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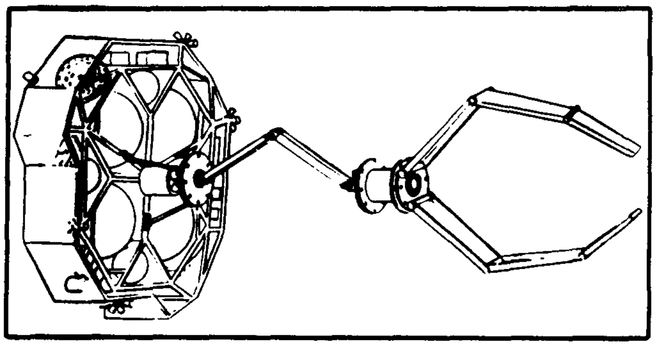
Final
Technical
Report

June 1986

Supporting Research and
Technology Report

Concept Definition Study for Recovery of Tumbling Satellites



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CONCEPT DEFINITION STUDY FOR RECOVERY OF TUMBLING SATELLITES

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FOREWORD

This document was prepared by Martin Marietta Corporation under contract NAS8-36609, Concept Definition Study for Recovery of Tumbling Satellites, Data Procurement Document 654 to fulfill the requirements of Data Requirement 6, Volume 1, Final Study Report, and Data Requirement 7, Volume II, Supporting Research and Technology Report. This effort was accomplished for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration under the technical direction of Mr. Herbert Lenox and Mr. Stephen B. Hall, as Contract Technical Managers.

CONTENTS

1.0 SUPPORTING RESEARCH AND TECHNOLOGY REPORT

1.1 Introduction

The Supporting Research and Technology (SR&T) Report for the Tumbling Satellite Recovery (TSR) conceptual definition study is presented in the Data Requirements Description format provided in Data Procurement Document (DPD)-654. The SR&T report was prepared as a subtask of Task 2, Concept Definition, to take advantage of the close association between the conceptual design effort in this task and the constant need to assess the technology status of any new systems or components under consideration during conceptual design.

The MMDA study team did not identify any problem areas requiring new state-of-the-art technology development initiatives. They did identify a number of areas where research and laboratory experiments could support resolution of technology issues that could lead to development of a cost efficient remote, disabled satellite recovery system.

The SR&T report includes title, status information, justification, technical plan, resource requirements data and target schedule, wherein it was feasible in regard to the low level of effort directed for this task by the Contract Technical Monitor.

1.2 Planning Estimates of Disabled Satellite Motion

A) Title - Planning Estimates of Disabled Satellite Motion.

B) Status - Present capability unknown. Equipment and trained personnel are available to generate estimate of capability.

C) Justification - The MMC conceptual definition of a TSR kit includes a modular system, composed of a number of subsystem mechanisms that can be readily integrated into varying combinations. This will enable the user to quickly configure a tailored remote, disabled satellite recovery kit to meet a broad spectrum of potential scenarios. Mission planners will require satellite orientation and motion data on each remote, disabled satellite to determine what mix of equipment is required for each specific mission.

D) Technical Plan

1) Objectives - Determine the capability of U.S. earth-based satellite tracking facilities to adequately determine the orientation and motion rates of disabled satellites.

2) Technical Approach - Request that a supporting study be conducted for NASA by the U.S. Space Command to meet the stated objective.

E) Resource Requirements

1) Manpower - Manpower estimate is one man year for FY 87, one man year for FY 88.

2) Specialized Facilities - Facilities exist. Satellite tracking data can be obtained by Haystack Radar at Westford, MA; laboratory and computer facilities are available at Lincoln Laboratory in Lexington, MA.

3) Funding - Funding requirements equate to two manyears of civil service engineering level direct labor, estimated at $200,000.

F) Target Schedule - The required analysis is schedule constrained, based on personnel availability. The estimated duration of the study effort is two years.

1.3 Deployment Dynamics of Capture Device

A) Title - Deployment Dynamics of Capture Device

B) Status - These analyses have not been conducted previously. The technical understanding of the analytical processes required to conduct the study and develop the software is high.

C) Justification - The deployment of a lengthy, cantilevered extendible boom and envelopment grapple mechanism that changes its shape, and the spin-up of this system will produce momentum effects and structural modes that must be determined to evaluate the potential impact on OMV attitude control capacity.

D) Technical Plan

1) Objectives - The objective of this study effort is to model the momentum effects and structural modes of a TSR kit mated to an OMV transfer vehicle and to evaluate the capacity of OMV to control this recovery system during deployment, configuration changes, and spin-up.

2) Technical Approach - Develop a set of offline (non-real-time) software simulation programs to model (1) the momentum effects of boom deployment, grapple mechanism deployment and spin-up of systems to 5-50 rpm, (2) the structural modes of this inherently flexible recovery system, and (3) the resultant impact of both on OMV control capability.

E) Resource Requirements

1) Manpower - Manpower estimate is twelve man months.

2) Specialized Facilities - Computer facilities exist at MSFC and MMC, programs can be written in transportable manner.

3) Funding - Funding requirements are twelve man months of direct engineering labor estimated at $100,000 and $10,000 in computer costs.

F) Target Schedule - The required analysis is schedule constrained, based on availability of personnel and funding. The estimated duration of the study effort is six months.

1.4 Contact Dynamics Between Recovery System and Target

A) Title - Contact Dynamics Between Recovery System and Target

B) Status - Tests are required to determine forces, torques and resultant position changes of target and recovery devices caused by contact between target and recovery systems during recovery operations. These tests have not been conducted previously. The general understanding of the analytical processes required to conduct this activity is fair.

C) Justification - The complex interactions between a spinning object and a device attempting to match spin rate and phase angle with the spinning object after the initial contact has been made have not been examined. The resultant forces and motions may be significant enough to impact the conceptual design of the eventual recovery system.

D) Technical Plan

1) Objective - The overall objective is to model the forces and torques and resultant positional changes induced by contact dynamics created by required contact with a target prior to rigidization of target/recovery system. These models will support: determination of potential target damage assessment; forces imposed/structural requirements on recovery system; determination of type of recovery grapple mechanism (gripper vs enveloper); and assessment of OMV attitude control system adequacy for this phase of the recovery mission.

2) Technical Approach - The initial modeling phase would include development of software simulation packages to model all contact dynamics forces and torques between a spinning target and a spin rate matching recovery system. This effort will provide valuable approximations of the scale of forces and torques created by contact during recovery operations and of resultant relative motion.

A follow-on activity would include development of hardware equipment capable of physically performing a recovery activity with spinning target and recovery device. This task would require building a scaled, composite of the future recovery target mission model. A mockup of a representative recovery system would also be built with load sensors on the grapple mechanism. The hardware load cell array would be integrated into the realtime software simulation to enable measurement of contact torques and forces. OMV/TSR and target states would then be generated in real time and with this data, estimates of new relative positions could be generated.

The hardware demonstration unit will refine the estimates of potential target damage, structural requirements of the recovery system and potential impacts on OMV attitude control requirements for this mission.

The results produced from these tests will provide clarity to questions related to the potential need for zero-gravity tests related to recovery system contact dynamics.

Phase 1 - Software Simulations

E) Resource Requirements

1) Manpower - Manpower estimate is 18 man months.

2) Specialized Facilities - Computer facilities exist at MSFC and at MMC, programs can be written in transportable manner.

3) Funding - Funding estimate is for 18 man months of direct engineering labor at $150,000 and $20,000 in computer costs.

F) Target Schedule - The required analysis is schedule constrained, based on availability of personnel and funding. Estimated duration of the study effort is 12 months.

Phase 2 - Hardware Simulations

E) Resource Requirements

1) Manpower - Manpower estimate is 3.5 man years to design and build hardware and software, and integrate and test the simulation system.

2) Specialized Facilities - Facilities exist both at MSFC and at MMC.

3) Funding - Funding estimate is 3.5 man years of direct engineering labor at $350,000 and $150,000 in equipment, material, and computer costs.

F) Target Schedule - This hardware and software development is schedule constrained, and should be accomplished after Phase 1 has been completed. The activity would be accomplished during a 15-month period.

1.5 Operator Control Capability Assessments

A) Title - Operator Control Capability Assessments

B) Status - These types of tests have been conducted on a very limited scale. Tests are required to determine the satellite recovery operator control capability required to conduct disabled satellite operations and to identify needed supporting hardware. Simulation facilities exist and have been operational for over one year.

C) Justification - Previously conducted tests on related OMV and Manned Maneuvering Unit (MMU) tests have indicated that operator workload on much simpler tasks is very high, due to communications delay in on-orbit teleoperations and difficulty in performing operations requiring precision alignment of mechanisms when translation and rotation actions are going on simultaneously. Satellite recovery operations include translation to the target, spin axis alignment, spin rate matching and grapple closure, performed in the environment of contact dynamics inherent in conducting a rigid grapple of a spinning satellite.

D) Technical Plan

1) Objective - The objective of this task is to assess the capabilities/ limitations of operators conducting teleoperated satellite recovery operations. The tests will include evaluation of the operations capability to identify the position of the target spacecraft's spin axis, the ability to align the TSR kit axis with the target spin axis, the ability to match spin rate and to synchronize or phase the position of the recovery system grapple mechanism with the spinning target. A related objective is to evaluate mission complexity to determine whether the OMV and TSR kit operation will require one or more operators. In addition, this analysis effort will provide insight on the type of sensors needed, the types of displays required, coordinate transformations needed to provide optimum target views, methods of compensating for time delays, and will support development of an overall operations philosophy.

2) Technical Approach - The initial phases of this test will be conducted with computer graphic simulations. The computer operator controls and displays for both the OMV and the TSR kit will be optimally collocated. A high fidelity model of a composite target, from the TSR mission model assessment, will be produced. The computer simulation will include solid models with collision detection software to enable modeling of contacts. A high fidelity model of the recovery systems will be built into the simulation software.

A series of recovery scenarios will be conducted using varying target model tumble orientations and rates. The target center of mass will be varied to challenge the operator(s) ability to determine the position of the spin axis. Recovery scenario initial conditions will be varied to provide alternative approach trajectories to challenge spin axis position identification and spin axis alignment by the operator during transit. Variations in target tumble/spin orientation and spin rates will support determination of operator limitations in dealing with multi-axis spin, appendage avoidance, and high spin rates.

A second phase of TSR operator control capability assessment will involve development of a hardware model to conduct similar tests. The hardware model recommended in Paragraph 1.4 of this volume will be designed to accommodate this category of testing.

One of the benefits to be derived from hardware simulation, over software simulation, is that the operator receives a more realistic view of what will be present in an actual recovery mission. In addition, observers can be placed in different positions to oversee the operation, and they would have an improved, realistic view of the test and exercises. Finally, with the use of load cell arrays, the test team can measure forces, view (and calculate and display for the operator) actual relative displacements and more accurately respond to the reactions created by the contacts between target and recovery system.

In this two-phase test series, a number of recovery system operations assessments will also be conducted. The experiment will be designed to enable assessment of mission operations timelines, of propellant usage rates and despin/stabilization rates and time required to complete the various operations. The potential for plume impingement on the target exists and thus will be modeled and evaluated. Another operations related recovery issue pertains to grapple mechanism positioning error. The existence of various levels of OMV deadband (accuracy within

OMV operator roll, pitch and yaw capabilities) can be modeled and introduced in both the computer graphic and hardware simulation assessment tests. These simulation setups can be later expanded and used for continuing concept evaluation and eventually for operator training.

Phase 1 - Software Simulations

E) Resource Requirements

1) Manpower - Manpower estimate is 12 man months if done at MMC with existing hardware and software.

2) Specialized Facilities - Facilities exist.

3) Funding - Funding estimate is 12 man months of direct engineering labor at $100,000 and $10,000 in computer costs.

F) Target Schedule - The required analysis is schedule constrained. Estimated duration of the analysis is 8 months.

Phase 2 - Hardware Simulations

E) Resource Requirements

1) Manpower - Manpower estimate is 12 man months.

2) Specialized Facilities - Facilities exist at MSFC and MMC. Hardware and software developed in recommended Task 1.4 would be used for this analysis.

3) Funding - Funding is estimated at 12 man months of direct engineering labor, at $100,000 and $10,000 in computer costs.

F) Target Schedule - The required analysis is schedule constrained. It would be initiated following completion of hardware/software simulation system developed in Task 1.4, and would be completed in eight months.