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Capture of Uncontrolled Satellites: A Flight Demonstration

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ABSTRACT

NASA is presently exploring concepts, systems, and devices for capturing uncontrolled or non-operational satellites. Understanding of this type capture involves development of requirements and options, analyses of approaches, and extensive ground simulations. The verification of an approach is expected to require flight demonstrations of the concepts and hardware to assure confidence in application. This paper addresses a flight demonstration involving the Shuttle, an Orbital Maneuvering Vehicle (OMV), a capture mechanism, and a target vehicle capable of providing characteristic motion. A mission scenario is projected which demonstrates a capture concept, mission sequencing, capture vehicle potential, and overall capture possibilities with man-in-the-loop control. The proposed demonstration is considered a stepping stone to more demanding capture requirements. On-orbit activities are deliberately constrained to existing technology and projected systems and hardware capability for the year 1990.

INTRODUCTION

The need for capture and retrieval or disposal of uncontrolled satellites has been recognized for some time. Use of an OMV to recover a valuable satellite that has failed prematurely, for potential repair and re-use, or to retrieve one that has completed its design life and has ceased operation, could provide significant economic and scientific benefits. Removal and disposal of "junk" satellites, spent upper stages/motor casings, and other space debris to preserve operational integrity in space, is also of some concern.

It is expected that some satellites to be captured will exhibit simple motion characteristics, while others may have moderate to high rates of motion in multiple axes. Some examples are:

- Skylab, tumbling at 1/3 RPM.
- Application Technology Satellite, ATS-5, spinning at 80 RPM.
- Solar Max Mission Satellite, spinning at 1/6 RPM.
- Tracking and Data Relay Satellite, TDRS-1, tumbling at 30 RPM.

The recent failures of WESTAR-6 and PALAPA B-2 resulted in those satellites going into similar anomalous orbits and spinning at rates on the order of 50 RPM. The system described herein, if equipped with appropriate end effectors, should be capable of effecting capture and recovery of such satellites.

Equations of motion for tumbling, spinning, and wobbling satellites have been treated extensively in other works (examples are references 1 and 2). Various capture devices and concepts for accommodating complex motion have been hypothesized over the past several years (many are identified in references 3 and 4). Treatment of such theoretical considerations is beyond the scope of this paper. The present intent is to discuss a flight demonstration using hardware and systems that are presently scheduled for maturity in 1990. The specific purpose of this mission is to demonstrate that an operator at a ground control station can control the planned free-flying OMV to the extent of approaching a target simulating uncontrolled motion, perform fly-around maneuvers, match rates and dock with the target, and bring the target under control. Vehicle and system response will also be evaluated during mission activities.

On-going OMV related studies and development work by the Marshall Space Flight Center include a prime interest in capture of satellites having unplanned motion, and in developing more advanced capture systems as part of the planned OMV advanced mission capability. Some advanced systems being considered are shown in figure 7.

TARGET VEHICLE

The Shuttle Pallet Satellite (SPAS) is considered as a candidate target vehicle. The SPAS has on-board capability to perform the required activities, and can be controlled from the Shuttle. Figure 1 identifies the SPAS subsystems. Some SPAS modifications would be required including addition of a second RMS grapple fixture as shown, to accommodate OMV capture, and the addition of ballast to force the center of gravity to the geometric center of the SPAS. The GN_2 system provides 968 pound·seconds of total impulse which is adequate to provide the motion identified in figure 2 and discussed later. Physical characteristics and mass properties of the SPAS are:

Length	156 inches
Width	27.5 inches
Height	27.5 inches
Mass	2645 pounds
I_x	925 slug.ft^2
I_y	194 slug.ft^2
I_z	986 slug.ft^2

CAPTURE VEHICLE

The Orbital Maneuvering Vehicle (OMV) is presently being defined for development by NASA, with operational status planned for 1990. Figure 3 depicts a representative OMV configuration. The OMV is a remotely controlled, free-flying vehicle capable of performing a wide range of on-orbit services including routine payload placement and retrieval, payload reboost and deboost, and payload sering. The initial OMV, equipped with an extendable docking mechanism with an RMS end effector, has the capability to do the rate matching and capture activities identified herein.

Propellant off-loading may be desirable, depending on whether this demonstration is the only on-orbit activity planned for the OMV. One thousand pounds of propellant is sufficient for the defined activities, and will provide a large margin for any contingency situations. The OMV main propulsion system will be used for approach and fly-around activities, while the RCS alone will provide maneuvering and rate matching for actual target vehicle capture. Figures 4 and 5 reflect OMV capabilities and impulse requirements to do circumnavigation of a target.

DOCKING/CAPTURE MECHANISMS

A docking mechanism concept for the proposed demonstration is shown in figure 6. The docking probe is partially recessed whenever the OMV is in the cargo bay. After deployment of the OMV, the probe is extended to provide an end effector reach of approximately 48 inches. This length is required to preclude interference between the OMV and the SPAS sill trunion. Some potential advanced capture systems for unusual conditions are shown in figure 7.

OMV/SPAS PROXIMITY OPERATIONS

The OMV controlled flight will be done in three phases: (1) OMV approach and fly-around the SPAS; (2) OMV position and capture the SPAS with simple spin; and, (3) OMV position and capture SPAS with complex motion. During phases 1 and 2 the SPAS will be spinning at 2-5°/second around the Y-axis. For phase 3 activities, the same spin will be induced plus coning (wobble) as shown in figure 2. In all phases the SPAS attitude control system will be de-activated to avoid coupling of the two control systems. Fly-around of the target will be done in the Z-plane at 30 feet from the target. The operator at the ground control station will match rates and make observations prior to positioning the OMV for phase 2 capture. Two circumnavigations should be adequate, however, at this point some liberty should be given the operator, since the OMV must translate from the circumnavigation position to a position for capture at the aft end of the target.

After the initial capture has been effected and the SPAS stabilized (despun), the OMV will release the SPAS and move to a position 100 feet away. At this time the SPAS control system will be re-activated and the appropriate commands given from the Orbiter to induce the spin and coning as shown in figure 2. A 16° cone angle will cause the docking grapple fixture to describe a circle of approximately 48 inches in diameter. This motion, coupled with a 2-5°/second spin, is considered adequate for the demonstration and is within the system and operator capability. After the SPAS has been brought under control, the total system will be powered down in preparation for recovery by the Orbiter.

MISSION SEQUENCE

Figure 8 shows the relative position of the three vehicles involved in the demonstration. Generally, the Orbiter deploys the SPAS then moves away to a safe distance; then the Orbiter deploys the OMV and again moves away to a safe distance; finally the OMV approaches the SPAS and the Orbiter moves into position for observation. Figure 9 is a simplified block diagram of the demonstration events. The entire flight demonstration, including OMV and SPAS deployment and checkout, can be done in three daylight periods, assuming ETR launch. Proximity operations will be curtailed during eclipse periods.

Since the on-orbit activities are pioneer in nature, some allowances should be made in the time block for unexpected occurrences such as mid-docks requiring second attempts, and for operator orientation. It must be recognized that the operator is doing real-time control of the OMV using hand controllers, and depending on video display and range/range rate data feedback for maneuver/docking information. Close proximity operations will be curtailed during eclipse periods.

COMMUNICATIONS

Communication links for on-orbit activities are shown pictorially in figure 10. Communications with the SPAS will be from the Orbiter only over the S-bank link. Communications with the OMV will be via the TDRSS Ground Station, K-band to the TDRS, then S-band to the OMV. The link between the OMV Ground Control Station and the TDRSS Ground Station is not defined, but may be either over land lines, or via some relay satellite such as DOMSAT.

CONCLUSIONS

The flight demonstration discussed is considered feasible in terms of existing technology, projected hardware availability, and programmatic considerations. The pacing item is the OMV which, based on present planning will be available in 1990. This on-orbit activity presupposes operational status for the OMV, and assumes that it has already demonstrated capability to capture a stable satellite. Extensive simulation work involving high fidelity systems is essential to this and follow-on work in this challenging and rewarding area of work.

REFERENCES

1. Ball Brothers Research Corporation, Experiments for Satellite and Material Recovery from Orbit, Final Report to NASA Contract NAS8-18119, March 1967.

2. Arun A. Nadkarni, Teleoperator Control for Passivation of Satellites Possessing Angular Momentum, Pennsylvania State University, published as Astronautics Research Report Number 75-2, April 1975.

3. G. C. Faile, D. N. Counter and E. J. Bourgeois, Dynamic Passivation of a Spinning and Tumbling Satellite Using Free-Flying Teleoperators, Internal Report, Marshall Space Flight Center, September 1972.

4. James M. Patterson, Investigation of Satellite Retrieval Concepts, Internal Report Number ASR-PD-SA-71-3, Marshall Space Flight Center, September 1971.

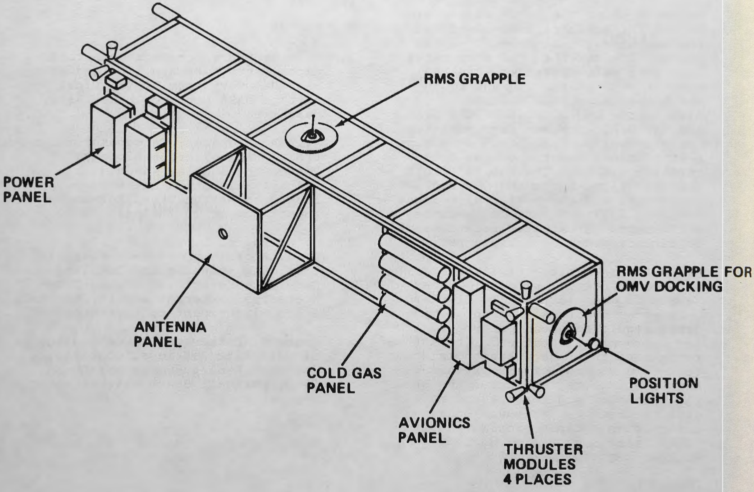

FIGURE 1. TARGET VEHICLE (SPAS)

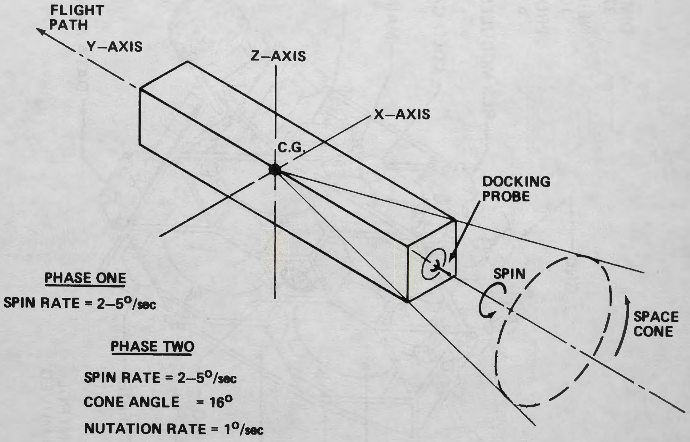

FIGURE 2. TARGET VEHICLE MOTION

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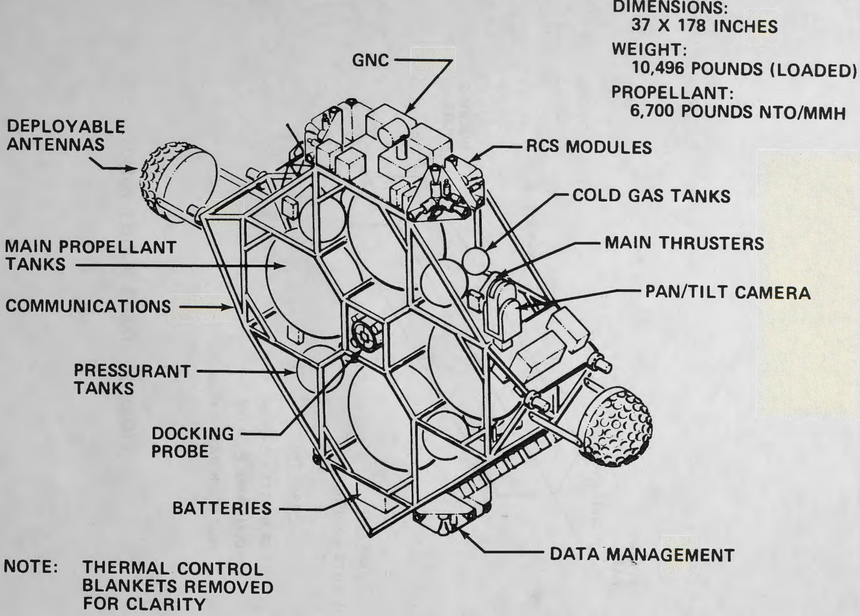

FIGURE 3. CAPTURE VEHICLE (OMV)

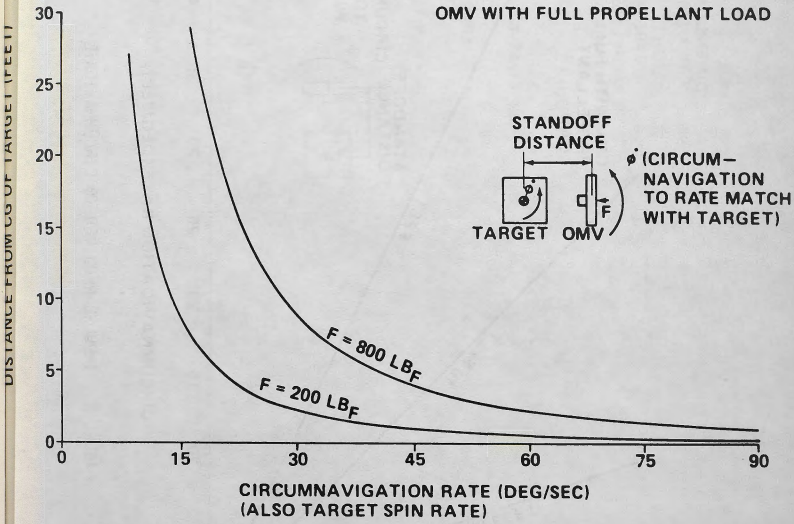

FIGURE 4. OMV CIRCUMNAVIGATION CAPABILITY

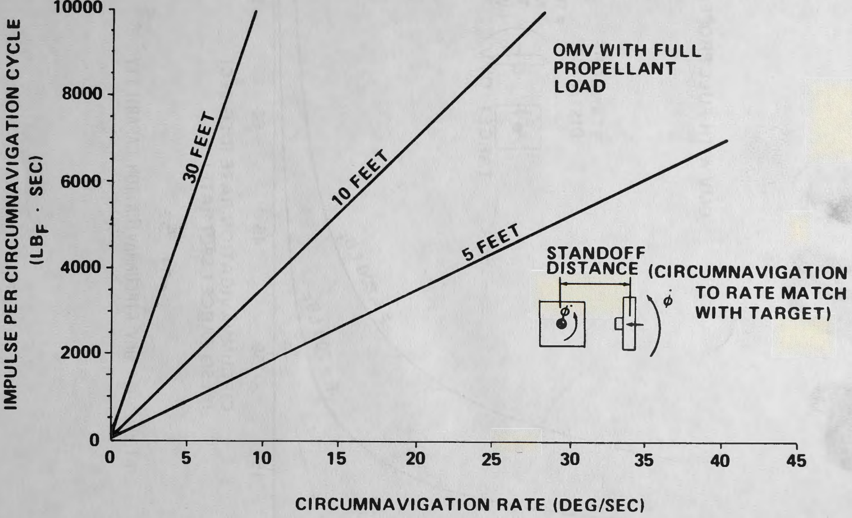

FIGURE 5. IMPULSE REQUIRED TO CIRCUMNAVIGATE

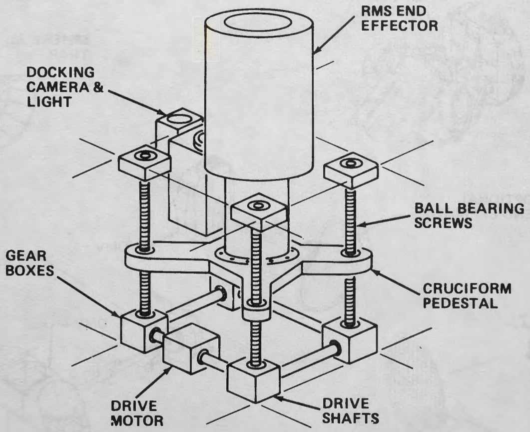

FIGURE 6. DOCKING MECHANISM

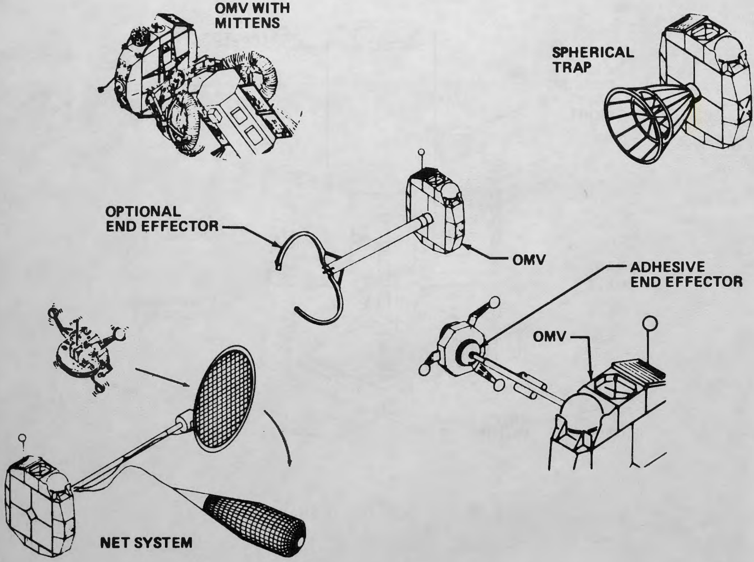

FIGURE 7. POTENTIAL FUTURE CAPTURE SYSTEMS

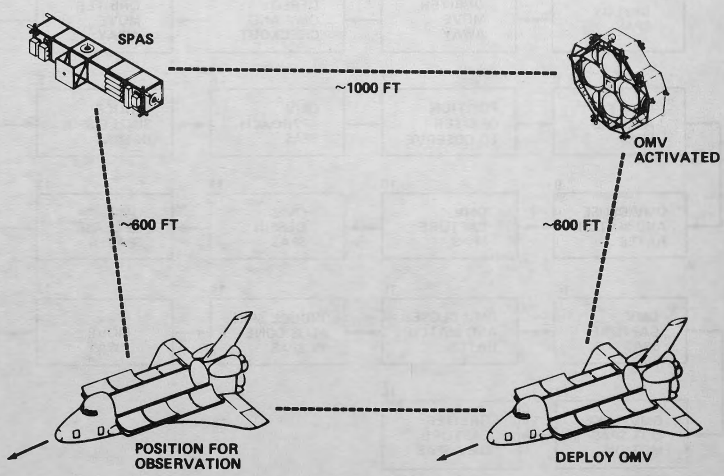

FIGURE 8. RELATIVE POSITION OF VEHICLES

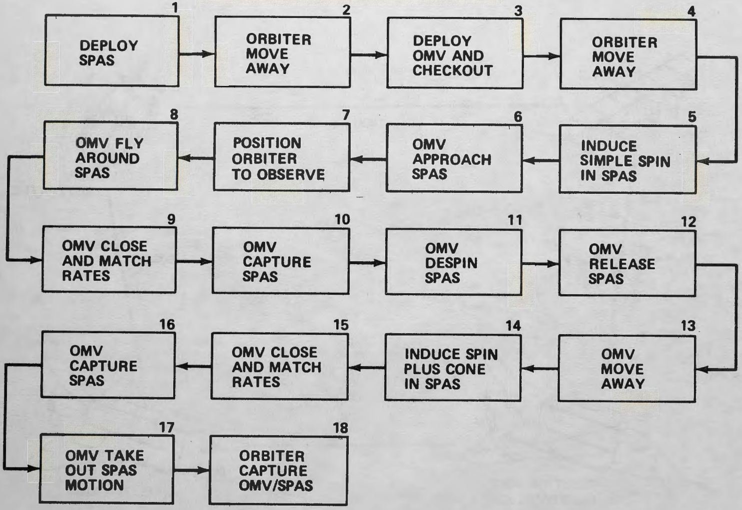

FIGURE 9. MISSION SEQUENCE

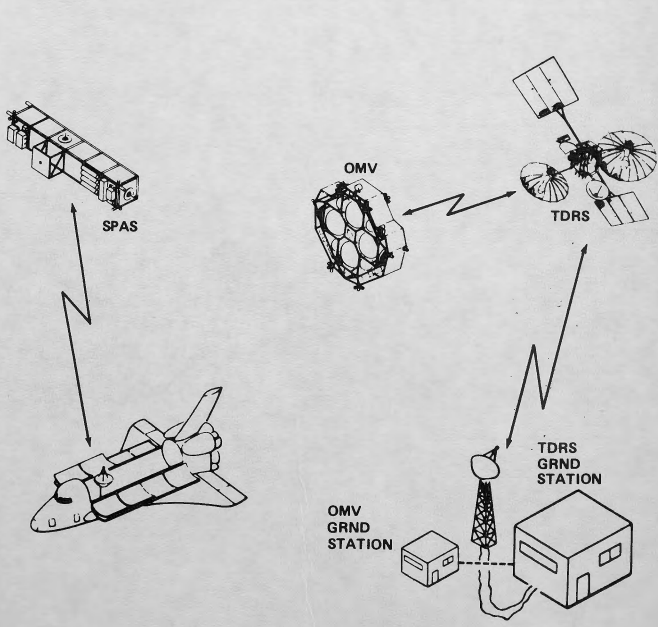

FIGURE 10. COMMUNICATIONS