Teleoperator Systems for Manned Space Missions

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In November, 1969, the President's Science Advisory Committee under the leadership of the distinguished Dr. L. DuBridge, unequivocally called for development of remote mechanical systems to augment man's capabilities in our manned space effort. A "teleoperator system" would extend man's innate intelligence and sensory capabilities to distant hostile and hazardous environments through a manipulator-equipped spacecraft and an RF link. This paper examines space teleoperator system applications in the Space Station/Space Shuttle Program, which is where the most immediate need exists and the potential return is greatest.

INTRODUCTION

As the space station and space shuttle development proceed, the necessity of applying teleoperator systems to extend man's innate intelligence and sensory capabilities to distant, hostile, and hazardous environments becomes apparent. The teleoperator system is a remote, electromechanical and visual system that utilizes video and manipulator-equipped spacecraft and an RF link to extend human capabilities across many miles in space.

The possibility of using manipulators in space environment has been suggested by space technologists for the last decade. Recent work in this area has:

1. Detailed the success of teleoperator systems on earth and described the extension of their technology to space.
2. Examined the feasibility and cost effectiveness of a ground controlled teleoperator system for refurbishing on-orbit satellites.
3. Described a teleoperator spacecraft design made up primarily of space-qualified components and with a high system reliability.
4. Described the space mission analysis and laboratory work performed to further prove feasibility and establish design criteria and concepts.

As a result of recent studies (References 1 through 4) conducted by the General Electric Company on remote manipulation, a teleoperator system concept was evolved that has many applications in the Space Station/Space Shuttle program. Three views (Figure 1) of the concept are illustrated, pictured within the volume envelope of the standard space station airlock. The system has a free flight capability with the appropriate attitude control and propulsion subsystem, and the system is controlled through the RF communication control subsystem either in the space station or in the shuttle.

The teleoperator is positioned at the worksite with sufficient accuracy and low enough drift rates to allow the manipulator arms to grasp the worksite and attach the docking legs. Of course a video subsystem is needed to see the worksite. Several cameras and an illumination subsystem are used to give the needed visual information despite the harsh visual condition in space. When properly

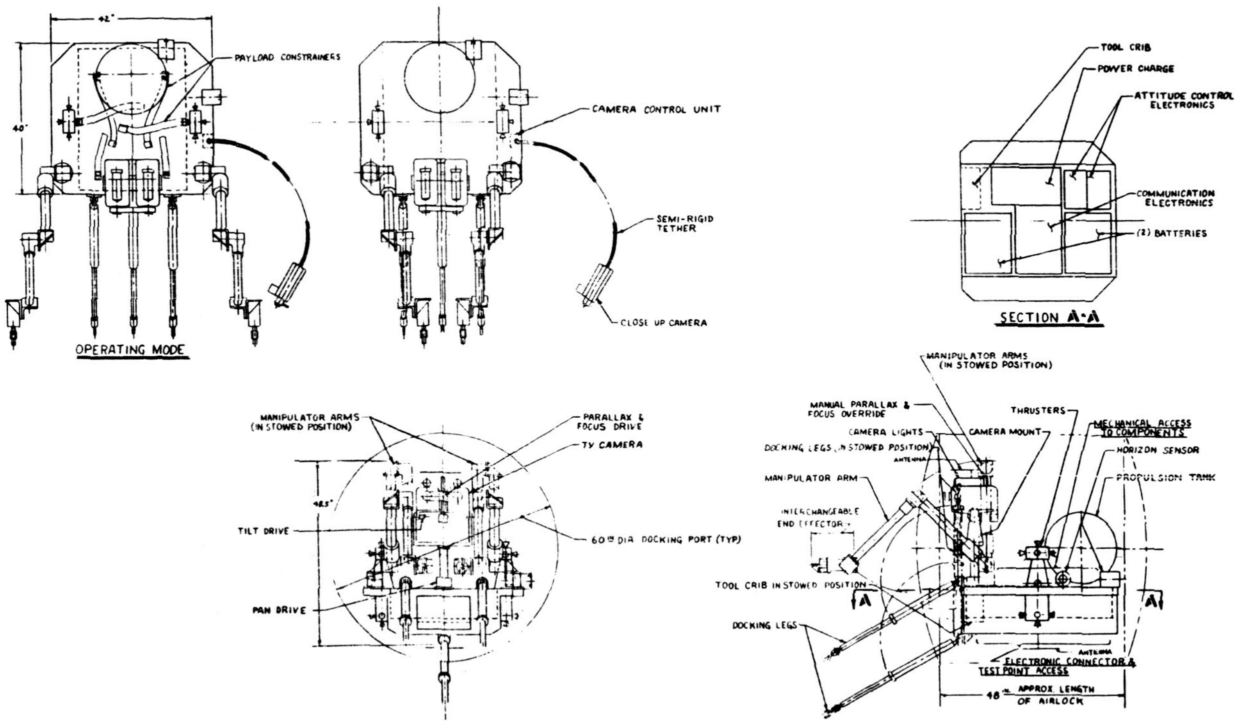

Figure 1. Baseline Teleoperator Configuration

secured to the work site the manipulator arms can perform the needed repairs or refurbishing with the use of tools and techniques previously worked out.

Estimates of the weight and power for this system are shown in Table 1.

Table 1. Space Station Teleoperator Weight and Power Summary

Subsystem	Weight (lb)	Average Power (watts)	Subsystem	Weight (lb)	Average Power (watts)
Manipulator	86.0	40	Video and Illumination	44.1	44
Docking Tethers	18.0	-			
Communications	69.0	30	Power	305.0	-
Propulsion (including fuel)	81.3	46	Structure	100.0	-
Attitude Control	40.2	35	Total	743.6	195

Several methods for station/shuttle maintenance and support are under consideration. One of these concepts would be designed around intravehicular activity, and another method would provide for maintenance through extravehicular activity and the use of special purpose mechanisms and designs.

While the current approaches do not consider general purpose teleoperators, we would like to describe their potential application and advantages. These applications will be presented first for the space station program and then for the space shuttle program.

SPACE STATION PROGRAM

On board a space station, teleoperators would support operation and maintenance of both the space station and station experiment program. A teleoperator of the type evolved from the General Electric investigation would be useful in performing inspection, maintenance, mass transfer and assembly.

Inspection

Periodic visual inspection of the exterior of the station would include a check for punctures, breaks or fouled deployment mechanisms. By taking along leak detectors, IR cameras, or contamination sensors, the teleoperator could carefully search for leaks from within the station, or from the RCS system, and for local hot spots. The environment in the vicinity of the station could also be measured in this way.

Maintenance

RCS Quadjets wear out and will have to be replaced periodically. Currently they are configured for IVA replacement, but these units could be replaced more simply from the outside of the station (Figure 2). The present technique requires large internal crew tunnels and work volumes and deployable outside covers or seals to maintain the station airtight integrity and environment in the work volume. Degraded thermal coatings could be replaced with properly coated tapes. Fouled deployment mechanisms usually operate with spring force levels of about 5 pounds and motor torques of about 200 inch-pounds. This is within the force capability of the general purpose teleoperator in the system anticipated by GE, so these devices could be overridden and deployed or undeployed by a teleoperator.

Mass Transfer

For those cases in which complete modules would not be transferred from the shuttle to the station, teleoperators could be used to transfer packaged logistics and equipment from the shuttle cargo bay to a station airlock (Figure 3). This operation would eliminate the need for docking the shuttle to the station.

Assembly

In addition to the assembly of such systems as antennas or solar arrays, a teleoperator could be used to assist in assembly of a modular space station in orbit and aid in the evolutionary operations of growing the station into a base.

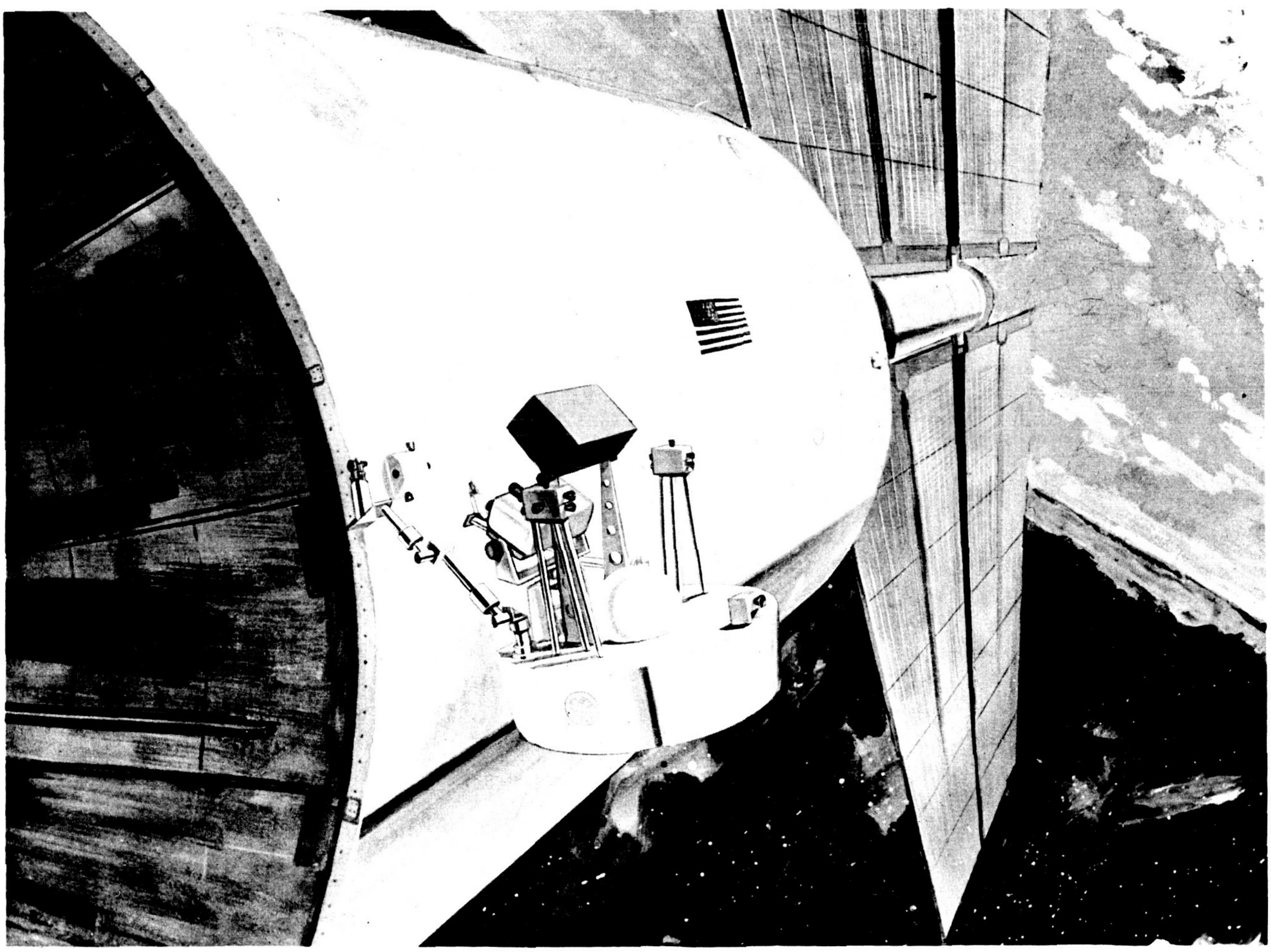

Figure 2. RCS Quadjet Replacement

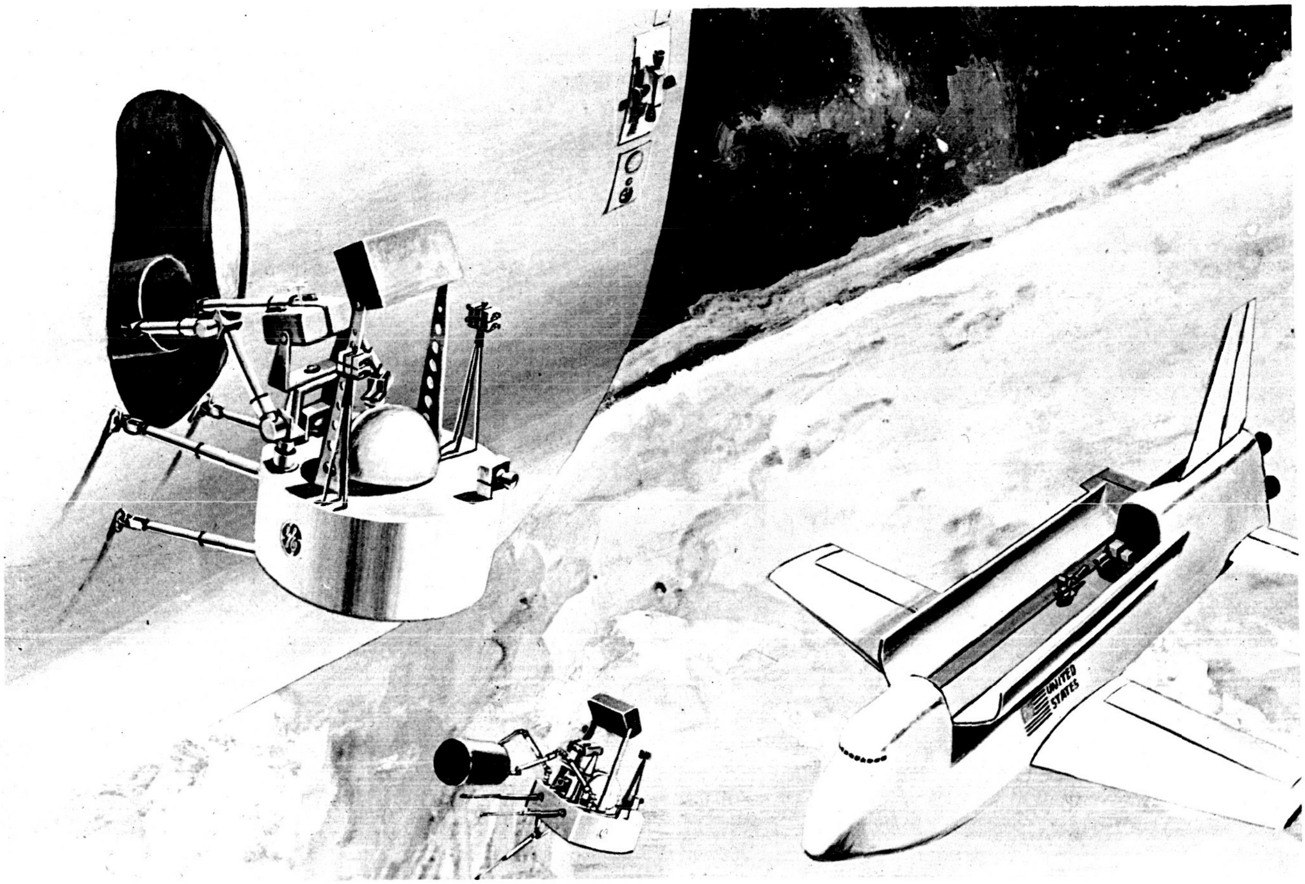

Figure 3. Logistics Transfer

EXPERIMENT PROGRAM SUPPORT

The diverse experiment program planned for the space station calls for the deployment and positioning of sensors and equipment on the station exterior. Some of these sensors will be grouped in modules that are attached to the station. Others will be part of free flight modules remote from the station. In order to accomplish this operation, use will be made of many special purpose booms, positioning devices, and special purpose subsatellites as well as frequent revisits and docking of detached modules to resupply the expendables.

Table 2 is a summary of the potential teleoperator applications that might be used in support of the experiment program. The techniques being considered are shown in the right-hand column.

Table 2. Teleoperator Applications on the NASA Space Station

Functional Program Elements		Teleoperator Applications	Technique Presently Considered
5.1 5.5A	Grazing Incidence X-Ray Telescope and High Energy Stellar Survey (X-Ray)	Film and tape retrieval and change Routine Maintenance and Servicing Refueling	Module docks to Space Station periodically. Astronauts enter module through docking port and service

Table 2. Teleoperator Applications on the NASA Space Station (Cont)

Functional Program Element		Teleoperator Applications	Technique Presently Considered
5.2	Stellar Astronomy Module	Film and tape retrieval and change Routine Maintenance and Servicing Refueling	Module docks to Space Station periodically. Astronauts enter module through docking port and service
5.3A	Advanced Solar Astronomy	Film and tape retrieval and change Routine Maintenance and Servicing Refueling	Module docks to Space Station periodically. Astronauts enter module through docking port and service
5.3B	Advanced Solar Astronomy	Film and tape retrieval and change Routine Maintenance and Servicing Refueling	Module docks to Space Station periodically. Astronauts enter module through docking port and service
5.4A	Ultraviolet Stellar Astronomy	Film and tape retrieval and change Routine Maintenance and Servicing Refueling	Module docks to Space Station periodically. Astronauts enter module through docking port and service
5.4B	Ultraviolet Stellar Astronomy Survey	Film and tape retrieval and change Routine Maintenance and Servicing Refueling	Module docks to Space Station periodically. Astronauts enter module through docking port and service
5.5B	High Energy Stellar Astronomy Survey (Gamma-Ray)	Repair of fouled deployment mechanism for detectors	Module docks to Space Station periodically. Astronauts enter module through docking port and service
5.6	Space Physics Airlock	Deployment and installation of sensors and instrumentation outside station Repair of fouled deployment mechanisms (booms)	Deployed on boom through airlock
5.7	Plasma Physics and Perturbation Investigation	Deploy Langmiur probes. Faraday cups, and cyclotron harmonic resonance mechanism (boom)	Some deployed on boom through airlock Dedicated subsatellite is presently used to deploy others

Table 2. Teleoperator Applications on the NASA Space Station (Cont)

Functional Program Element		Teleoperator Applications	Technique Presently Considered
5.8	Cosmic Ray Physics Laboratory	Photographic plate retrieval and change Resupply of liquid cryogen and plate emulsion Refueling Routine maintenance and service	Module docks to Space Station periodically. Astronauts enter module through docking port and service
5.11	Earth Surveys	Retrieve and replace film Repair fouled deployment mechanism	Module is unpressurized during operational phase and is pressurized during maintenance phase
5.12	Meterology Sub-satellite	Transport sensors, probes and instrumentation to new orbital position	Dedicated subsatellite is presently used
5.14	Man System Integration	Experiment calls for maneuvering subsatellite and teleoperators	A teleoperator system is called for
5.16	Materials Science and Processing	Deployment of processing equipment outside station during experiment operating	Space chamber is built into laboratory area for experiment operating mode
5.17	Contamination Measurements	Deploy and install sensors and instrumentation outside station	Deployed on boom through airlock
5.18	Exposure Experiments	Deploy, install and retrieve sensors and instrumentation outside station	Deployed on panel pallet through airlock and installed on outer skin of station - retrieved again using panel pallet.
5.20	Fluid Physics	Film retrieval and change Routine maintenance and Servicing Refueling	Module docks to Space Station periodically. Astronauts enter module through docking port and service
5.21	IR Stellar Survey	Resupply of liquid cryogenics Routine Maintenance and Service Refueling	Module docks to Space Station periodically. Astronauts enter module through docking port and service

Table 2. Teleoperator Applications on the NASA Space Station (Cont)

Functional Program Element	Teleoperator Applications	Technique Presently Considered
5.22 Component Test	Deploy and install equipment and instrumentation outside station	Equipment installed in space chamber in station and operated
	Conduct space welding experiment in space	Conduct space welding experiment in space chamber
5.24 MSF Engineering	Experiment calls for a maneuvering subsatellite and teleoperator	Use teleoperators
	Maintenance of isotope Brayton power system	No extensive maintenance planned

A listing is made in Table 3 of the estimated weight and volume of current techniques considered for performing experiments.

The weight and volume summary of special purpose booms and subsatellites is shown in this table but no attempt has been made to include such special mechanisms as: tunnels, structure, or gases, which will be necessary to environmentally seal-off work areas or provide access and habitability in work areas. These items are not completely defined or estimated yet but will clearly be large and heavy.

A comparison is made in Table 4 of weight and volume between current techniques for experiments and the use of a teleoperator.

Table 3. Currently Planned Techniques

Item	Weight (lbs)	Volume (ft^3)
Articulated Booms	170	120
Panel Pallet	35	120
Materials Processing Vacuum Chamber	500	72
Remote Maneuvering Satellite - FPE 5.7 & 5.12 (Mobility Package Savings)	100	-
Remote Maneuvering Satellite - FPE 5.24	80	5.0
TOTAL	885	317

Table 4. Weight and Volume Comparison

Item	Weight (lbs)	Volume (ft^3)
General Purpose Teleoperator	750	60
Other Techniques	885	317

This same teleoperator lighter and more compact would be capable of performing the maintenance missions previously described in addition to supporting the experiment program.

SPACE SHUTTLE PROGRAM

Some of the applications mentioned for the station are also applicable to the shuttle. Additional applications arise from the shuttle's ability to inject and maneuver into many different orbits. Some important applications are now being considered:

Visual Inspection

Visual inspection (Figure 4) will include the condition of the shuttle heat shield and the condition and operation of the aerodynamic control surfaces and doors prior to de-orbit and re-entry.

On-Orbit Resupply of Unmanned Satellites

The life of operational satellites may in many cases be economically extended by resupplying spent consummables such as fuel, cold gas, or batteries. Close rendezvous with the target satellite would be accomplished by the shuttle followed by deployment of the teleoperator from the shuttle, and terminal rendezvous and docking of the teleoperator to the target satellite. The teleoperator would then perform the resupply operations and return to the shuttle.

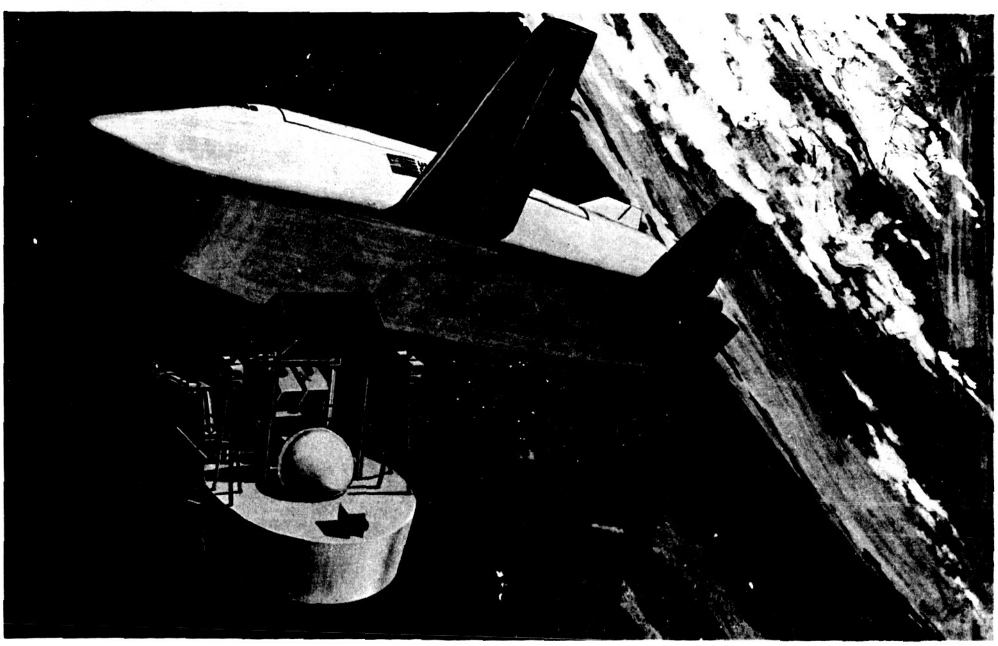

Figure 4. Inspection of Space Shuttle Re-entry Shield

On-Orbit Refurbishment or Retrieval/Deployment of Unmanned Satellites

An extension of the resupply mission would be to change satellite payloads or perform diagnosis and repair on-orbit. These missions (Figure 5) would again be performed by the general purpose teleoperator but the tasks would be greatly simplified if consideration were given to designing satellites for maintainability. The teleoperator would transfer the satellite to the cargo bay for complex tasks for operations by the astronaut crew or perhaps for return to earth.

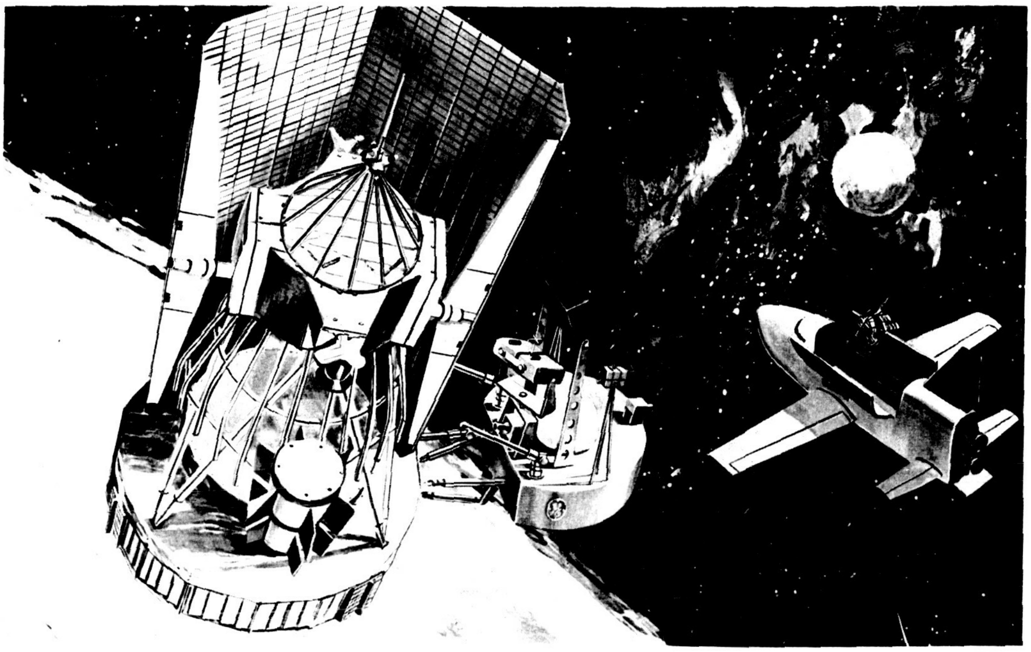

Figure 5. Satellite Retrieval

GROWTH POTENTIAL

The same teleoperator systems would play an important role in the space program of the next decade. Such studies as "The Nuclear Rocket in the Space Future," which was prepared for NASA by D. S. Gabriel, have shown that great savings can be achieved if the nuclear shuttle is made reusable. One limiting item, however, is the engine life. By replacing the engine in orbit (after approximately 10 reuses) the life of the nuclear shuttle could be greatly lengthened. This mission is illustrated in Figure 6. The radiation environment in the vicinity of the spent engine presents a hazard for man-attendance methods but is an ideal application for the mechanical teleoperator. A similar situation will exist on the space base where nuclear reactors will be used for electrical power and require replacement every two years.

Teleoperators with surface roving mobility units could be used to perform lunar or planetary surface explorations (Figure 7). These teleoperators would include many of the same subsystems as their orbiting relatives, such as: manipulators, video, power and communications. They could be deployed and controlled from lunar landing space tugs or from orbiting space stations. As teleoperators with limited artificial intelligence (robots) are developed, extensive exploration activities can be envisioned on distant planets without the detrimental effects of long transmission time delays.

Space teleoperator systems can be made ready for the first space station/space shuttle missions currently planned for about 1977. Complete on-orbit checkout and test would be performed following launch to evaluate predicted teleoperator performance in space. Based upon the results of this phase, system

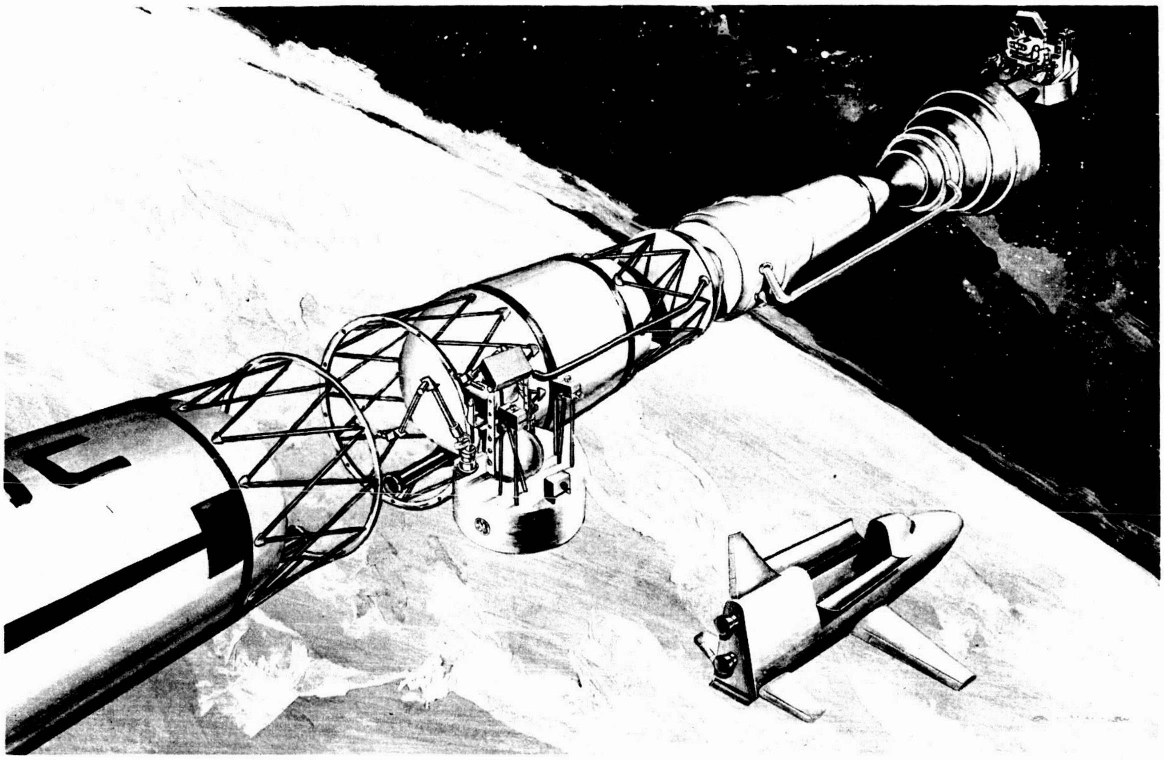

Figure 6. Nuclear Shuttle Engine Replacement

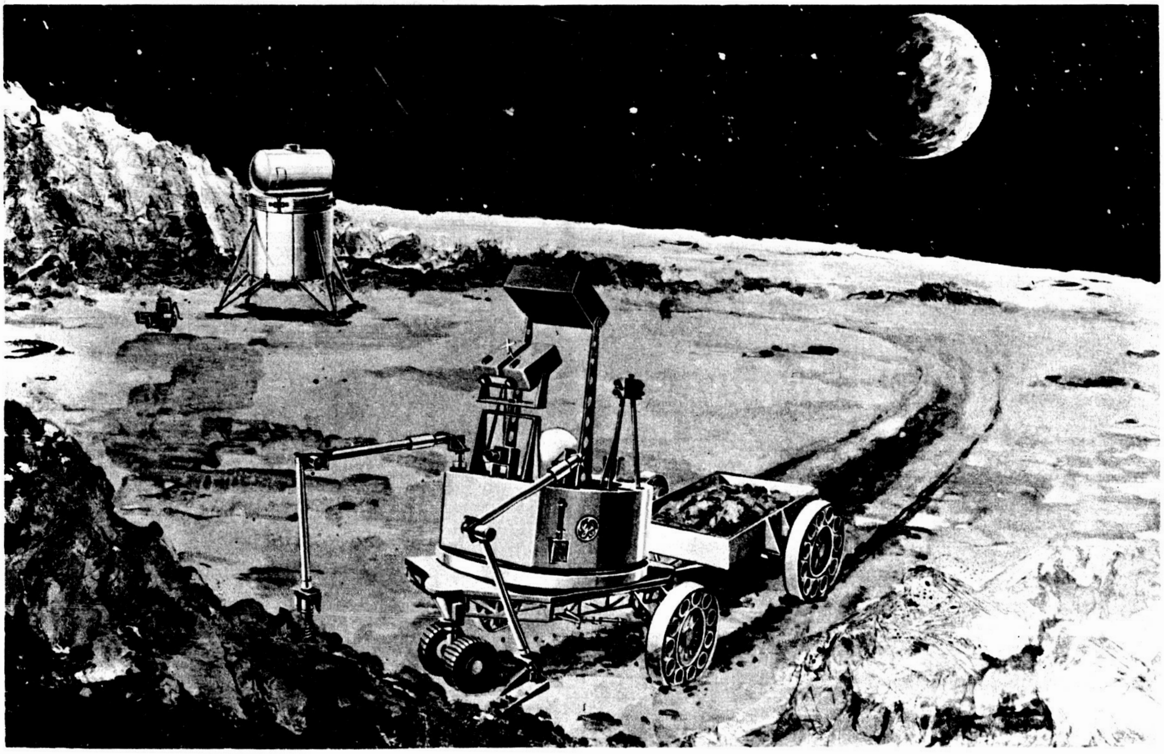

Figure 7. Teleoperations on the Lunar Surface

operating procedures, crew work schedules, and final system adjustments could be made in preparation for its operational deployment.

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