

A ROBOT END EFFECTOR EXCHANGE MECHANISM  
FOR  
SPACE APPLICATIONS

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Introduction

Efficient robot operation requires the use of specialized end effectors or tools for tasks. In many cases, multiple end effectors must be used, at different times, to complete a single complex job. These tools are normally stored on a simple rack fixture and attached to the manipulator as needed by the use of a simple grip mechanism. In most terrestrial applications, the tools are retained in the tool rack by the force of gravity. The grip mechanisms used to attach them to the manipulator are generally single acting, zero failure tolerant designs.

In spacecraft applications, the microgravity environment precludes the use of gravitational forces to retain the tools in the holding fixture. As a result of this, a retention mechanism which forms a part of the tool storage container is required. In addition to this obvious effect of the microgravity environment on-orbit, hazards are created which must be controlled for manned spaceflight applications. The safety requirements imposed for space operations near the National Space Transportation System Orbiter and the Space Station Freedom require multiple safety precautions which are not normally a part of ground operations.

One of the safety requirements imposed is that all items that could be "lost" in orbit, such as an end effector, must be held safely in place even in the event of two failures. This implies that the mechanisms used to attach the end effector to the manipulator and the tool storage container must incorporate not only a primary mechanism, but two redundant ones as well. Because a minimum of three catches must be active at all times, an interlock that prevents the release of one attachment before its opposite number on either the manipulator or the tool storage container is engaged is also required.

Because of these requirements, robot end effector exchange mechanisms for space applications tend to become large, heavy, and complex. They generally incorporate motor-driven actuators, a variety of sensors, and both electronic and mechanical interlocks.

A unique approach to this problem has resulted in the development of an end effector exchange mechanism that meets the requirements for spaceflight applications while avoiding the complexity usually involved. This mechanism uses multiple latching cams both on the manipulator and in the tool storage container, combined with a system of catch rings to provide retention in both locations and the required failure tolerance. Because of the cam configuration the mechanism operates passively, requiring no electrical commands except those needed to move the manipulator into position. Similarly, it inherently provides interlocks to prevent the release of one cam before its opposite number is engaged.

A working model of the latch cam system has demonstrated the operation of the mechanism. Extensive analyses and detailed models of a spaceflight design have shown that the proven concept can be manufactured without unusual difficulty.

### Tool Exchange Requirements

For a robot manipulator to provide a wide variety of different capabilities, it must be capable of replacing the tools with which it works. This is an especially important capability for general-purpose space robots such as the Flight Telerobotic Servicer (FTS) because of the wide variety of tasks which are likely to be performed, the high cost of the robot, and the unique operating conditions associated with space flight. Since the full range of tooling that will be required over the life of the program has not been identified the ability to exchange one tool for another is especially critical.

For space applications, each tool must be thought of as an item to be firmly attached to the manipulator rather than a smaller part to be gripped by a general-purpose end effector. It must also be positively retained in a toolbox or tool storage container when it is not in use. In the microgravity environment of space, the tool storage container itself must contain mechanisms to grip and secure the tool.

The requirement for positive retention of the end effector both on the manipulator and in the tool storage container is made more complex by the safety requirements defined for manned space flight. These requirements categorize the loss of an end effector into space as a "catastrophic hazard", which must be controlled by not less than three independent inhibits.

To provide an effective method of removing and installing various end effectors on the manipulator, the mechanism used must provide the following functions:

- a. The End Effector Exchange Mechanism (EEEM) must provide for tool pickup and release;
- b. The EEEM must provide automated fail-safe latching with the tool on the manipulator, in the tool storage container, and at all times during the exchange;
- c. The EEEM must provide automated tethering of the tool to the manipulator or a tool storage container by incorporating sufficient interlocking inhibits to tool release;
- d. The EEEM must provide sufficient preload between the end of the manipulator and the base of the end effector to react the loads applied by the manipulator without allowing a gap to form between the end effector and the manipulator;
- e. The EEEM must provide an electrical/electronic interface between the manipulator wire harness and the end effector, which provides all of the power and signal leads necessary for tool function;
- f. The EEEM must incorporate sufficient instrumentation to provide a positive indication that the end effector is properly latched in place on the manipulator or tool storage container;

- g. The tool storage container box must provide launch and landing accommodations for the end effectors.

### Exchange Mechanism

The Fairchild Space Company (FSC) developed an EEEM (called the Fairchild Exchange Mechanism or FEM) under an internal research and development effort. The emphasis of this program was to develop a highly reliable, simple EEEM which would meet all of the space application requirements.

The FEM is a part of an end effector system that incorporates the end of the manipulator, the EEEM, the end effector, and the tool storage container. This approach, illustrated in Figure 1, recognizes the interrelationships between the various requirements and the difficulty in meeting these requirements at all times in the exchange process with a series of independent mechanisms.

The central part of this system, the FEM itself, operates using six spring actuated latching cams. These cams, and the retention ridges they engage, inherently operate in a reversing manner. This inherent reversal allows the simple mechanism shown to retain the end effector both on the arm and in the tool container storage while affecting the change of grip in both directions without using electrical commands.

The FEM is totally mechanical. The spring-powered latch cams, located on both the manipulator and in the tool storage container, latch onto the latch ramps, which are a part of the tool for tool pickup and replacement. Because of the location of the springs that provide the torque necessary to grip the end effector, the maximum clamping force is provided at the fully engaged position. As the latch cam lifts away from the latch ramp during the exchange operation, the resulting decrease in the lever arm associated with the spring serves to reduce the force necessary to lift the cam.

As illustrated, the FEM is integrated into all of the other three system components. One set of latching cams is associated with the end of the manipulator, the second set of latching cams is a part of the tool storage container, and the catch ramps are a part of the end effector itself. Because of the FEM integration into the overall system, effective service is provided during all phases of operation with a minimum of volume and complexity.

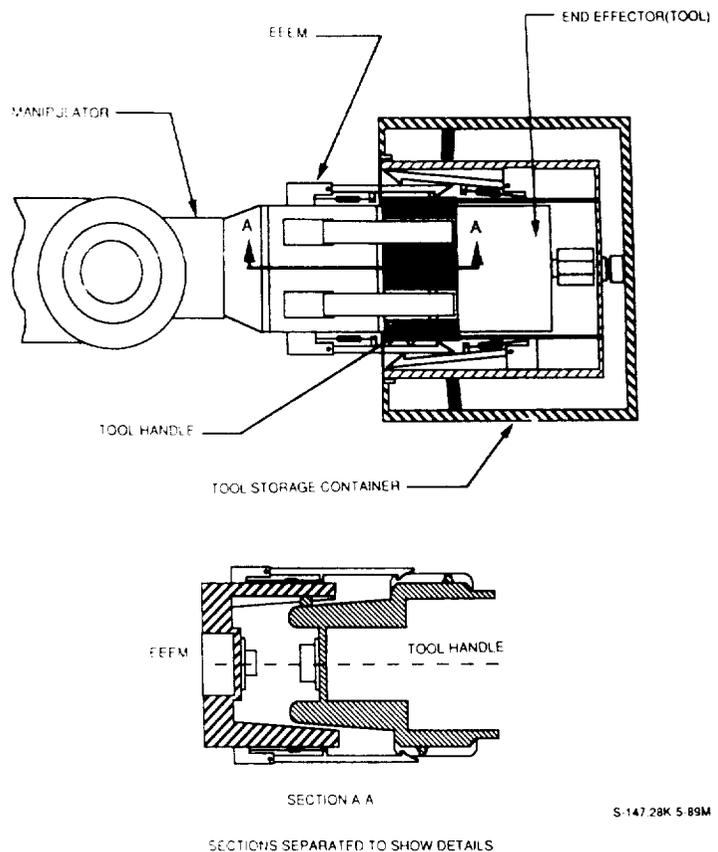


Figure 1: The FEM Provides Positive Retention of the Tool Both on the Arm and in the Tool Storage Container

The FEM is adaptable to all end effector requirements. It is illustrated in Figure 2 for small tools such as a Nut Runner and in Figure 3 for large tools such as the Module Service Tool (MST).

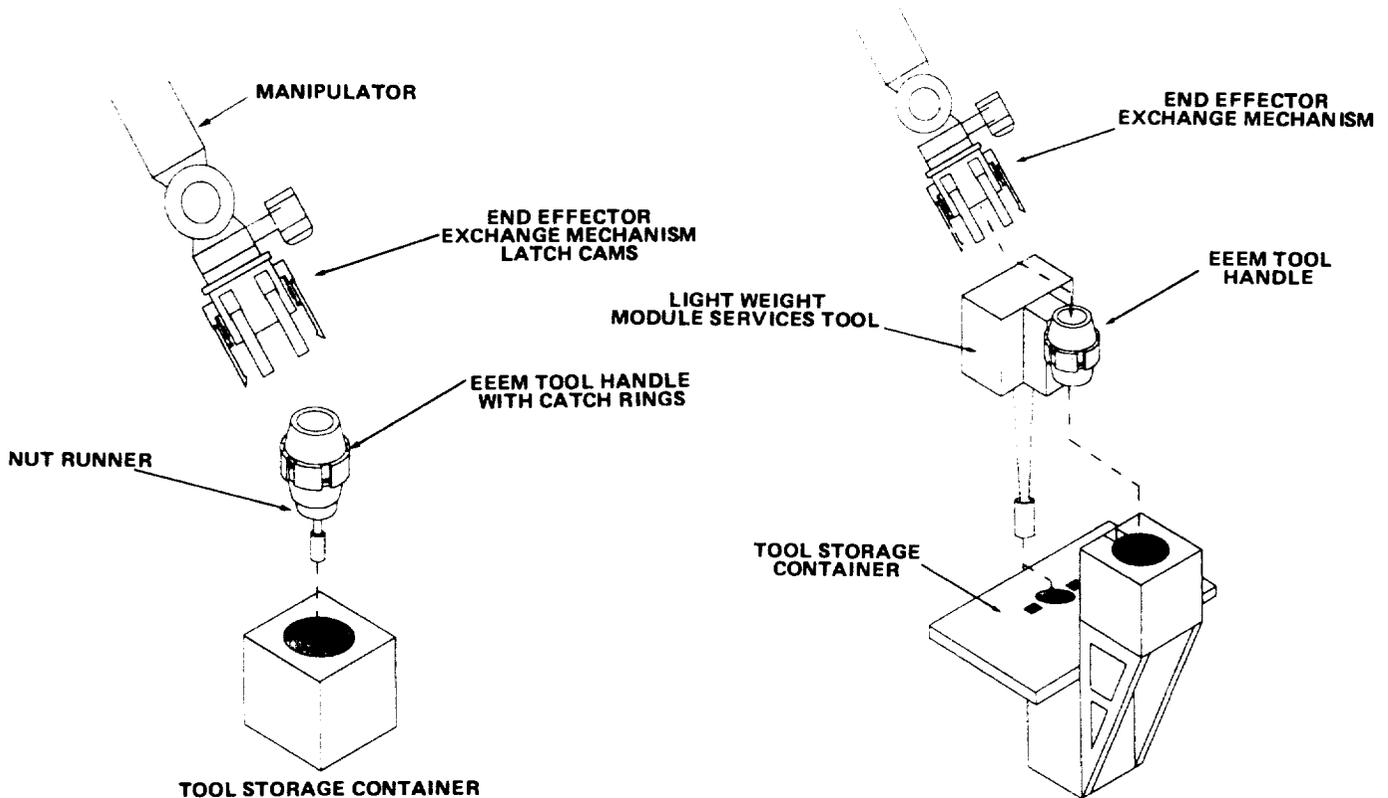


Figure 2. The FEM Incorporates the Manipulator Interface, the Tool and the Tool Storage Container into the End Effector Exchange System

Figure 3. The FEM is Suitable for use with Large Tools Such as the Module Service Tool

The FEM is simple to operate. It uses an insertion motion in which the manipulator arm is moved linearly into the tool interface for tool pickup. A similar motion, moving the tool into the tool storage container, replaces the tool in the tool storage container. This movement requires only the push force the manipulator provides to actuate the latch cams attaching the tool to either the manipulator or the tool storage container and to interface the electrical connector.

Tolerance stackup analyses have been performed to verify that the FEM will be relatively straightforward to manufacture because the precision required is no greater than is normal for aerospace hardware. Similarly, analyses have been performed to verify that the insertion forces required will be within the range possible for general-purpose space manipulators. These same analyses show that the clamping forces the FEM provides will be sufficient to maintain positive contact between this tool base plate and the manipulator face.

The complete absence of motors and gears significantly reduces the complexity of the FEM. It also minimizes power requirements, thermal problems, command requirements, and the number of system parts.

The selection of the number of latching cams and the location of the latch ramps which form a part of the FEM is based on the failure tolerance requirement associated with manned space flight. The FEM incorporates six latch cam pairs and six latch ramps. These are arranged as three primary latches and three backup latches on both the manipulator and the tool storage container. The primary latch cams are aligned to latch onto the three primary latch ramps on the tool handle during the tool exchange operations. The three backup latch cams on both the manipulator and the tool storage container engage with the secondary ramps before the primary cams are lifted from the primary ramps. This provides the necessary interlocking architecture and redundancy for system safety.

The backup cams and ramps for retention on the manipulator are the primary cams and ramps for retention in the tool storage container and vice versa. During the exchange process, if for some reason the primary latches fail, the secondary latches will retain the tool in a safe position either on the manipulator or in the tool storage container. They will not, however, position it suitably for use. When the tool is held by the secondary latches, simply re-inserting the tool into the tool storage container will engage the tool into the primary latches.

As a result of its design, the FEM provides all of the primary services required for a flight system EEEM, retaining the tool on both the manipulator and in the tool storage container, and providing sufficient failure tolerance for manned spaceflight applications. In addition, the FEM offers several other advantages. It is a passive system which requires no electrical commands or complex interlocks for operation. It provides both the mechanical attachment of the end effector to the manipulator and the electrical interface as a part of a single, linear mechanical motion provided by the manipulator itself without additional motors or actuators. It is inherently failsafe.

### Tool Storage Container

As with most hardware for space applications, the EEEM, tools, and tool storage container must survive both the launch and landing phases of the mission. The nature of the system is that the latch cams attached to the manipulator will be required only to survive this environment in an "unlatched" condition. Similarly, the tools will be required to simply survive the launch environment. The tool storage container, however, will be required to support the end effectors during launch and landing. As a result, it must incorporate all of the provisions necessary for it to do so. This will include sufficient preload on each tool to retain it positively in position and sufficient latching moment on the latching cams to retain their position.

In orbit, the tool storage container will continue to protect the end effectors, providing them with a controlled environment. This implies protection from viewing both the direct sun and deep space for long periods of time. To accomplish this, the tool storage container will be equipped with a container lid which will open when the tools are in use.

In addition to firm support during the launch environment, the tool storage container must also provide some compliance during tool exchange to

minimize the precision with which the manipulator must be positioned. This capability is also provided by using a spherical bearing scheme that allows the tool receptacle to rotate slightly to align with the tool during exchange.

Both the latch cam system and the tool storage container compliance design are based on an existing Fairchild spacecraft product, the Soft Umbilical Mechanism (SUM). While the appearance and purpose of the SUM are completely different from that of the EEEM and tool storage container, the principles of operation are identical. This design heritage provides a high level of confidence in the expectation that the FEM and tool storage container systems can be built and qualified for flight with a minimum level of risk.