

## TELEOPERATORS FOR REMOTE OPERATIONS IN SPACE\*

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### INTRODUCTION

Early in 1970 a NASA Task Team was assembled to evaluate the potential application of teleoperators/robots to the integrated space program requirements. The term teleoperator as applied to space programs is generally defined as general purpose, dexterous, cybernetic, man-machine systems that augment man by extending his capabilities across distances and through physical barriers into hostile environments and amplify his energy and force capability. Teleoperators are a prime candidate to augment or possibly eliminate Extra Vehicle Activity (EVA).

EVA operations will also be limited by natural space radiation environment and will be eliminated from some operations due to manmade radiation environment. The NASA Task Team recommended the development and application of teleoperators for a variety of space tasks whose missions were broadly divided into four areas: inspection and servicing of spacecraft; construction in space; mission operations; and emergency operations.

The report described eight major classes of teleoperators, which included:

- Remote Maneuvering Teleoperators (RMT)
- Lunar Roving Vehicle - Unmanned Operation
- Space Station/Shuttle Teleoperator
- Mars Roving Vehicle
- Tug
- Reusable Nuclear Shuttle Teleoperator
- Space Assembly Teleoperator
- Planetary Support Teleoperator/Robots

One of the major classes required is the development of a teleoperator for nuclear programs. Some of the typical tasks identified by NASA for this teleoperator system were nuclear-engine replacement and maintenance, propellant transfer and refueling, cargo handling for the reusable nuclear shuttle, and the package and disposal of spent reactors.

Aerojet Nuclear Systems Company, under the direction of the Space Nuclear Systems Office, is conducting detailed analysis to:

1. Establish requirements for a Remote Nuclear Teleoperator (RNT)
2. Establish engineering concepts for the RNT
3. Establish a development and qualification plan for the RNT

The analysis has been based around the concept of the Reusable Nuclear Vehicle. The concept of the RNV involves many normal and maintenance operations in space which could require either an EVA mode or a teleoperator.

Once the propulsion system has been activated the radiation level essentially precludes any EVA

operations; therefore, similar to the ground test program, any operations performed on the propulsion system will require a teleoperator. Many teleoperator concepts exist, from on-board the RNV to a flyable unit. The on-board units appear to establish large weight penalties on the RNV, so the original teleoperator concepts have been led to a flyable unit.

### NERVA TELEOPERATOR PROGRAM REQUIREMENTS

System engineering documentation has been generated for both the ground and flight phases of the NERVA engine. Also, a maintainability design trade study has been completed and a maintenance concept has been formulated and published. Using this basic information, which has identified many requirements allocated to the teleoperator system, a systems analysis approach was continued to further delineate NERVA Program teleoperator requirements. Many guidelines were used in generating these functional requirements; the most important being:

No planned EVA operations in space for NERVA operations and maintenance, and

Teleoperator and NERVA engine design must be interrelated for maximum compatibility

The following specific tasks were identified for the normal and maintenance operations from the analysis:

#### Normal Operations

1. Install and remove external shield
2. Checkout nuclear engine (visual inspection)
3. Install or remove cargo as required
4. Remove launch support equipment
5. Disposition of spent engine

#### Maintenance Operations

1. Remove engine from stage, dispose/acquire, install engine to stage
2. Remove and replace engine hardware modules
3. Replace engine electronics modules
4. Support verification of maintenance actions and checkout

The teleoperator system analysis indicated (based on all ground rules, guidelines, and both normal and maintenance tasks determined from engine system analysis) that the teleoperator should consist of two or more separate parts: (1) a control unit which may be in space or earth-based; and (2) orbiting satellite teleoperators which can be maneuvered and operated by the teleoperator controller. Other requirements identified by the analysis were:

1. The teleoperator must have docking arms to attach to the engine, stage, and other devices at points to which the teleoperator must be secured as a working or transporting platform for the various tasks assigned.
2. The teleoperator must attach to the stage/

\*The Nuclear Engine for Rocket Vehicle Application (NERVA) program is administered by the Space Nuclear Systems Office, a joint office of the USAEC and NASA. Aerojet Nuclear Systems Company is prime contractor for the engine system and Westinghouse Electric Corporation is principal subcontractor responsible for the nuclear subsystem.

engine, disengage and separate the engine and/or engine module/component, disengage from the stage/engine and deliver it to a point or area of disposition.

3. The teleoperator must acquire and then transport the engine and/or engine module/components from a space source to the stage/engine and attach them to the stage/engine as required, and effect their alignment, mating, and securing as required.
4. The controller must remotely checkout, control, maneuver, and secure the teleoperator slave.

#### FLIGHT CONFIGURATION CONCEPT

To meet the identified requirements an advanced teleoperator is required. Teleoperators of today can be built and flown but their capabilities will be limited. The remote handling technologies have been advanced to meet the "hot cell" requirements but are still considered first generation and will require advancement to meet the outer space requirements. To truly transmit man's sense of presence and instinctive control to a remote teleoperator, advancement in manipulators/controls, sensors, and display is necessary.

The present remote nuclear teleoperator concept (Figure 1) consists of a system of integral or separable space vehicles that are capable of performing the required flight preparation and maintenance tasks on the NERVA engine (Figure 2) while in earth orbit. The teleoperator is a closed-loop system with man in control at all times for surveillance and decision-making.

The concept consists of a teleoperator controller (TOC) system, a teleoperator slave (TOS) effector and, as required, a support system.

The TOC contains human operators and all subsystems necessary to control the functions of the TOS in the performance of space tasks (Figure 3). It receives data from, and transmits commands to, the TOS. The TOC is always manned but may or may not be located in space.

The subsystems consisting of actuator, sensors, control and communications appear to require the most technical advancement. Propulsion, environmental control, computers and power systems have had significant advancement in the manned space flight program.

The need is for an advanced teleoperator, and with development in the mentioned subsystems, a totally remote space teleoperator can be made available. Such things as three-dimensional television, force amplification, logarithmic force feedback, tactile sensors, light-weight, powerful actuators, and high-density communication systems, are some of the advancements which will enable a teleoperator to perform tasks which would require a man in an EVA mode plus many others.

To develop a space teleoperator, ANSC has formulated a program plan identifying the areas of advancement required and a logical approach to developing the system.

#### GROUND TEST CONCEPT

The time requirements for a remote nuclear teleoperator are such that a qualified space teleoperator will be required by about 1980. A development and qualification plan has identified a detailed sub-plan to advance teleoperator technologies to meet the remote nuclear teleoperator concept.

The plan identifies development of teleoperator subsystems (i.e., manipulators, controls, and sensors) utilizing a ground test configuration vehicle (Figure 4). This vehicle will be a test bed for the advancement of teleoperator technologies.

This vehicle will also be used as test support equipment (TSE) for the NERVA engine program, thus providing program-required support hardware. Conceptually, this system would consist of a prototype teleoperator slave with all space subsystems operable (except those of propulsion and environmental control, and the interface), a conveyor vehicle to provide support and maneuverability to the TOS, and the control console (representing the TOC) behind a barrier to simulate remote conditions.

#### CONCLUSIONS

The primary objective of the remote nuclear teleoperator study program was to define in detail a program plan which would provide a qualified operational space teleoperator system by about 1980.

The concept and philosophy presented provides a product considered to be an advanced teleoperator when compared to today's state-of-the-art. Previous studies have shown that an operational space teleoperator could be developed in two to three years, but such a teleoperator would contain today's technology and be considerably restricted in its capabilities.

The teleoperator concept was formulated to meet NERVA requirements. This concept is considered preliminary, permitting flexibility during the development period and the time at which the total integrated space program is being defined.

Considerable effort can be expended in the areas of subsystem development (e.g., actuators, sensors, communications, and controls) assuring a program of developed basic subsystems prior to final concept selection. The areas of propulsion, attitude control, and logistics can follow.

The following conclusions are made:

1. An advanced qualified remote nuclear teleoperator can be available by about 1980.
2. An integrated program for the development of a nuclear/space teleoperator is required to meet the commonality and cost-effective requirements of the integrated space plan.
3. To meet reliability and operational requirements of today's space vehicles, without EVA, a teleoperator is required to perform the planned space maintenance.
4. Teleoperator technology must be advanced to meet the requirements for a remotely operated nuclear/space teleoperator.
5. New inventions are not required, only an advancement of today's technology to develop a teleoperator to meet requirements of the nuclear/space teleoperator concept.
6. Utilization of existing facilities can meet teleoperator development and qualification requirements.
7. The design philosophy of a nuclear/space teleoperator must be one of self-repair and maintenance with modular construction.
8. Through the development of a nuclear/space teleoperator, technology can be utilized in development of planetary surface rover units and also "spinoff" applications to industrial robots for remote, hazardous operations on earth.

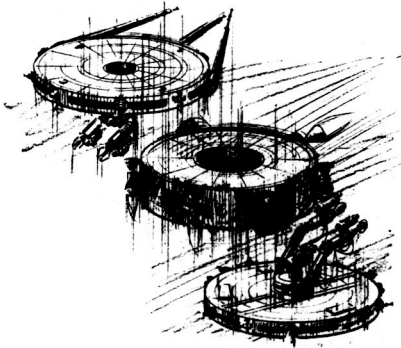


Figure 1 Teleoperator Vehicle Showing Manned Command Module With Two Unmanned Slave Units

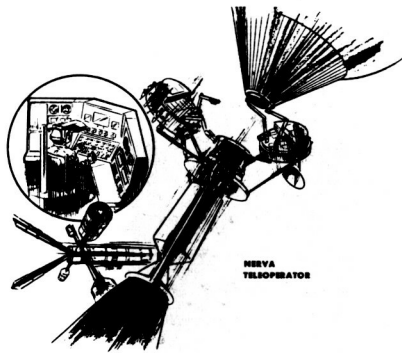


Figure 2

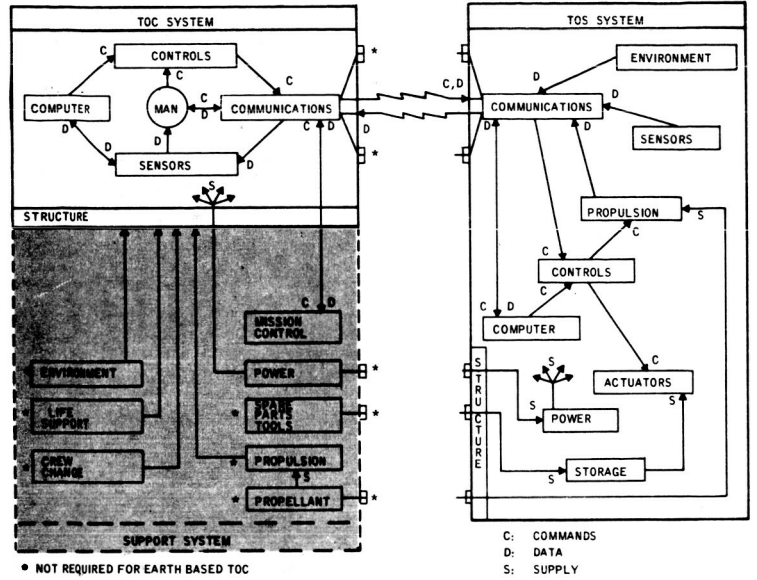


Figure 3 Teleoperator System Block Diagram Flight Configuration

GROUND TEST DEVELOPMENT VEHICLE

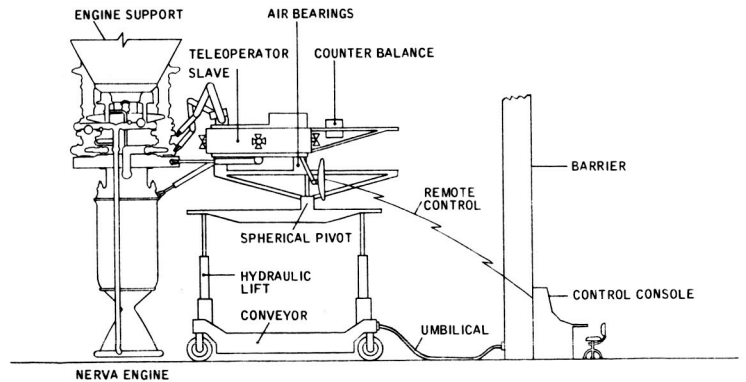


Figure 4 Ground Test Development Vehicle