DEXTEROUS MANIPULATOR FLIGHT DEMONSTRATION

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ABSTRACT

The Dexterous Manipulator Flight Experiment, an outgrowth of the Dexterous End Effector (DEE) project, is an experiment to demonstrate newly developed equipment and methods that make for a dexterous manipulator which can be used on the Space Shuttle or other space missions. The goals of the project, the objectives of the flight experiment, the experiment equipment, and the tasks to be performed during the demonstration are discussed.

1.0 INTRODUCTION

The DEE project is managed out of the Technology and Commercial Projects Office of the NASA Johnson Space Center (JSC) New Initiatives Office. The project, with its precursors, began almost 5 years ago as an effort to develop a force torque sensor (FTS) for the Shuttle Remote Manipulator System (RMS). As it currently exists, the DEE project includes a flight experiment and other development activities. After a brief overview of the project goals and background, this paper will focus primarily on the flight experiment.

1.1 PROJECT GOALS

DEE project goals are (1) to gain experience in operation of the RMS with the FTS system; (2) to develop an end effector with improved capability for performing space operations in less time and with greater facility; (3) to develop an improved target and alignment system; and (4) to gain experience with the hardware and software developed.

1.2 PROJECT BACKGROUND

The magnetic end effector (MEE) was conceived and developed at JSC. Since the first tests of the MEE/FTS concept demonstration prototype in September 1987, the DEE project has operated periodically 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 feature was added to the MEE, MEE grapple plate, or the TRAC system and each time a new procedure was developed, this 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 objectives of the flight experiment are the following:

a. To demonstrate constrained motion of the RMS with the use of the FTS to control the loads imposed upon the arm.

b. To demonstrate TRAC mirror docking with the RMS in zero-gravity dynamics.

c. To demonstrate magnetic grappling and ungrappling in space conditions on fixed payloads. This will determine the proximity required before the magnetic attraction overpowers the flexibility of the RMS, and the dynamic effect when the magnets close the final air gap and impact the grapple fixture on the payload.

d. To demonstrate the right-angle TV camera as an aid in docking and manipulating payloads.

e. To demonstrate the use of a magnetic holding fixture for cases where temporary stowage of a payload may be necessary.

f. To determine the RMS control resolution, which possibly is better than indicated by the published data.

2.0 GENERAL DESCRIPTION OF THE FLIGHT EXPERIMENT

The DEE flight experiment is a longeron-mounted payload (see figure 1), a portion of which is deployed when grappled by the RMS using the standard end effector (SEE). The DEE therefore does not affect the standard configuration of the RMS or any other payload using the RMS.

2.1 FORCE TORQUE SENSOR

The FTS is a complex system which provides six-axis force data to the RMS operator. A full description is beyond the scope of this paper; a few key features, however, are described as follows. The FTS is in two parts – the part in the payload bay (on the MAT), and the part in the aft flight deck (AFD). These are connected by the RMS special purpose end effector (SPEE) cables. The part in the payload bay is the FTS data collection assembly (DCA); and the portion in the AFD is the display electronics assembly, which consists mainly of the SC-1D computer and the video graphics generator (VGG). The monitor display of the VGG output is shown in figure 2.

2.2 MAGNETIC ATTACHMENT TOOL (MAT)

The MAT (see figure 3) is the assembly which is grappled by the SEE on the RMS for experiment operation. It is mounted on a longeron-mounted carrier for launch and landing. The magnetic attachment tool is made up of the MEE, the FTS data collection assembly (DCA), and the electrical flight grapple fixture (EFGF). There is also an adaptor, or spacer, between the FTS and the EFGF.

2.2.1 MAGNETIC END EFFECTOR

A structural housing contains the various MEE subsystems (see figure 4). The primary subsystems are the two magnet assemblies, the two TV cameras, the backup batteries, and the alignment pins. In addition, there are switches, indicators, camera lights, heaters, control circuit boards, and a TV remote select switch. MEE specifications are shown in the table below.

MEE Specifications	
Holding force in tension	1500 lb
Shear force (magnets alone)	50 lb
Shear force (with alignment pins)	750 lb
Torque	700 ft-lb
Over turning moment	530 ft-lb
Diameter	11.38 in.
Length	10.50 in.
Weight	38 lb

2.2.1.1 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 hold-in coils and are identical, with each producing sufficient magnetization to saturate the core and thus develop the full rated holding performance of the MEE. The two hold-in coils are connected to separate power sources for redundant operation. The magnets are arranged with the pole faces within a 7.0-in. square footprint; they are independently mounted on a spring suspension system in such a way that the poles move slightly toward the grapple fixture during the grappling process. This motion is detected by microswitches 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.

2.2.1.2 TV Cameras. Two TV cameras are mounted in the MEE – one on the MEE centerline and the other normal to the centerline. The cameras are used only for targeting and alignment; thus they are preset to a fixed focus distance, and the lens apertures are also preset. Supplementary incandescent lighting is provided during the closeup portion of the targeting and alignment process. Since only one camera output can be utilized at a time, a remote camera selector switch (Government-furnished equipment, previously qualified) is used to power up and select the output of the proper camera.

2.2.1.3 Battery Backup. A failure condition 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-V battery backup systems, each of which independently powers two of the magnet hold-in coils. The MEE can therefore survive two failures without danger of an inadvertent release of a grappled payload.

2.2.1.4 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. Microswitches detect the fully out position of the pins.

2.2.2 FTS DATA COLLECTION ASSEMBLY

The DCA, which is located in the payload bay, consists of the sensor element (see figure 5) and the data collection electronics (DCE).

2.2.3 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 target plate to improve visibility around the EFGF when the TRAC system is used with the RMS wrist TV camera.

2.3 GRAPPLE FIXTURE

The grapple fixture for the MEE is simply a 7.5-in. square metal plate. Figure 6 shows a generic grapple fixture which could be attached to any payload; the base would be designed for or integrated into specific payloads. (The grapple fixture used by the DEE flight experiment is slightly different.) The material must be magnetically soft; and for maximum performance in load-critical applications, permendure is the preferred material. The thickness of the grapple fixture for the DEE flight experiment is 0.6 in. The surface of the grapple fixture is used as a mirror in the TRAC system and is polished to the point of producing a good spectral reflection. The surface is also fitted with a TRAC target pattern. Holes for the alignment pins are also provided.

2.4 EXPERIMENT STOWAGE AND ACTIVITY PLATE (ESAP)

The ESAP (see figure 7) is the device that supports the components of the DEE flight experiment during launch and landing via two latch assemblies. In addition, it provides two sockets and a grid, which are used in carrying out the experiment operations.

2.5 TASK BAR

The task bar, a short panel structure as shown in figure 8, is the device to which the MEE grapples and manipulates during the task operations. One end of the task bar simulates a heat pipe panel, and the other end simulates a module servicing tool (MST).

2.6 AFT FLIGHT DECK INSTALLATION

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

2.7 TARGETING AND REFLECTIVE ALIGNMENT CONCEPT

The TRAC system uses a TV camera viewing its own image in a mirror on the grapple fixture (or on an offset surface) to achieve alignment in all six axes. The TRAC consists of a TV camera and a TV monitor (both with alignment marks) and a mirror/cross hair assembly (see figure 9). Mirror/cross hair assemblies 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.

3.0 EXPERIMENT OPERATION

The task operations for the flight experiment include the following:

a. Radiator panel replacement / rotating panel task

b. Magnetic hold down task

c. MST simulation task

d. RMS control resolution task

3.1 INITIAL HARDWARE CHECKOUT

The RMS is powered up and uncradled, and the SEE is placed in the vicinity of the MAT. The RMS operator then aligns the SEE with the MAT's EFGF. After alignment is complete, the latch assembly electromagnets are energized, and upon loading verification, the mechanical latches are released. Then the SEE grapples the MAT. MAT operational capability is now verified. Operational verification consists of turning on the FTS and performing a "health check." MAT TV cameras, lights, and electromagnets are turned on. When the MAT operational verification is complete, latch assembly electromagnets are turned off and the RMS moves away from the latch assembly (see figure 8) and the ESAP. Once the RMS is configured, the experiment tasks begin. In each of the following tasks, the task is initially performed without the operator using the FTS. The observer crewmember monitors the FTS output and alerts the operator if the loads exceed a predetermined value. The task is then repeated with the operator using the FTS. The differences between the two sets of data are examined in the postflight analysis.

3.2 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 and its latch assembly, and is translated to approximately 7 ft above the ESAP structure. A wrist roll is commanded, and the task bar is perpendicular to the ESAP.

3.3 RADIATOR PANEL REPLACEMENT / ROTATING PANEL 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. After alignment, the FTS point-of-resolution (FTS-POR) is changed to reflect the new MAT orientation. 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. The task bar is adjusted such that the FTS-displayed forces and torques are minimized and remain below a predetermined threshold. Full insertion is detected by monitoring the digital readouts on the RMS display and control panel and by observing a low-magnitude compressive force on the FTS display. A clockwise roll (wrist camera point-of-view) will be performed (see figure 10) in multiple, small-degree segments, so that the loading on the task bar can be monitored, up to approximately 30°. The task bar is then returned, using small-degree increments, to the vertical position. During the rotation, the calculated torque required to rotate the panel will be compared to the FTS-measured torque. This task will be repeated for a counterclockwise roll of 30°.

3.4 MAGNETIC HOLD DOWN TASK

The task bar is removed from the slot and 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. The task bar is released from the ESAP and the FTS-POR is changed to reflect the new orientation of the FTS.

3.5 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 loading cases may be examined as time permits.

3.6 RMS CONTROL RESOLUTION TASK

Once the MST simulation is completed, the task bar is returned to its original stowage configuration, using the TRAC system for alignment and the FTS for force and torque minimization. The task bar latch assembly electromagnets are powered up, and the preload indicator is checked. When loading has been verified, the MAT releases the task bar and the latch assembly rigidizes its grapple using the mechanical latches. The latch assembly electromagnets are turned off when latching is complete and verified.

The MAT is repositioned at the control resolution grid and is aligned with the basic TRAC pattern. Several motion types will be examined – specifically, those involving translation (Y and Z axes) and rotation (wrist roll). The commanded motion versus actual RMS response will be compared in the postflight data analysis.

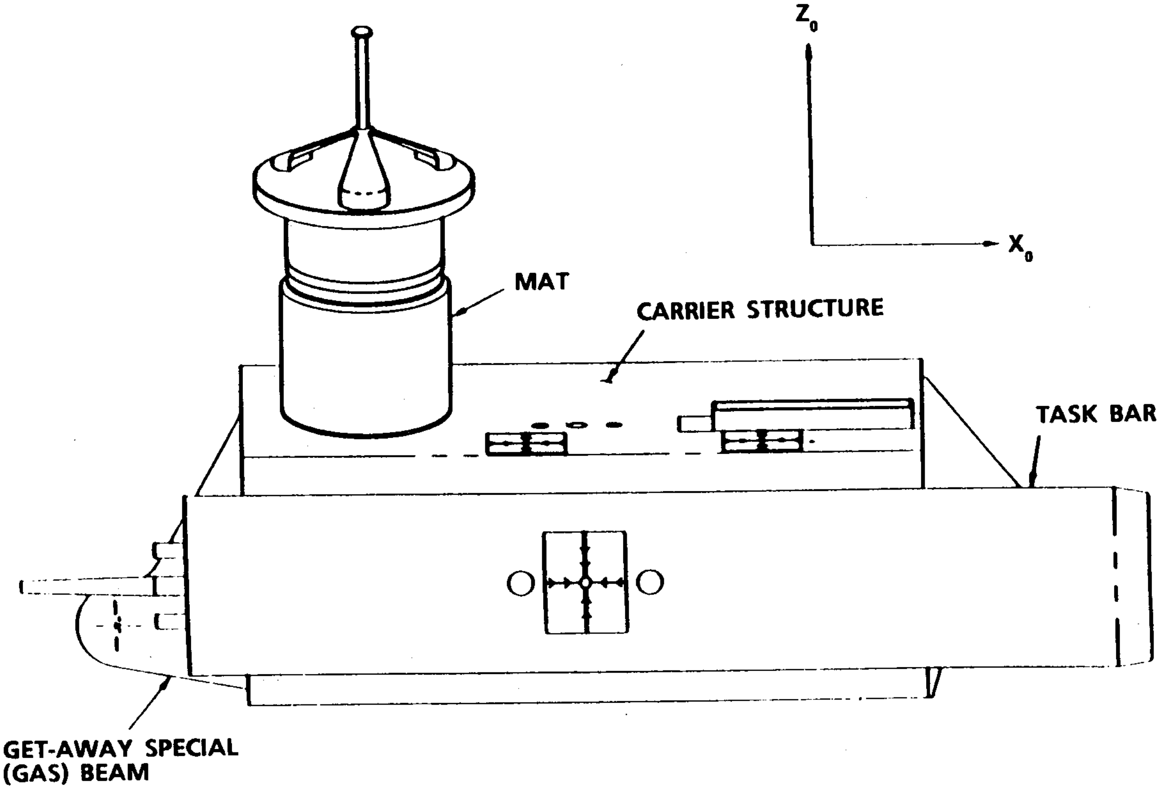

Figure 1.- DEE flight experiment launch configuration.

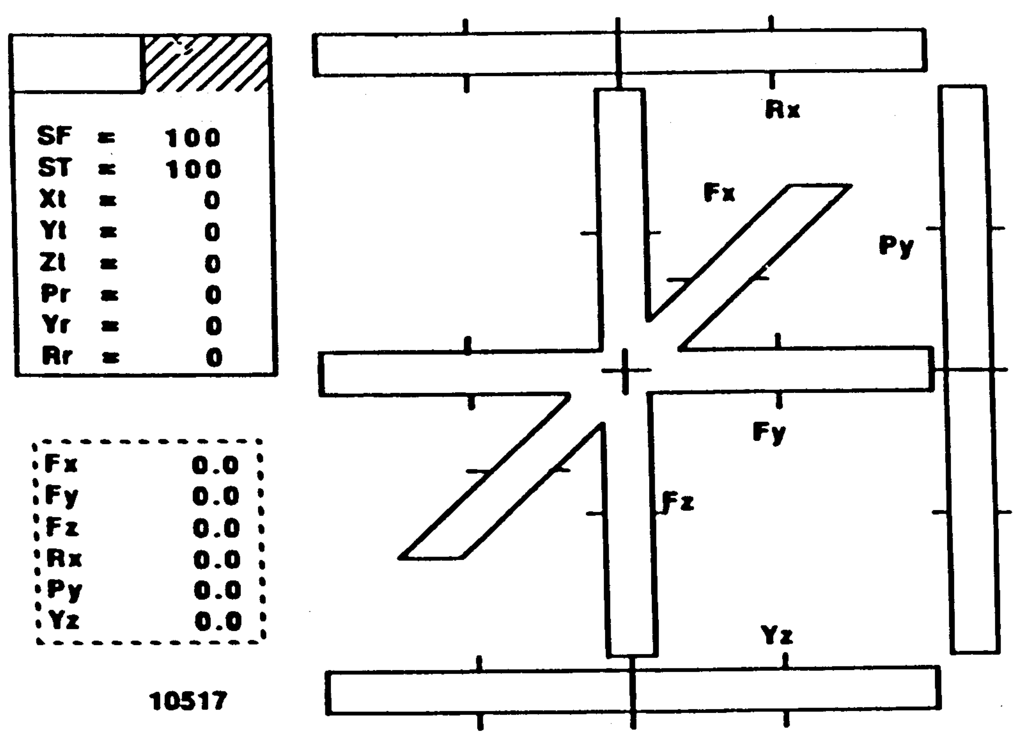

Figure 2.- Force-torque display layout.

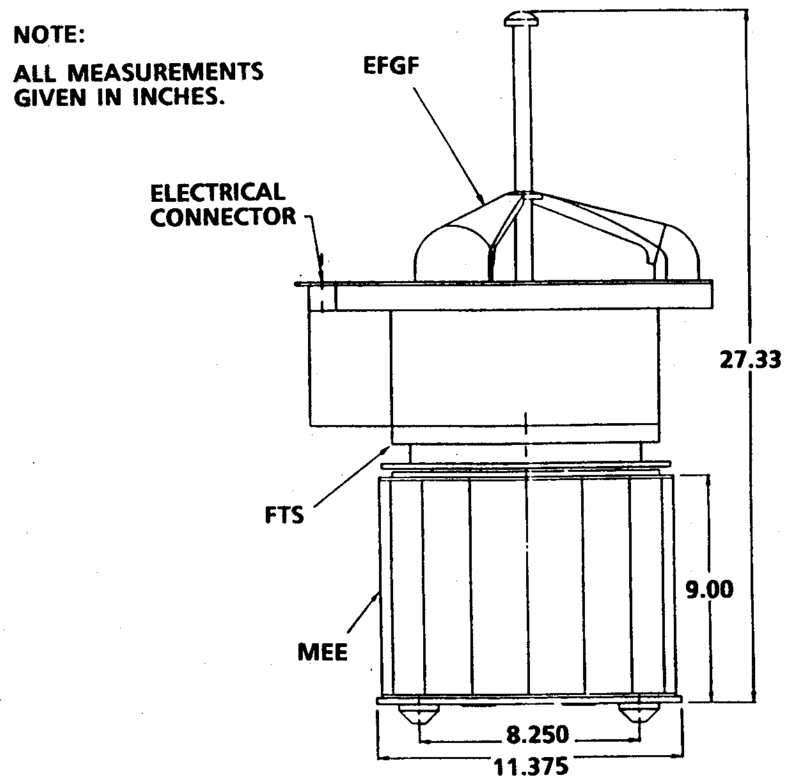

Figure 3.- Magnetic attachment tool (MAT).

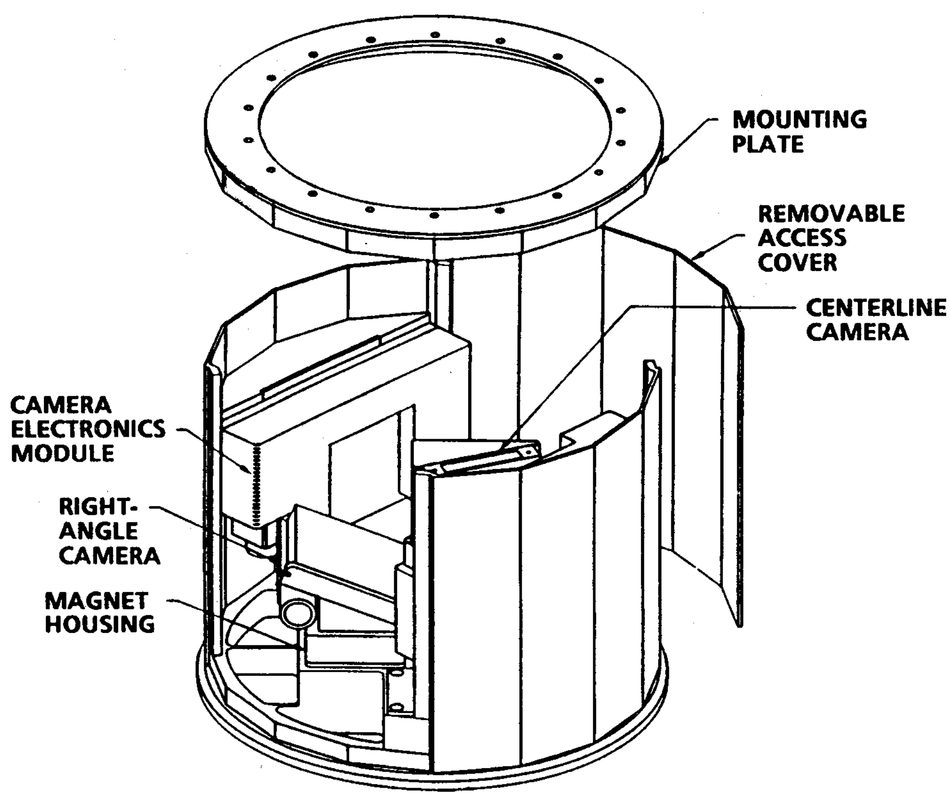

Figure 4.- Magnetic end effector (MEE).

LOAD PATH: ARM → RING → DEFLECTION SYSTEM → CENTER BLOCK → END EFFECTOR.

SAFETY FEATURE: PINS SHARE OVERLOAD OR HOLD LOAD IF FLEXTURE SHOULD BREAK → FAIL SAFE

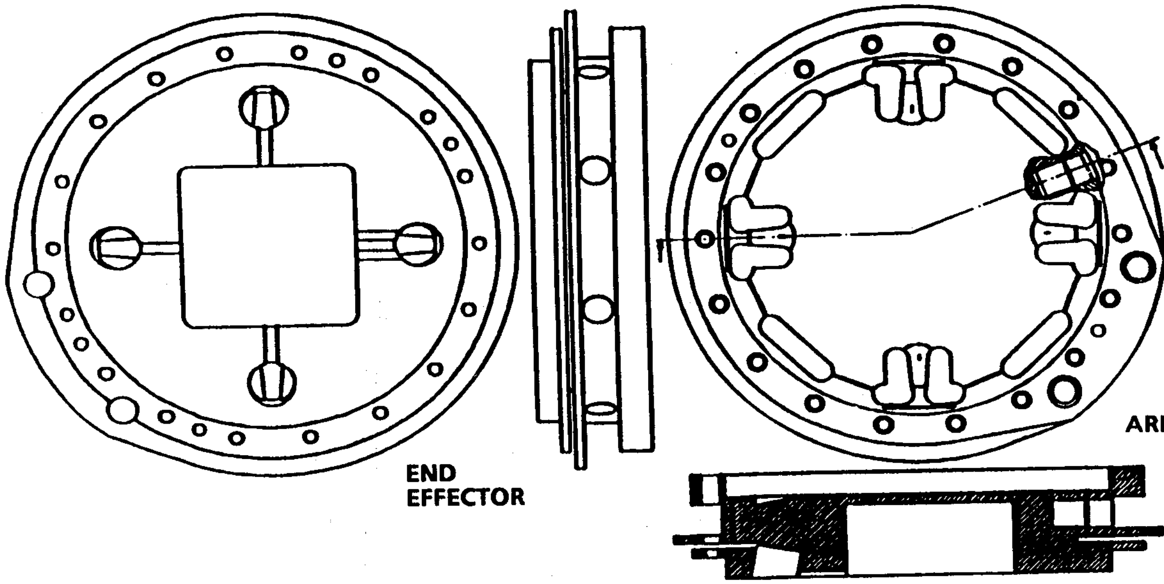

Figure 5.- FTS sensor element – mechanical design.

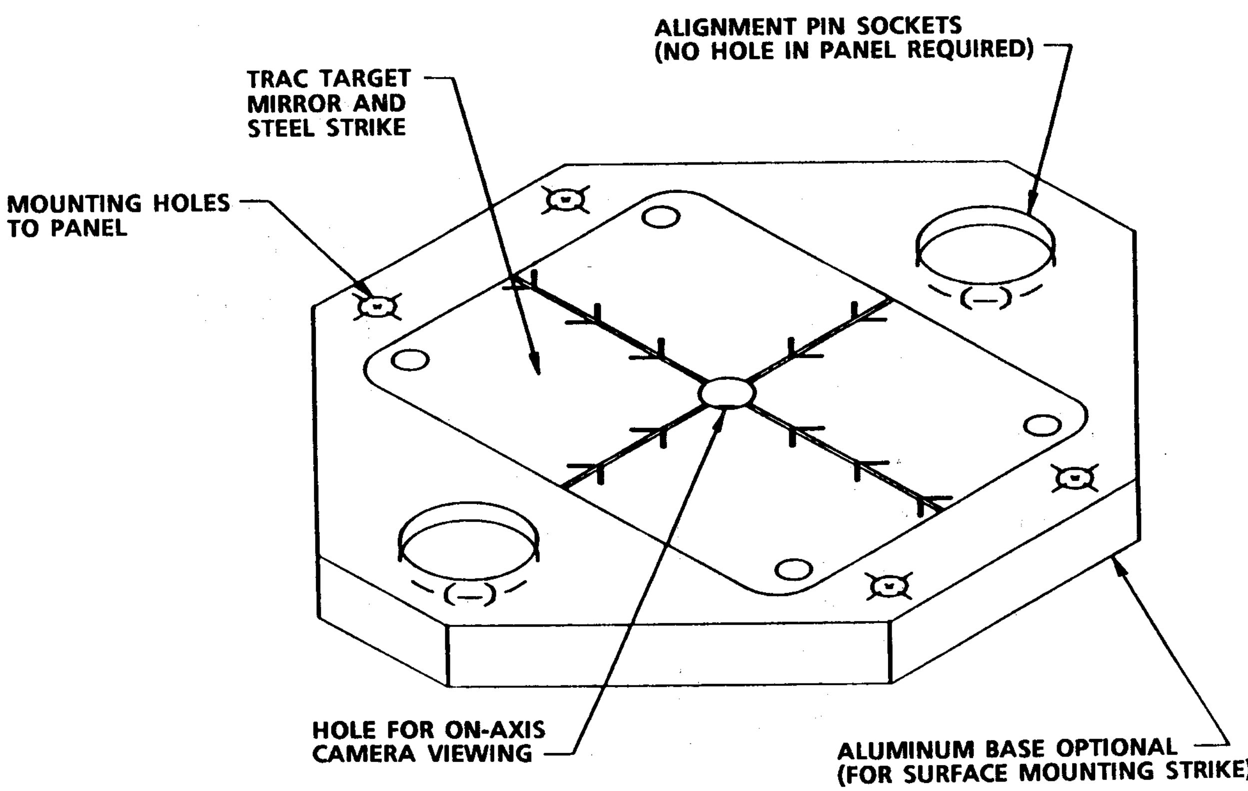

Figure 6.- Grapple fixture.

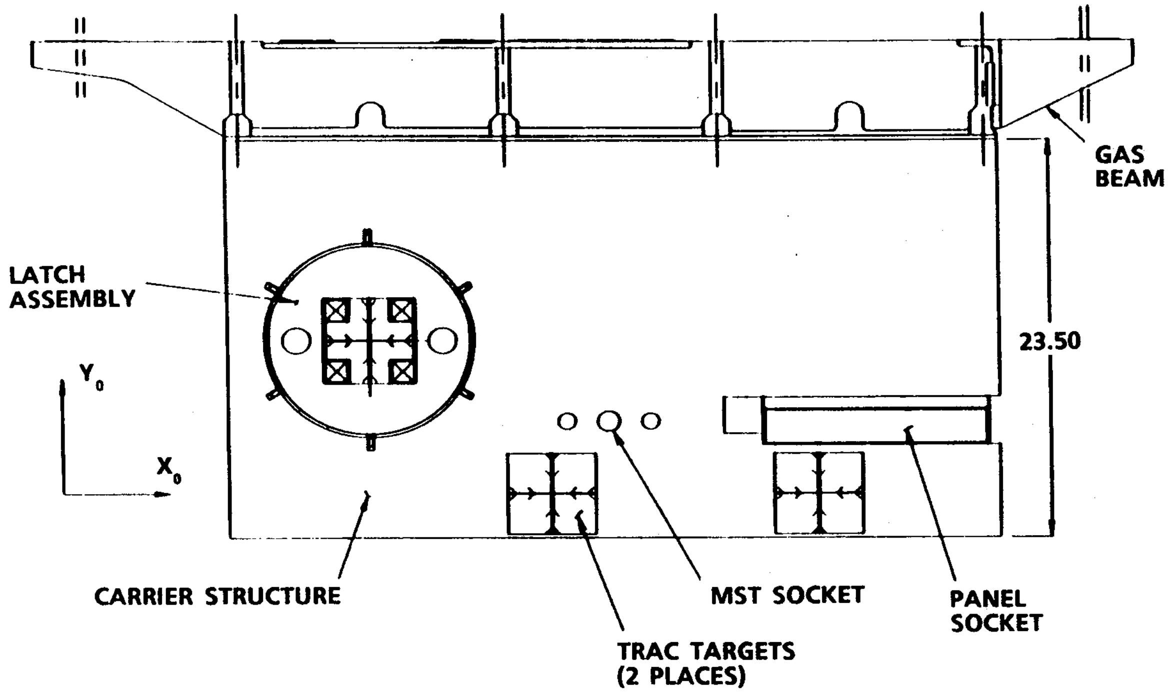

Figure 7.- Experiment stowage and activity plate (ESAP) plan view.

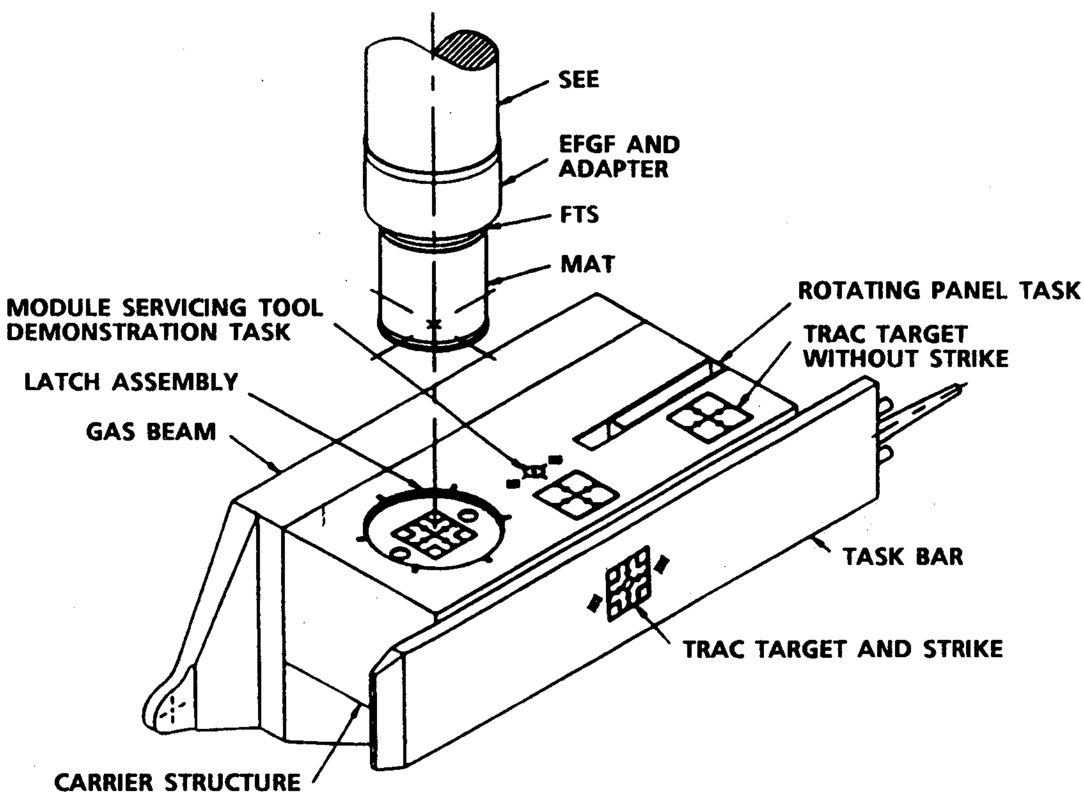

Figure 8.- MAT removed from the ESAP.

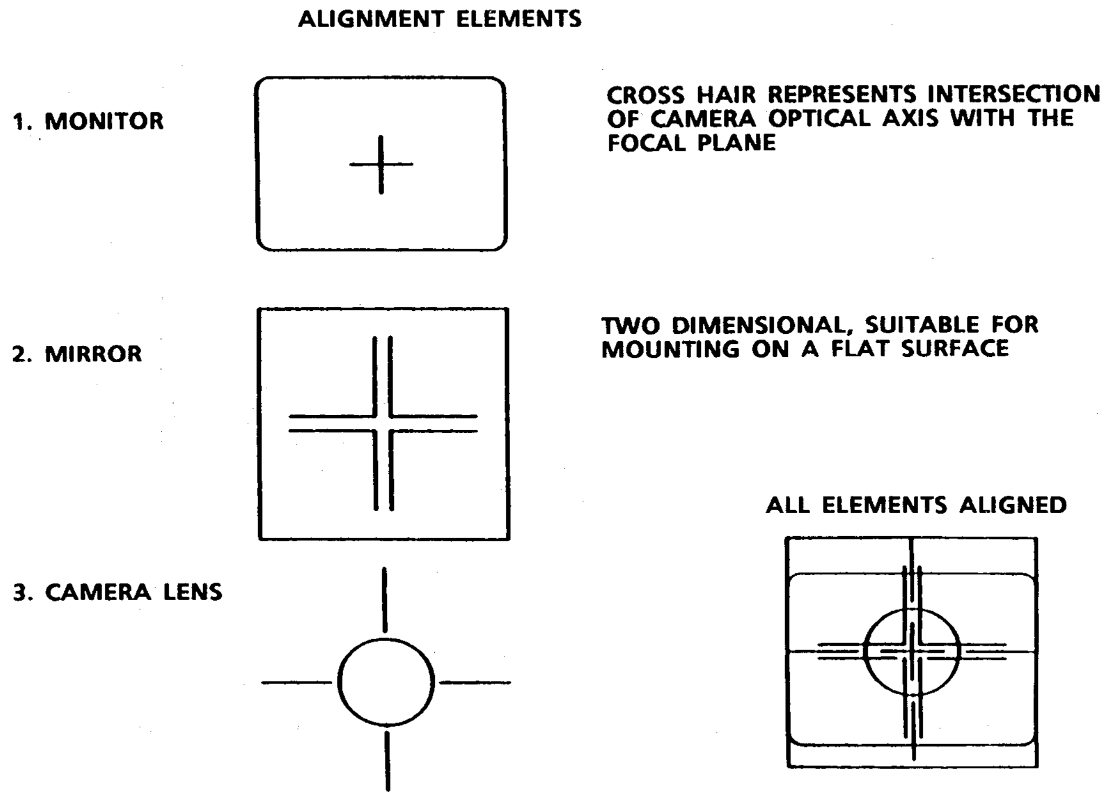

Figure 9.- Targeting and Reflective Alignment Concept (TRAC) targets.

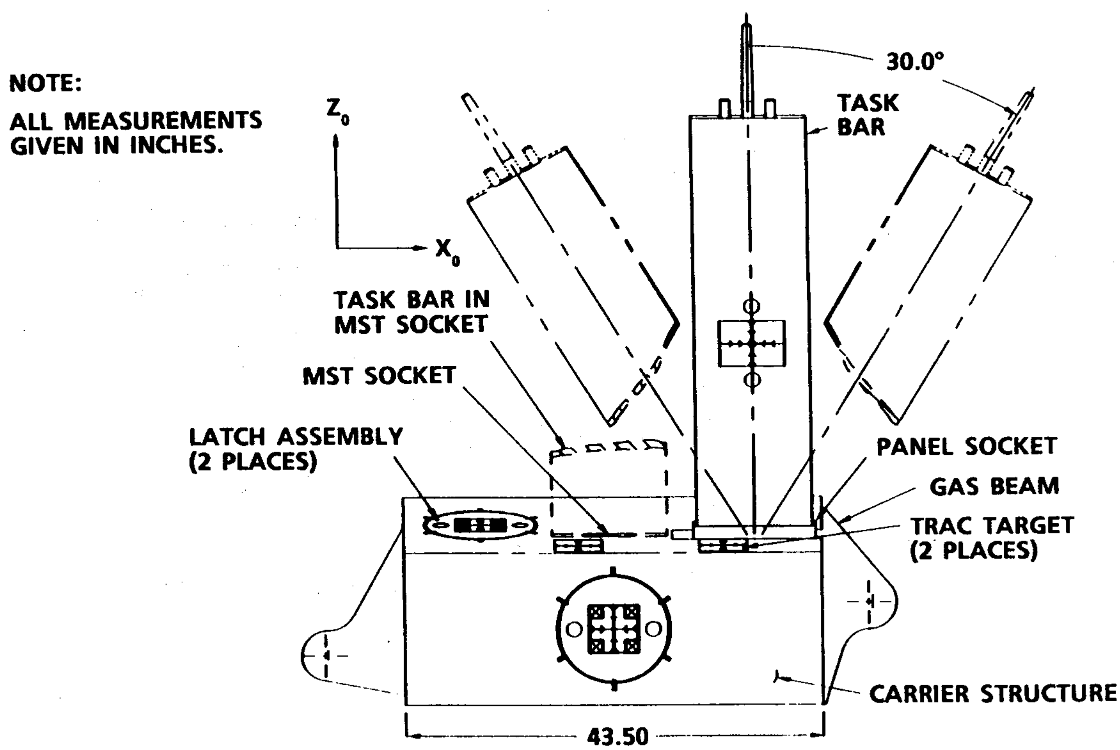

Figure 10.- Radiator panel replacement / rotating panel task – view looking starboard.