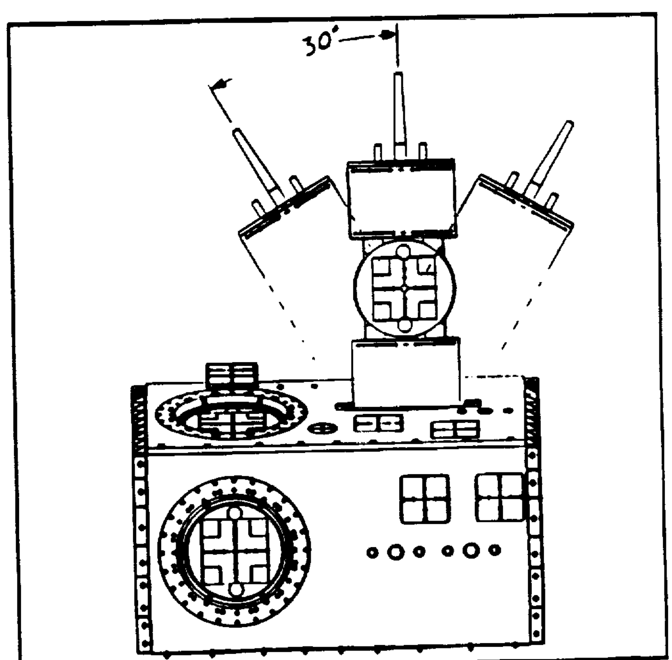

Figure 8 - Task Bar Rotation Task

3.2 RMS CONTROL RESOLUTION TASKS

RMS control resolution is to be determined for unconstrained position alignment control and for constrained force control.

3.2.1 UNCONSTRAINED CONTROL RESOLUTION

The MAT is positioned over a TRAC target, and the operator is asked to align to the target as closely as possible. The errors and the un-commanded RMS motion will be recorded for postflight data analysis.

3.2.2 CONSTRAINED CONTROL RESOLUTION

The MAT is grappled to the task bar while the task bar is in its CLA. The operator is asked to input small forces or to maintain the forces as small as possible. The error and the residual forces will be recorded for postflight data analysis. This data will also be analyzed real time to insure that the control required for the other tasks is within the RMS capability.

3.3 TASK BAR GRAPPLE

Using TRAC for alignment, the MAT is magnetically grappled to the task bar located as shown in figure 8. The task bar is then released from the experiment carrier.

3.4 GENERIC CONSTRAINED MOTION TASKS

3.4.1 PANEL INSERTION AND ROTATION TASK

The RMS is translated to the rotating panel task area. Using the TRAC mirror and MAT right-angle TV camera, the task bar is aligned with the mating slot. With the correct FTS display showing and being monitored, and TRAC alignment maintained as shown by the right-angle view, the task bar is inserted into its mating slot. Full insertion is detected by monitoring the digital readouts on the RMS display and control panel and by observing a stripe on the Task Bar. A roll will be performed (see figure 8) and loading on the task bar will be monitored, up to approximately +/-30°.

3.4.2 MODULE SERVICING TOOL SIMULATION TASK

Simulation of the MST operations begins with the MAT grapple of the task bar and the subsequent wrist roll of the task bar to the vertical position. Using the corresponding TRAC target, the task bar probe is aligned with the receptacle and inserted into the receptacle while forces and torques exerted on the task bar are minimized as before. Several methods of insertion may be examined as time permits.

3.5 MAGNETIC HOLD DOWN TASK

Between the panel insertion task and the MST simulation task, the task bar is temporarily restowed on its latch assembly. The MAT then releases the task bar, leaving it on the latch assembly with only the electromagnets holding the task bar. This demonstrates the magnetic hold down task. Next, the MAT is rolled 180° and regrappled to the task bar.

3.6 AUTO-TRAC DEMONSTRTION

The MAT will be positioned so that the AUTO-TRAC target will be aligned in the view from the targeting camera. The position will be recorded from the RMS joint angles. The MAT then will be moved to a misaligned position. Next the RMS will be commanded to return to the recorded position using the auto sequence mode of operation. This will be repeated several times from different conditions of misalignment. The residual alignment errors will be recorded for post flight analysis.

4.0 CONCLUSION

The DEE flight demonstration has the potential for bringing five new developments into the realm of technology for use in space. With the completion of the STS-62 demonstration the concepts will be proved, and the hardware designs will be available for other users. Some of the demonstration hardware may be available for other flights. The use of these concepts and/or hardware will improve the efficiency, lower the cost, improve safety, and even allow totally new concepts of how men work in space.