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Space Tug Docking Study

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SPACE TUG DOCKING STUDY

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FOREWORD

This study was performed under Contract NAS8-31542 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration under the direction of Mr. James I. Newcomb and Mr. Paul T. Craighead, the Contracting Officer's Representatives. The final report consists of five volumes:

Volume I - Executive Summary
Volume II - Study of Results
Volume III - Procedures and Plans
Volume IV - Supporting Analyses
Volume V - Cost Analysis

The study results were developed during the period from June 1975 to January 1976. Principal Martin Marietta contributors to the study were:

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R. Zermuehlen	Subsystem Requirements
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W. Koppl	Ranging Sensors
C. Park	Docking Dynamics Analysis
B. Dickman	Docking Simulation Program
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B. King	Task C Leader, Simulation Demonstration Test Program Definition
E. Cody	Task D Leader, Programmatics Definition

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ACS	Attitude Control System
ASTP	Apollo Soyuz Test Project
Ang.	Angular
c.g.	Center of Gravity
CO_2	Carbon Dioxide
deg.	degrees
DOF	Degrees of Freedom
FFTO	Free Flying Teleoperator
FMEA	Failure Modes and Effects Analysis
fps	feet per second
ft	feet
GaAs	Gallium Assenide
GDC	General Dynamics Corporation
HRS	Hours
IGS	Inertial Guidance System
JSC	Johnson Space Center
IMPRES	Martin Marietta Developed Dynamics Program
IOC	Initial Operating Capability
IOSS	Integrated Orbital Servicing Study
ITT	International Telephone and Telegraph
LED	Light Emitting Drode
LOS	Line-of-Sight
MDAC	McDonnell Douglas Astronautics Company
MSFC	Marshall Space Flight Center
MM	Man Months
MMC	Martin Marietta Corporation
MMSE	Multiuse Mission Support Equipment
mph	miles per hour
n.mi.	nautical miles
PCM	Pulse Code Modulation
R&D	Rendezvous and Docking
RDS	Rendezvous and Docking System
RF	Radio Frequency
RFP	Request for Proposal
RH	Relative Humidity

ACRONYMS/ABBREVIATIONS (Cont'd)

S/C or SC	Spacecraft
SLR	Scanning Lasar Radar
SRT	Supporting Research and Technology
STDN	Space Tracking Data Network
STEM	Storable Extendible Member
STDS	Space Tug Docking Study
S/W	Software
TBD	To Be Determined
TDRSS	Tracking Data Relay Satellite System
TMS	Target Motion Simulator
TV	Television

I. SCOPE

This volume is a compilation of the plans and procedures developed under the Space Tug Docking Study (STDS). Each plan or procedure is a stand alone document having a table of contents so that it can be removed from this volume as usage dictates.

VOLUME III - PROCEDURES AND PLANS

Part II - SUPPORTING RESEARCH AND TECHNOLOGY PLAN

RENDEZVOUS AND DOCKING SYSTEM

SRT PLAN

Part II - SUPPORTING RESEARCH AND TECHNOLOGY PLAN

A. INTRODUCTION

We have defined a $4.345 million program of Supporting Research and Technology (SRT) designed to minimize risk and maximize confidence in developing a rendezvous and docking system that meets the performance, cost and schedule goals established during this study contract. Since remote rendezvous and docking has not been demonstrated in either a manual or autonomous mode by the U.S.A., considerable SRT is required to establish this technology base. The Space Tug Docking Study (STDS) has had as a goal the identification of SRT activities to establish a national capability for rendezvous and docking. The SRT activities are not separated into autonomous and manual technology support, but address all candidate activities required to maintain parallel paths open. These activities bring candidate subsystems to the level of development necessary for simulation/demonstration testing. The SRT activities identified as a result of the study are summarized in Table II-1 and a schedule of the SRT efforts is presented in Figure II-1. The schedule supports and is compatible with the simulation/demonstration test schedules presented in Volume II, Section IVD of this report.

TABLE II-1. RDS SRT Summary

Task No.	Task Title	Required for Candidate M	H	A	Est. Cost ($K)	Schedule (Months)
	<u>SENSORS</u>					
S-1	Autonomous Docking Sensors (SLR/RF)		X	X	2,100	15
S-2	Onboard Image Data Processing for Autonomous Control		X	X	350	15
S-3	Spacecraft Mounted Docking Aids	X	X	X	150	9
S-4	Non-Impact Docking Sensor Development	X	X	X	100	12
	<u>ALGORITHMS (Strategies)</u>					
A-1	Software for LOS, Range and Target Attitude used as Control	X	X	X	210	12
A-2	Rendezvous Phase Maneuver Strategy	X	X	X	225	15
A-3	Inspection Phase Maneuver Strategy		X	X	90	8
A-4	Closure Phase Maneuver Strategy		X	X	165	12
A-5	Docking Dynamics & Control Strategy	X	X	X	75	8
A-6	Commit-to-Dock or Abort Decision Algorithm Development			X	280	12
A-7	Image Data Management & Compression Techniques	X	X		225	15
	<u>MECHANISMS</u>					
M-1	Non-Impact Docking Hardware	X	X	X	150	12
M-2	Impact Docking Hardware	X	X	X	125	15
M-3	Capture Hardware for Non-Cooperative & Spinning Spacecraft	X	X		100	9

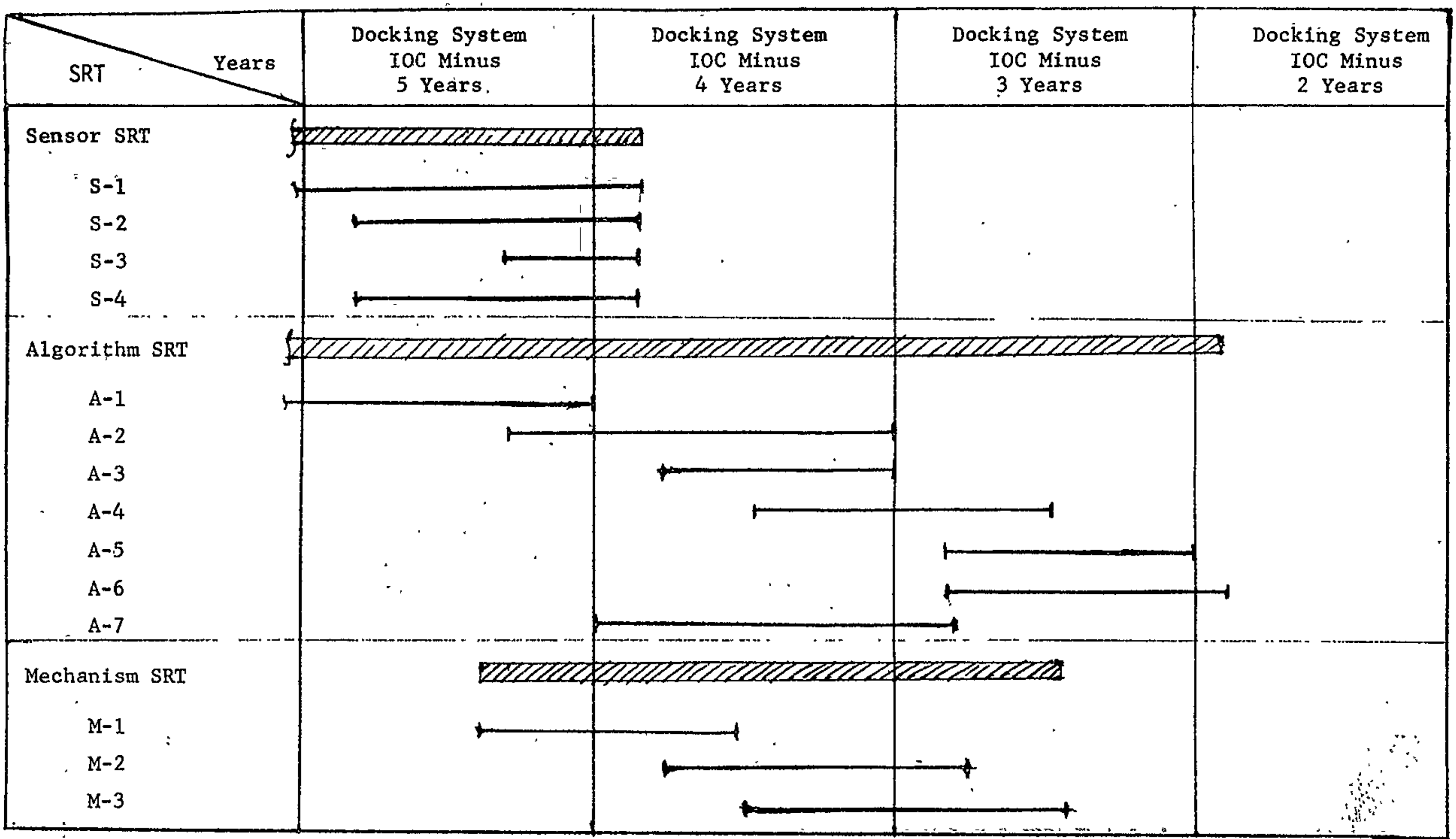

FIGURE II-1. Rendezvous & Docking System SRT Schedules Support Simulation/Demonstration Tests

D. Subsystem SRT Data Sheets

1.0 SENSOR SRT

New sensor technology or new applications of existing technology will be required to perform autonomous rendezvous and docking functions. The candidate systems which exhibit the most merit from the current STDS effort include a Scanning Laser Radar (SLR) and a Radio Frequency (RF) Radar as sensors. The SLR represents new technology, while the RF radar has been used for the rendezvous phase during Apollo. The SLR has undergone considerable research and development work, but still represents new and untried technology. The application of the existing rendezvous radar technology to the docking range of operations also presents significant technology challenges. This study derived requirements which should be placed on the docking sensors. The sensor hardware SRT recommended before incorporation of the sensor into a system for simulation/demonstration testing is described in the following data sheets.

Subsystem: Sensors SRT No.: S-1

Task Title: Autonomous Docking Sensor Development (SLR and RF Radar)

Statement of Problem: The Scanning Laser Radar (SLR) has been developed and development is continuing by ITT Gilfillan, San Frenando, California, under contracts with NASA/MSFC, Huntsville, Alabama. Its specific purpose is for rendezvous, stationkeeping, and docking in the Space Shuttle Program, and it is applicable also to the Space Tug. The SLR is designed to operate with a pulsing Gallium-Arsenide (GaAs) Laser of a wavelength of approximately 0.9 micron wavelength and CO_2 lasers at 10.6 microns wavelength, are also under development. However, the sensor design and circuitry do not represent current state-of-the-art. Further, SLR sensors have not been subjected to the rigors of space environments. Since the application being considered flys in the 1985 time frame, the updating of the sensor to take advantage of technology advances is recommended.

The RF rendezvous radar for the Shuttle Orbiter is being updated to current technology under an RFP to be issued soon. The requirements are for rendezvous in the 100 feet to 12 miles range, which closely match the rendezvous requirements derived in the current study.

The option for parallel development of two sensors for this function appears to be economically feasible and technically sould since some of the development costs are already funded and, in some cases, complete. However, docking ranges need further analyses.

Objective: The objective of this task is to update the development of SLR and RF radar sensors for both rendezvous and docking applications to represent current circuitry technology before entering the simulation/demonstration test program. An additional objective is to bring each sensor to an approximately equal development state.

Approach: Updated sensor designs for the newly derived requirements for ranges and accuracies will be fabricated and demonstrated in bench tests.

Since SLR sensors have never been subjected to flightenvironments, some design analyses will be done to examine environmental tolerances and to identify areas where unusual protection from an anticipated environment (e.g., vibration) is required.

SRT No. S-1 (Continued)

Estimated Costs: Two manyears of engineering plus $1M for SLR and $1.5 for close-in RF sensor technology updates.

Subsystem; Sensors SRT No.: S-2

Task Title: Onboard Image Data Processing for Autonomous Control

Statement of Problem: A TV camera is baselined for inspection purposes during early flights of the rendezvous and docking system. For the manual system the TV image is used for control of the vehicle, but a loss of downlink RV data could preclude accomplishing the docking objectives. Also, for an autonomous system having a TV onboard, the capability for automated usage of the image data for control would provide functional redundancy to the primary sensor providing control.

Preliminary work on this concept has been done in Martin Marietta remote manned simulation facilities and several methods appear feasible. The accurate computation of range, line-of-sight angle and target attitude require recticles on the sensor or aids on the target and processing software.

A miniprocesser capability shall be developed as part of the sensor electronics. This will provide the same parameter variations as the other sensors at the interface with the active vehicle control system.

Objective: The objective of this task is to develop and evaluate sensor mounted aids, target mounted aids and techniques for determining range, LOS angle, target attitude and their rates using image data and associated algorithms.

Approach: Several techniques are currently under investigation at Martin Marietta. One promising method involves concentric circle recticles on the sensor and a circular pattern on the target for range determination. Also, the eccentricity of the observed ellipse is a measure of target attitude. Another method involves a software algorithm for finding the center of an observed spacecraft (target) image, which allows determination of LOS angles.

However, these techniques are conceptual and need evaluation to determine how accurate measurements can be made and over what ranges the techniques are effective. Other concepts exist which have even less development work done and should also be examined.

Estimated Costs: Four manyears of engineering effort, $150K for materials, computer and facility costs.

Subsystem; Sensors SRT No.: S-3

Task Title: Spacecraft Mounted Docking Aid Development

Statement of Problem: A number of passive cooperative target aids have been proposed for the rendezvous and docking system. These aids differ depending on the kind of sensor used on the active vehicle. For an SLR, corner cube reflectors are proposed in a "T" arrangement to permit target attitude and roll reference determination. For an RF radar the retroflectors have variable delays built in for location identification. The aids must provide a reflected signal for the autonomous sensor to lock on and control the vehicle. The aids for a TV sensor take on an entirely different form. The functions aids must perform, including location of the docking port and enhancement of measurement accuracy.

Objectives: This task is to evaluate various target identification and sensor enhancement aids. Selecting optimum designs for each sensor before entering a simulation/demonstration program can be cost effective.

Approach: Parametric analysis and bench tests of candidate target aids with arious arrangements will be performed. Lighting effects will be evaluated for TV sensors.

Estimated Costs: Eighteen manmonths of effort (engineer and technician) and $50K for materials over a nine-month activity is estimated.

Subsystem: Sensors SRT No.: S-4

Task Title: Non-Impact Docking Sensor Development

Statement of Problem: Several non-impact docking schemes have been proposed. One concept includes extendable steerable probe or stem with a Light Emitting Diode (LED) sensor mounted on the end of the device. This stem is retractable to draw the vehicles together for hard latch if required. Another concept include the servicer approach identified in Martin Marietta's Integrated Orbital Servicing Study (IOSS) in which a manipulator arm could be used to grasp and draw the vehicles together for latching. For an autonomous non-impact docking this sensor and the associated electronics represents a major new technology effort. Even for a manual or hybrid system the capability for manually steering the stem or manipulator arm may require additional sensors in addition to the TV baselined.

Objective: The objective of this activity is to examine the sensor candidates and requirements for this system, and to select and evaluate sensor candidates for simulation/demonstration testing and further development.

Approach: The candidate sensors will be examined in the light of non-impact requirements, mechanism compatibility and stationkeeping capability of the active vehicle. Candidate sensors will be purchased and subjected to bench tests to verify feasibility and assure readiness to support simulation/demonstration test activities.

Estimated Costs: Two manyears of engineering effort is proposed for this activity with $50K materials costs.

2.0 ALGORITHM (STRATEGY) SRT

Docking with a cooperative passive satellite using an unmanned spacecraft requires the conversion of a variety of sensor data into appropriate vehicle responses. The sensitivities to errors in these responses will be extreme. Sophisticated logic will be required to interpret radar, optical and contact sensor data in terms of the complicated and highly dynamic nature of the two-vehicle relative geometry. The definition of the functional requirements of this on-board logic will require extensive simulation and analysis. The technologies required include rigid body dynamics (6 DOF), classical and dynamic filtering, modeling of hardware functions, pattern recognition, discrimination and/or enhancement, and optimal control theory. Experience in the application of these disciplines to the unmanned docking problem is limited and driving technology issues may not yet be thoroughly identified.

However, a number of technology issues have been defined as a result of this study which require sophisticated algorithms be developed and strategies defined. The generic categories of algorithm and strategy requirements for the rendezvous and docking system include:

a) Decision Algorithms
b) Maneuver Strategies
c) Sensor Utilization
d) Redundancy Management

The SRT algorithm development includes analyses for the early definition of software requirements, coding the programs and computer runs to prepare for simulation/demonstration testing. It does not include flight software (either onboard or mission control), but is useful tool in the building process to flight status.

Subsystem; Algorithms (Strategies SRT No.: A-1

Task Title: Develop Software for LOS, Range and Target Attitude Measurements Used as Control

Statement of Problem: Sensed data for rendezvous and control includes range, line-of-sight (LOS) angle, target attitude and rates of each. The problem is to control these values and reduce them to essentially zero in an optimum fashion. The proposed method for performing this function is to close the attitude control system loop on these sensed values and operate on them as error sources. To accomplish this effort, control logic algorithms are required. The current Space Tug Docking Study would indicate this software is appropriate for the Tug flight computer. However, the better approach at this time is considered to be a more universal application in the light of changing program requirements.

Objective: This task is a basic software algorithm development effort, and shall include the development of a software program which is adaptable to implementation into future space vehicle control systems.

Approach: Software requirements will be developed, algorithms coded and validated to perform these functions. This software program can then be adapted to a simulation/demonstration program in which a specific vehicle (Tug or other) control system is modeled.

Estimated Costs: The implementation of this capability into flight software was estimated to require 1050 words. Development costs for this support were computed at $20 per word, based on average support software complexity.

Subsystem; Algoriths (Strategies) SRT No.: A-2

Task Title: Rendezvous Phase Maneuver Strategy Development

Statement of Problem: The rendezvous phase of the scenerio requires selection and analysis of a rendezvous methodology. The use of sensed data to close the control loop for this phase need only be concerned with range and LOS data, since target attitude determination is not critical for rendezvous. Previous rendezvous methods included Lambert type and proportional navigation schemes. The selected method requires verification and optimization to reduce the propellant required.

Objective: The objective of this activity is to develop a rendezvous phase strategy to the point that it is easily adapted to and implemented in the simulation/demonstration test activity.

Approach: A software analysis, coding and program checkout will be performed. Parametization runs will be made to optimize the rendezvous maneuvers from time and propellant usage standpoints.

Estimated Costs: Control of these maneuvers was estimated to required 1500 words of flight software. Costs for the development of this support were computed at $15 per word, based on lesser than average complexity, and considerable existing technology base.

Subsystem: Algorithms (Strategies) SRT No.: A-3

Task Title: Inspection Phase Maneuver Strategy Development

Statement of Problem: The inspection maneuvers consist of a "fly-around" orbit of the target spacecraft. The strategy must minimize ACS propellant consumption while also minimizing ACS thruster plume impingement on the spacecraft. This is especially critical if the mission involves servicing and must, therefore, leave the spacecraft in an operational status. The algorithms used for automated control of the active vehicle during inspection must be designed to close the control loop using sensed data.

Objective: This activity will develop the inspection phase strategy to the level that it can readily be adapted to the simulation/demonstration test activity.

Approach: A software analysis, coding and program verification checkout will be performed. Computer runs will be made to demonstrate the range of initial condition variations expected.

Estimated Costs: Control of this phase of the scenerio was estimated to require approximately 300 words of flight software. Costs for the support of this development was computed at $30 per word due to the new technology involved and greater than average complexity.

Subsystem; Algorithms (Strategies) SRT No.: A-4

Task Title: Closure Phase Maneuver Strategy Development

Statement of Problem: The closure maneuver for an autonomous, manual or hybrid system is the most critical due to the relative ranges involved. Accuracy of control becomes of more concern due to inadvertant contact and resultant damage potential. It is in the closure maneuvers that the scenerio changes between impact and non-impact systems. The strategy developed for this phase involves closure rates as well as accuracies and the effects of loss of sensed data as a function of range must be considered. Sensor field of view is a parameter of considerable significance in the closure phase. The strategy must account for the interaction between docking sensor data and the active vehicle (e.g., Tug) inertial measuring system.

Approach: A software analysis, coding and program checkout will be performed. Computer runs will be made to verify effects on residual values of sensed data at simulated impact or entering a stationkeeping mode. Variations in closure rate and range at loss of sensed data will be input to the computer program and these effects determined.

Estimated Costs: Control of the active vehicle during this phase was estimated to require 550 words of flight software. These support costs were computed at $30 per word due to new technology involved and also this support software development is considered more complex than average.

Subsystem: Algorithms (Strategies) SRT No.: A-5

Task Title: Docking Dynamics & Control Strategy Development

Statement of Problem: The effects on the active vehicle control system during the docking transients are unknown. Further, the mass properties of the combined vehicles (e.g., Tug and spacecraft) may require changes in the control modes. Some mode change may also be required during impact or to provide a stationkeeping mode for non-impact docking.

Objective: The objective of this task is to develop the strategy for control during contact and post-latch dynamic perturbations.

Approach: A software analysis is planned. However, the inputs for the anticipated vehicle dynamics are not currently available. These data are obtained from the SRT Task No. M-2 in which mechanism design dynamics are defined by use of the IMPRES program. This program models vehicle dynamics and the details of the docking mechanism. It provides a time history of the docking and post-latch dynamics.

The algorithms developed under this task involve analyses of control gains and switching control modes after docking sensor data is lost due to the reduced ranges.

Estimated Costs: Control of the active vehicle during this phase was estimated to require 250 words of onboard software. The SRT support costs were computed at $30 per word due to the complex and untried technology involved.

<u>Subsystem</u>; Algorithm (Strategies) <u>SRT No.</u>: A-6

<u>Task Title</u>: Commit-to-Dock or Abort Decision Algorithm Development

<u>Statement of Problem</u>: Inherent in the inspection phase of the rendezvous and docking scenerio is a determination of spacecraft status for docking and a self-check of the active vehicle systems. For an autonomous system these decisions must require sensing off-nominal situations and being able to isolate a specific problem to the level where decisions for abort or corrective action can be made. Without man-in-the-loop this places a burden on the algorithm developer to pre-program all the combinations of situations which impact these decisions. A functional level failure modes and effects analysis (FMEA) of both passive target and active vehicle anomalies is required for the preliminary development of failure sensors required and the software to analyze and act on this intelligence.

<u>Objective</u>: The objective of this activity is to perform a top level functional FMEA and define the software to autonomously make the decisions required.

<u>Approach</u>: A systems analysis will be performed to define the failures, detection means and corrective actions using a top level functional approach. It is not considered necessary at this time to define all the failures, but to develop a representative set for the decision algorithms to operate upon and demonstrate the feasibility of this approach. The software algorithm development is also planned under this task.

<u>Estimated Costs</u>: The functional FMEA system analysis is estimated at two manyears. The flight software to support this activity is estimated at 600 words and the cost computed at $30 per word due to the complex and advanced technology.

Subsystem; Algorithm (Strategy) SRT No.: A-7

Task Title: Image Data Management and Compression Techniques

Statement of Problem: Image data handling has historically required higher data rates than presently planned for the Space Tug data system. General Dynamics has proposed a hybrid docking system with the man in a supervisory position. Due to data loading limitations the TV image update rate of once each 16 seconds. If the manual system is truly a backup for an autonomous capability, this update rate is too slow.

A number of techniques are available to improve this situation. Onboard image compression techniques are in various states of development. Some Martin Marietta work has demonstrated compression of 6 to 1 with image reconstruction to an apparently acceptable quality for this application using Fourier or Walsh transforms.

Other techniques proposed include reducing the portion of the image transmitted to include only the spacecraft (no surrounding background) or only the docking target.

Objective: The objectives of this task are to explore the methodologies for image data compression and develop a selected method for use in the manual and hybrid docking system simulation/demonstration testing.

Approach: The approach to this SRT includes a review of the existing candidate methods for image data compression and selection of 3 to 5 likely approaches. These approaches will then be subjected to a remote manned system simulation at Martin Marietta. Algorithms will be developed under this SRT for the methodology considered most applicable to the manual candidate recommended.

Estimated Cost: The software estimate for this function (onboard and mission control) was approximately 1000 words which was costed at $20 per word. An additional 0.5 manyear of analyses and requirements assessment for screening candidates is also included.

3.0 MECHANISM SRT

A number of new or different requirements are imposed on the mechanism by groundrules of the current study. Accommodation of the NASA mission model for Tug delivery and retrieval missions requires delivery of more than one spacecraft and retrieval of another. These spacecraft represent different configurations, sizes and weights. The Apollo and ASTP docking mechanism designs have provided a pressurized crew passageway which was not required under present study groundrules. However, in selecting mechanism designs, which should be developed further, the flexibility to changing requirements should be considered. The role of servicing versus retrieval is an issue not fully resolved, for example.

The SRT activities proposed include development of two conceptual designs to the point where prototype hardware can be fabricated for simulation/demonstration tests. The subsystem requirements developed in the study define the misalignments which must be accommodated by the mechanisms. Both impact and non-impact docking mechanism design options should be kept open and carried forward into simulation/demonstration tests.

Subsystem; Mechanisms SRT No.: M-1

Task Title: Non-Impact Docking Hardware Development

Statement of Problem: A non-impact docking system has many advantages in reducing spacecraft impacts; both physical and design. Since rendezvous and docking are necessary steps in a servicing mission, the non-impact system has numerous advantages. For a retrieval mission, the spacecraft appendages (i.e., solar arrays, antennae, etc.) must be retracted or jettisoned before retrieval and the spacecraft is not required to operate after docking. However, for servicing the idea is to leave the spacecraft in a better operational state than originally found. Also, it is operationally desirable to leave appendages deployed to preclude the potential failures and loss of function associated with retract/redeploy cycling after prolonged space exposure.

A non-impact design has advantages in the physical sense, since it also provides reduced docking load factors at the spacecraft interface. A design concept has been developed by Martin Marietta which uses the basic square frame design, less shock attenuation members. The stem device is added to capture the spacecraft and slowly draw the vehicles together for hard latching. Bending moments and dynamic effects of drawing the large masses together using a flexible STEM are unknown.

Objective: The objective of this task is to develop the non-impact docking mechanism to the point where simulation/demonstration testing can be performed.

Approach: Gross capture boundaries will be established and requirements on stationkeeping capability developed using hardware mockups and bench tests. A computer simulation will be developed to determine STEM mechanism backdrive capability, Tug thruster plum impingement effects, Tug control inputs and STEM stiffness required based on dynamics computer simulation of the two bodies (Tug and spacecraft) under the conditions resulting from this operation.

Estimated Costs: The costs for this development are estimated to be $75K for hardware development and test plus $75K for the dynamics program analyses.

Subsystem; Mechanisms SRT No.: M-2

Task Title: Impact Docking Hardware Development

Statement of Problem: The dynamics associated with docking are a function of many variables. Approach velocity, mechanism stiffness and damping and propellant slosh effects must be considered, to name a few. A series of dynamics simulation runs should be performed to bound the capture capabilities by modeling these dynamics effects and the mechanism characteristics in a high fidelity dynamics simulation.

A simplified propellant slosh dynamics analysis was performed on the current study to size the problem. Martin Marietta previously developed a dynamics docking program (IMPRES) under a previous MSFC contract which has a detailed representation of the Apollo probe/drogue mechanism. However, no propellant slosh effects were included, and the current study slosh model is being added to the IMPRES capability.

Due to time and budget limitations of the current study, the dynamics analyses necessary to evaluate all these variables for new mechanism designs could not be performed. The detailed designs could not be performed. The detailed design characteristics of the mechanisms are not well defined and IMPRES runs are time consuming and costly. The representations should be accurate before performing the runs to maximize the outputs.

The runs will provide capture boundaries on misalignments and a time history of the contact and post-latch dynamics for input to SRT Task No. A-5. These data derived from the runs is also useful in developing mechanism design parameters such as stiffness and damping to reduce the transmissibility of dynamic effects to spacecraft.

Objective: The objectives of this task are threefold; (1) to refine mechanism design, (2) to establish capture boundaries, and (3) to provide dynamic history for control mode definition.

Approach: The approach for this effort involves modeling the candidate mechanisms in detail and performing an adequate number of IMPRES runs to accomplish the objective.

Estimated Costs: One manyear of engineering effort and 100 runs for each of two mechanisms is estimated to be required. Each IMPRES run is estimated at $375 for a 5-second run duration. The integration interval can be reduced for all but the contact period, which is approximately 2 of the 5-second run.

Subsystem; Mechanisms	SRT No.: M-3
Task Title: Capture Hardware Development for Non-Cooperative & Spinning Spacecraft	

Statement of Problem: The rendezvous and docking system is required to dock with and retrieve spin-stabilized spacecraft. Several concepts for this capability have been proposed. The technology is untried and feasibility of some of these concepts is questionable. Promising candidates include the MDAC Square Frame with despin by the capture latch friction and a probe concept with the capture portion having bearings providing rotation capability and despin braking capability.

Objective: The objective of this activity is to develop feasibility hardware designs to the point where simulation/demonstration testing can be performed with some assurence of success.

Approach: Hardware concepts will be developed and bench tests conducted on at least two concepts.

Estimated Costs: The mampower is estimated to require 1.5 manyears of engineering and technician effort plus $30,000 materials costs.

Part III - TEST DESCRIPTIONS

RENDEZVOUS AND DOCKING SYSTEM

TEST DESCRIPTIONS

III TEST DESCRIPTIONS

The following test description sheets represent the initial definition of recommended tests to be performed on selected autonomous and manual rendezvous and docking system candidates. Since the hybrid candidate system is planned to draw from the subsystem elements of the manual and autonomous candidates, the hybrid system tests will derive from the selected candidate tests. The basic philosophy used in selecting these tests is driven by demonstrating the selected system throughout all appropriate operational phases. A building block approach is used with many intermediate checkpoints, at which results are evaluated and complexity is increased before proceding to the next test phase. The test phases lend themselves to this approach since system complexity requirements increase as the vehicle separation range closes.

These test descriptions were developed prior to candidate selection. Detailed test procedures, bearing the same test identification, may be found in Section III of this report.

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. R1A

FUNCTION TO BE TESTED: Autonomous acquisition, Tracking and Ranging at Maximum Range

CANDIDATE:	PHASE: Rendezvous
APPLICABLE TO: /_/ MANUAL /X/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to establish that the sensor can acquire the target, maintain track, and provide range, range rate, and LOS data over the expected range of spacecraft conditions (lighting, orientation, dynamics) as well as Tug conditions (power, vehicle rates, etc.) at initial acquisition and tracking.

b) Reason for Test: Analysis has determined a specific range (~25 n mi) at which target acquisition and tracking must be established to achieve an optimum rendezvous within an allocated ACS propellant budget. The sensor selected for this phase must meet this requirement. In addition, nonoptimum but realistic conditions to be expected (particularly on the target) have not been evaluated. Before commitment to final design selection, a high degree of confidence must be established that the representative flight hardware can meet the requirement. It is in a new technology status and has no space flight experience.

c) Supporting Analytical Studies: None

d) Related Hardware Development Required: Sensor hardware development to prove concept and design feasibility has been completed. Additional design and development will be required for the specific ranging requirements to be determined, but this development can and should be conducted in conjunction with the simulation/demonstration testing below.

e) Simulation/Demonstration Test Approach: This testing should be done with prototype or flight hardware at true ranges and with a good representation of a target spacecraft and anticipated optical interference phenomena (sun, moon, etc.). An aircraft test program is most suitable. However, a high altitude test (above 10,000 ft) is considered a low-cost alternative. It minimizes atmospheric effects. It should also provide results that indicate sensitivity to atmosphere so results can be extrapolated to deep space.

f) Facilities: Target spacecraft mobile mounted sensors (truck) model with reflectors.

NOTE: See Test Procedure for detailed facility utilization.

g) Final System Verification: A Shuttle test flight is recommended to satisfy this verification.

h) Desired Test Output: See attached check list.

i) Justification: The test is important because there have been no previous applications of the sensors being considered in similar roles. The function is the first step in the series to demonstrate, end-to-end, a successful rendezvous and docking mission profile.

SIMULATION OUTPUT CHECKLIST

Concept Development	
Concept Verification	
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	
Hardware Design Verification	X
ACS Propellant Requirements	
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	
______	
______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. R1M

FUNCTION TO BE TESTED: Manual Acquisition, Tracking and Ranging at Maximum Range

CANDIDATE:	PHASE: Rendezvous
APPLICABLE TO: /x/ MANUAL / / AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to: (1) determine the maximum range at which manual acquisition of a target spacecraft can be accomplished, (2) when effective ranging can be accomplished, and (3) to what accuracy the anticipated range of S/C conditions, such as lighting, shall be considered. The scheme by which the developed range, range rate and LOS data will be implemented in the rendezvous algorithim shall be evaluated.

b) Reason for Test: A TV has been baselined on the Tug for inspection purposes as well as some role in rendezvous and docking; in particular, manual options. Acquisition is a feasible capability of a TV, but the range at which this can be reliably accomplished is a function of target shape and lighting as well as TV and ground display resolution. In order to ascertain the range of capability available, testing will be required.

The usefulness of TV as an alternate or backup sensor depends on its ability to determine range and range rate and to do it accurately. Simulation of this capability under expected lighting conditions and anticpated spacecraft visual cues is necessary to not only verify concept feasibility, but to determine hardware parameters and alogorithims as well.

d) Hardware Development Required: TV camera development is virtually complete from a hardware standpoint. No other flight hardware is concerned with this function.

e) Simulation/Demonstration Test Approach: An aircraft test program is desirable to evaluate acquisition performance. This may be cost effectively accomplished in conjunction with the SLR rendezvous test program. Manual TV ranging has been shown analytically, to not be practical beyond TBD ft. At this range, an initial evaluation of acquisition, but more specifically range determination, can be accomplished with a TV and a scaled down range and target. (200:1) This simulation should be conducted and an aircraft flight test decision withheld until completion of this.

f) Facilities: T27 Flight Simulation or Target Motion Simulator.

NOTE: See Test Procedure for detailed facilities utilization.

g) Final Systems Verification: A shuttle test flight is recommended to satisfy this verification.

h) Desired Test Output: See attached checklist.

i) Justification: Use of the TV as a backup to the primary ranging sensor appears to be a viable option. In the event of failure of the primary sensor the capability of the TV to perform the same function should be established, as well as the degree of degradation in the sensed data that can be expected in a backup mode.

SIMULATION OUTPUT CHECKLIST

Concept Development	
Concept Verification	
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	X
ACS Propellant Requirements	
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	
______	
______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. R2

FUNCTION TO BE TESTED: Rendezvous Algorithm Verification

CANDIDATE:

PHASE: Rendezvous

APPLICABLE TO: /X/ MANUAL /X/ AUTONOMOUS

PREPARED BY:

DATE:

a) Objective: This function shall be tested to; (1) aid in the selection of a rendezvous scheme, (2) verify that the selected approach can accomplish the rendezvous under all anticipated conditions, both initial and in-flight variations, of vehicle dynamics, sensor performance, and (3) develop performance criteria (timelines, ACS propellant, etc.) for support of related trade studies and total subsystem definition. Visual scenes may be recorded for ground crew training purposes.

b) Reason for Test: Apollo rendezvous has used a lambert form of rendezvous targeting, utilizing the ground for major course correction parameter determination. MMC studies on a Mars Surface Sample Return mission have proposed a proportional navigation type of guidance. Other potential methods also may appear attractive in light of the Tug rendezvous scenario, particularly the autonomous operation. The ultimate recommended rendezvous scheme may be a combination of several of these methods. The criteria aiding this selection is ACS propellant usage, timelines, vehicle orientation, sensor pointing requirements, ground monitoring considerations, etc. Analytical analyses and some simulation/demonstrations are necessary to provide that data and make a recommendation.

c) Supporting Analytical Studies: Initial analysis and concept identification which must consider the pre-rendezvous phases as well, involves quite a range of mathematical algorithms. This effort is most efficiently conducted by computer analytical studies. Simulation/demonstration tests, involving a large S/W effort such as rendezvous does, is very expensive if a number of relatively different rendezvous concepts must be implemented. A simulation/demonstration for this phase is most useful for verification of the ultimate concept and for sensor evaluations and timeline/propellant usage assessment if man is in the loop. Consequently, most of the load regarding this test must be borne by computer analytical studies.

d) Related Hardware Development: None

e) Simulation Demonstration Test Approach: Simulation/demonstration testing of the rendezvous phase algorithms should be incorporated, wherever practical, into those tests already established for other function tests such as sensor evaluation, man-in-the-loop procedure development, etc. Analytical analysis alone can adequately, and with considerable fidelity, determine the candidate algorithm performance. Very little man-in-the-loop activities are involved in this phase and, in general, they do not impact performance of the vehicle for a given algorithm. This test of rendezvous algorithm performance is influenced primarily by orbital conditions and the programmed equations in S/W that govern the algorithm. Even vehicle performance dispersions do not greatly influence the ultimate performance of one rendezvous scheme over another.

f) General Facility Requirements: Scientific Computation Laboratory.

g) Final System Verification Considerations: Since this phase is implemented principally by computer software equations and under an explicit time phased sequence, also computer initiated, the flight software validation will constitute the most effective form of a final system verification.

h) Desired Test Output: See the following checklist.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	X
Procedure Development	X
Procedure Verification	X
Algorithm Equation Verification	X
Software Parameter Definition	X
Software Parameter Verification	
Hardware Concept Verification	
Hardware Design Verification	
ACS Propellant Requirements	X
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	X
Ground Operations Hardware Requirements	
Ground Operations Operational Impact	X
Communications Impact	
Other ______	
______	
______	

FUNCTION TO BE TESTED: Autonomous and Manual Rendezvous Sensor Tracking	
CANDIDATE:	PHASE: Rendezvous
APPLICABLE TO: /x/ MANUAL /x/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to; (1) determine the capability of the candidate rendezvous ranigng sensors to maintain line-of-sight lock on the target under all anticipated target characteristics, mission parameters, and Tug and target dynamic conditions and (2) evaluate the methods and capability of the sensor to automatically reacquire the target upon loss of lock, whether intentional or not, and evaluate the impact of that temporary loss on the overall rendezvous solution.

b) Reason for Test: Both manual, hybrid, and automatic rendezvous and docking subsystem candidates will utilize an autonomous or at least semi-autonomous rendezvous phase. Key to that phase is the range, range rate and LOS data generated by the on-board sensor (TV, SLR, etc.) while it is locked on the target. There are a number of conditions that could result in loss of that lock, such as Tug dynamics during mid-course corrections, or even normal altitude hold; target attitude changes; undesirable reflections; noise; or background distractions for a TV, such as stars, earth or moon. In the event of a "loss-of-lock", an algorithm, either sensor or software type, must provide for reacquisition. The reliability of that scheme must be know. In addition, the data generated is being used through guidance equation filters to maintain accurate relative vehicle states. The effect on vehicle state knowledge due to loss of that lock must be known as a function of time.

c) Supporting Analytical Studies: A tradeoff analysis will be conducted to determine the most efficient means of reacquisition upon loss of lack of either SLR, TV, or whatever. Methods of implementation, including software equations, will be analytically derived and an estimate of performance under the anticipated conditions made.

d) Related Hardware Development: The basic hardware for this function, either an SLR, TV or RF radar, are virtually through development for the anticipated ranges. The results of this test, however, may result in more stringent requirements on certain parameters; such as target scan rates, etc. Consequently, some development on a small scale should be anticipated, planned for accordingly, and costed.

e) Simulation/Demonstration Test Approach: A two-step approach is recommended. The first is to perform a "scaled down" simulation for the development, evaluation and selection of reacquisition algorithms. The second step is to evaluate the selected candidates in a true space environment. That should be accomplished in an aircraft flight test program, specifically the same aircraft flights proposed for test R1.

The scaled down simulation/demonstration test for an autonomous TV sensor will have to evaluate a number of potential cues (light sources, target outline or edges, etc.) as well as the sensor performance and reacquisition algorithm. A good simulation representation is important and is feasible. For an SLR sensor, however, a good simulation/demonstration setup involving true sensor and cue hardware is not as straight forward for the ranges in question (50 n mi to 100 ft). Because of the work done to date on the SLR and retroflector development, it may be feasible to extrapolate results from SLR performance in the inspection phase (Test I1) to this phase, showing by analysis, the adequacy of the design and the algorithms. The aircraft test program alone may provide a good and sufficient development test.

f) General Facilities Requirements:

- o Flight Test Aircraft
- o High Attitude Test
- o T27 Space Simulator Facility (TV)

g) Final System Verification Considerations: The aircraft test program proposed could almost serve as a form of dinal system verification, however, in light of other requirements for an early Shuttle flight test, this function should be made a part of that test program. Its verification is important as it is a key part of the rendezvous sequency, yet little capability for manyal override or manual completion is feasible, particularly for loss-of-lock at long ranges.

h) Desired Test Outputs: See attached checklist.

i) Justification: Some of the sensors being considered for rendezvous target tracking have not been demonstrated in this role. Neither have the software/hardware techniques being considered for loss-of-lock. This test evaluates the combined software/hardware mechanization to perform the tracking function.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	X
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	X
Software Parameter Definition	X
Software Parameter Verification	X
Hardware Concept Verification	X
Hardware Design Verification	X
ACS Propellant Requirements	X
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirements	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ____________	
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FUNCTION TO BE TESTED: Automatic Target Tracking	
CANDIDATE:	PHASE: Inspection
APPLICABLE TO: /_/ MANUAL /X/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to verify that the sensor can effectively maintain line-of-sight tracking of a target vehicle during the inspection phase. Development of specific algorithms will be conducted, if required, for functions such as reacquisition. Variable ranges for inspection will be evaluated to ascertain sensitivity of sensor performance to range. The key sensor hardware characteristics will be evaluated to assure they are specified adequately over the range of Tug and Target dynamic conditions, including the Tug maneuvers to initiate inspection and to maintain inspection orbit range. Realistic target vehicle retroflector configuration will be provided to evaluate the transfer from one to another at the inspection range. Skin track feasibility shall be investigated. Vehicle dynamics during the phase plane attitude control will be evaluated. ACS propellant usage data will be generated.

b) Reason for Test: For an autonomous inspection phase capability, continuous vehicle tracking is necessary to; (1) provide the necessary range data to maintain the inspection orbit radius and (2) to maintain LOS of the target for TV inspection, if desired. The inspection control algorithm will more than likely be based on the assumption the Tug LOS is maintained on the target.

Maintaining track of the target during the inspection phase (75'-300') is a different problem than at the long ranges of rendezvous. The Tug is orbiting the target making retroflector spacing and reflector signal return overlaps a major factor. Undesirable reflections will also be present somewhere in the orbit. The effect of Tug vehicle dynamics is more pronounced during inspection. The Tug is consistently being maneuvered; that is, rotated to maintain LOS on the target and translated toward the target to remove normal acceleration induced by the orbit rotation. Evaluation of all these factors has not been conducted with realistic Tug dynamics or slosh, nor with flight hardware or representative target retroflector locations. This evaluation must be conducted before sensor specifications are finalized because of their sensitivity to accomplishing inspection automatically and reliably.

c) Supporting Analytical Studies: Analytical studies can efficiently be applied to development of reacquisition algorithms. In addition, hardware error analysis studies will be required to support test definition. Similar analysis will be required later in conjunction with the test program to relate test results explicitly to specified sensor parameters.

d) Related Hardware Development: SLR development, as related to the inspection phase, is sufficiently far along to initiate design verification with a simulation and demonstration test program. As this test is conducted, however, further development areas will be identified. Such activity should be planned for and costed.

e) Simulation/Demonstration Test Approach: The simulation/demonstration tests should be the focal point in accomplishing verification of this functional capability. As a minimum, a prototype SLR sensor and retroflectors should be utilized. Target size and retroflectors size may be scaled down as necessary to accommodate the facility constraints. Ranges from 75' to 300' should be accommodated.

Tug vehicle dynamics should be simulated accurately about the SLR reference base. S/C dynamics may not be required initially, but as testing proceeds target limit cycle motion should be provided. Inspection orbit tug motion should be implemented via a rotation of the target vehicle. Lighting and celestial scenes are not critical to this test. Data representing vehicles' dynamics and sensor performance shall be recorded. Six DOF motion of the sensor shall be provided. Target vehicle may be 3 DOF (rotation only) with possibly only one axis driven automatically.

f) General Facilities Requirements:

- o Dalto Gantry/TMS Combination
- o Test Lab Flat Floor

g) Final System Verification Considerations: This phase depends on software algorithms in the Tug computer, consequently, this function's test program at some point should involve the Tug computer and software. That test should be the software validation. The proposed Shuttle flight demonstration will serve as the Final System Verification.

h) Desired Test Outputs: See attached checklist.

i) Justification: Autonomous operations from the inspection phase on into docking is a totally new technology for the USA. Complete end-to-end verification of all hardware and software elements which must work together is mandatory. Dynamic simulations must be higher fidelity as the range decreases.

SIMULATION OUTPUT CHECKLIST

Concept Development	
Concept Verification	X
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	X
Software Parameter Definition	X
Software Parameter Verification	X
Hardware Concept Verification	
Hardware Design Verification	X
ACS Propellant Requirements	X
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirements	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	
______	
______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. I1M

FUNCTION TO BE TESTED: Manual Target Tracking with TV

CANDIDATE:	PHASE: Inspection
APPLICABLE TO: /X/ MANUAL / / AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to evaluate concepts for manual tracking of a target during target inspection. Algorithms for range, range rate and LOS data developed in test R2 shall be evaluated and modified as required for inspection ranges. Even if a TV is not the primary sensor for this phase it is desirable to know if it can accomplish all functions in a backup role. Vehicle dynamic effects on sensor performance during maneuvers shall be evaluated. The vehicle control parameters during manual control shall also be evaluated (phase plane logic parameter development and verification). ACS propellant required for a typical inspection shall be tabulated. All the above shall be investigated over a reasonable expectation of inspection orbit radii (75'-300'). Evaluation of TV target cues shall be performed and the most promising identified together with data supporting the selections. Impact of the expected lighting conditions on sensor performance shall be evaluated.

b) Reason for Test: No detailed evaluation has been conducted on a TV in the role of manual tracking of a S/C at these ranges. The greatest uncertainties exist in the pattern or cue the TV will use, and the reliability of always finding and tracking that cue under a range of dynamic conditions and lighting. Maintaining track of the target vehicle, while performing maneuvers to initiate the inspection orbit and maintaining the orbit's radius, impacts sensor performance parameters directly and may impose some requirements (scan rates, resolution, etc.) beyond current off-the-shelf TV design capabilities. Another key area of concern, shared with test R2, is the ability to determine range data man ally by some sort of pattern cue or S/C outline on the target, then using that data to manually generate vehicle commands to change or maintain a given range.

c) Supporting Analytical Studies: Analytical studies will be required for development of the TV pattern/cue recognition algorithms. Also, some vehicle control algorithm development will be required, including reacquisition techniques. TV sensor hardware error analysis will be necessary to relate simulation test results to specified TV performance characteristics.

d) Related Hardware Development: No new hardware development is required prior to this test since a range of TV capabilities are available off-the-shelf. There is a possibility some hardware development regarding a few TV parameters may be identified as a result of this test. Planning and costing such tasks should be provided for.

e) Simulation/Demonstration Test Approach: A number of TV cameras should be evaluated. Vehicle dynamics of both target and Tug vehicle should be represented quite accurately. Since much of the testing is algorithm-oriented, such as pattern recognition, and is dependent on visual targets, the use of scaled down target simulation is quite acceptable, provided good target models are used. Background visual scenes should be provided, particularly star field and brightly lit earth and moon, to evaluate the ability of the camera and its pattern ranging algorithm, to filter out these distractions reliably. A two-revolution inspection is certain to encounter one or even all of these visual distractions.

f) General Facilities Requirements:

- o T27 Space Flight Simulator

g) Final System Verification Consideration: Because of Tug software involvement the software validation will be a form of verification and should be conducted in a simulation environment such as this test describes. The proposed Shuttle flight test will be the ultimate system verification.

h) Desired Test Outputs: See attached checklist.

i) Justification: Manual inspection and target tracking has been conducted during the Apollo program. However, this was done with the man onboard. In this case a ground controller will conduct the inspection and tracking. Data downlink and command uplink delays and onboard software algorithms result in anything but direct control of the vehicle. The uncertainties associated with these concerns require verification.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	
Procedure Development	X
Procedure Verification	
Algorithm Equation Verification	X
Software Parameter Definition	X
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	X
ACS Propellant Requirements	X
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. I2A

FUNCTION TO BE TESTED: Automatic Target Tracking and Inspection

CANDIDATE:	PHASE:
APPLICABLE TO: / / MANUAL /X/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to evaluate the capability to autonomously initiate an inspection orbit, maintain tracking of the spacecraft during inspection maneuvers and maintain desired range during inspection. The feasibility of autonomous use of LOS and range sensed data shall be evaluated in comparison with manual means.

b) Reason for Test: This test is recommended since this capability has not been previously developed in a space proven system; except by the Russians. The capability for converting the sensed data into control logic should be demonstrated due to cost risk involved.

c) Supporting Analytical Studies: Development of the software requirements or hardware signal conditioning needed to accomplish this job should be defined. Tradeoffs for implementation by Tug computer or sensor related mini-computation capability.

d) Related Hardware Development: Sensor development, as related to the inspection range, is sufficiently developed in the SLR area. RF sensors need development, not of technology, but specific applications to the inspection close in range operations.

e) Simulation/Demonstration Test Approach: Tug vehicle dynamics and control using inputs from the sensors are required. S/C dynamics should be realistically simulated, but relative tug motion can be simulated by rotation of the target vehicle (SC). Data representing vehicles' dynamics and sensor performance shall be simulated. Six DOF motion of the sensor shall be provided. Target vehicle may be 3 DOF (rotation only) with possibly only one axis driven automatically.

f) General Facilities Requirements:

- o Test Lab Flat Floor
- o Dalto Gantry
- o Comp Lab

g) Final System Verification Considerations: This function depends on software operations on sensor inputs to the Tug computer control. Therefore, a good simulation of the Tug dynamics and control system is essential. Use of validated software for the final testing is considered a firm requirement.

h) Desired Test Outputs: See attached checklist.

i) Justification: New technology; see I1A.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	X
Procedure Development	X
Procedure Verification	X
Algorithm Equation Verification	X
Software Parameter Definition	X
Software Parameter Verification	X
Hardware Concept Verification	X
Hardware Design Verification	X
ACS Propellant Requirements	X
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	X
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	X
Communications Impact	
Other ______	
______	
______	

FUNCTION TO BE TESTED: Manual Target Inspection	
CANDIDATE:	PHASE: Inspection
APPLICABLE TO: /X/ MANUAL /_/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to evaluate the capability to manually initiate an inspection orbit, maintain visual track on the vehicle during the required maneuvers, and maintain the desired range during the inspection. The feasibility of manually determining LOS and range shall be evaluated in comparison with automatic means, such as an SLR or a TV. Time and transmission delays shall be thoroughly evaluated and sensitivity of the man-in-the-loop performance to these delays shall be defined. The GDC hybrid configuration (supervisory control) shall be evaluated. A spectrum of inspection radii shall be considered.

b) Reason for Test: Because of time delays in getting data to the ground and commands back up, partially due to data rate constraints, the TV picture update rate on the ground for manual control of the Tug does not provide direct control. During inspection, maneuvers are required to initiate the inspection orbit and maintain a constant range. The ability to perform this manually, to successfully maintain track of the vehicle and to detect range errors and correct for them manyally, must be established. Even if this is nominally provided under automatic or semi-automatic control the manual capability must be evaluated as a backup mode that the TV and man will provide in the event of failures. GDC's simulation was not truly manual control. Their 16-sec constraint on RV picture update raises grave concern that a successful manual backup capability is feasible with the current Tug avionics baseline. Special data compression schemes may be of considerable benefit and are feasible. This test should establish the requirements for these schemes and whether they are necessary.

c) Supporting Analytical Studies: No major analytical effort is foreseen. However, in the event data compression is found to be a cost effective addition, a paper study should research available methods and select optimum data compression and handling algorithms for TV data.

d) Related Hardware Development: There is no flight hardware development identified at this time, however, flight software development is sizeable. TV development is well along for this application.

e) Simulation/Demonstration Test Approach: This test will evaluate several types of cameras. They should be as representative of flight hardware as possible. The target may be scaled down, but not so far that good vehicle dynamics effects are lost. Tug dynamic motion is as important as the target's. Translation simulation should not be necessary at this range. Lighting and visual effects may not be as critical. The technical concern is related more to vehicle dynamic effects on the man's view of the target and on his ability to respond with the proper commands when considering communications data rates and time delays. Therefore, proper vehicle dynamics and its effect on the visual scene and proper simulation of the ground scenario is important.

f) General Facilities Requirements: A T27 type simulation may be adequate provided good vehicle dynamics can be achieved. Modifications may be required to properly simulate the ground operations and the TV data available to the ground.

g) Final System Verification Considerations: This function should be tested in a final system verification because of its role as a backup docking sensor, even if it doesn't get utilized as the primary method. It should be incorporated in the presence of the true operational constraints and delays.

h) Desired Test Outputs: See attached checklist.

i) Justification: New application of existing technology. See Test I1M.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	
Procedure Development	X
Procedure Verification	
Algorithm Equation Verification	
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	
Hardware Design Verification	X
ACS Propellant Requirements	X
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	X
Ground Operations Hardware Requirement	X
Ground Operations Operational Impact	X
Communications Impact	X
Other ______	
______	

FUNCTION TO BE TESTED: Autonomous Docking Port Identification	
CANDIDATE:	PHASE: Inspection
APPLICABLE TO: /__/ MANUAL /X/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to determine if and how the docking port of a target vehicle can be detected by the SLR on the Tug; either automatically or with ground aid. A variety of cues and patterns shall be evaluated and the effectiveness of each quantatively determined under a variety of anticipated conditions (LOS offset angle vehicle dynamics, reflections, etc.). Feasibility of locating the docking part without prior knowledge of vehicle attitude shall be compared with conditions where previous knowledge of vehicle attitude is known and mission operations are planned to optimize that knowledge. Ground support activities that may aid the locating process shall be investigated and defined.

The actions the Tug may take upon locating the docking port shall be evaluated. Some typical alternatives are: (1) determine target vehicle attitude, provided the cues exist, while continuing inspection; (2) store tug attitude upon sighting and continue inspection; and (3) stop inspection orbit and station keep until target attitude determination or closure is initiated.

b) Reason for Test: Location of the docking part on the target vehicle is essential to retrieval. In reality, for most early flights that data will be available as a target attitude and stored in the Tug computer, however, presence of the port in the expected location must still be verified by sensor prior to closure. It is felt little must be added to the current candidate systems to extrapolate their use to locating the docking port of a S/C for which attitude is not known. Therefore, it is appropriate that this capability be determined early in development, thereby identifying the growth capability of the Tug to handle failed S/C.

Ultimately the docking port location function may be combined with the attitude determination capability, however, it is felt more objective results will be obtained if at first the methods of docking port location alone are investigated. Attitude determination with its multitude of reflectors may not even be necessary if good prior knowledge of S/C attitude is stored in the computer. A simple sensor for port verification may be adequate and cost effective.

No known studies for autonomous accomplishment of the above has been done at this time.

c) Supporting Analytical Studies: No significant analysis should be necessary to accomplish this test. There will be some analysis, specifically during the test, concerned with the software algorithms that take the sensor "sighting" information and translate it into Tug vehicle commands.

d) Related Hardware Development: Hardware development is focused principally on the docking port cue or pattern and the sensor's capability to present the sighting data in a useful form. No real SLR development is foreseen.

e) Simulation/Demonstration Test Approach: This simulation should be conducted over a range of orbit radii from 75' to 300'. Some scaling down may be necessary, but not at the sacrifice of docking port cue fidelity, particularly if its an optical corner reflector. For this test the target need not be a representative S/C; only the docking port and related surface that affect cue detection. Target attitude should be variable enough to rotate the docking port out of sight of the SLR. Visual scenes or lighting should not play a large part.

Vehicle control modes and dynamics should be wrapped around the sensor to the point where the control algorithms to be used for lock-on of the docking port after detection can be exercised.

f) General Facilities Requirements:

- o Dalto Gantry/TMS Combination
- o Flat Floor Facility

g) Final System Verification Considerations: This function should be tested in the Shuttle flight test, but may very likely be combined with other functions such as attitude determination.

h) Desired Test Outputs: See attached checklist.

i) Justification: This is a totally new concept which has never been proven; sensor cues and software are unique. Demonstration is necessary for feasibility verification.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	X
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	
ACS Propellant Requirements	X
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	X
Communications Impact	
Other ______	
______	
______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. I3M

FUNCTION TO BE TESTED: Manual Docking Port Identification

CANDIDATE:	PHASE: Inspection
APPLICABLE TO: /x/ MANUAL / / AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to: (1) determine that a visual presentation will be provided to the ground that permits positive docking port location under all lighting and visual background conditions and worst case TV picture representation; (2) evaluate and determine the optimum procedures to align on the port following sighting of it; and (3) to evaluate various methods of automatically locating the docking port with a TV. The latter shall consider target cues, ranging inspection orbit radii and varying visual backgrounds. Capability of maintaining lock on the port shall be determined for the expected dynamic disturbances and lighting conditions.

b) Reason for Test: For manual operation this function is relatively straight forward. The only testing necessary is to insure a good port cue is available under worst case conditions. To cover all the possible candidate configurations the capability of autonomous TV docking port location is of value. It is primarily an addition of target cues (lights or whatever) and some related software algorithms. Should the potential of a TV-only rendezvous and docking system ever arise (SLR development problems, etc.), this data must be available.

c) Supporting Analytical Studies: Some studies may be beneficial in automatic TV docking port location, pattern definition or related software algorithm definition.

d) Related Hardware Development: The only hardware development is for patterns, cues or special lighting techniques.

e) Simulation/Demonstration Test Approach: This test should provide a good simulation of ground operations, TV data presentation, the target, and visual effects in conjunction with the target. For autonomous operation, vehicle dynamics become a little more important. A number of docking port cues (may require larger scale target) are required as well as software algorithms for processing TV software image data.

f) General Facilities Requirements:

- T27 Space Flight Simulator
- Test Setup for C4M(Objective 3)

g) Final System Verification Considerations: Unless autonomous TV identification of a docking port is required this function should easily be verified as a fallout of other functions tested (e.g., I2M) during the Shuttle flight test.

h) Desired Test Outputs: See attached checklist.

i) Justification: Manual docking port identification was conducted during Apollo and Skylab. However, it has never been extended to remote manned operations over the wide range of lighting and orbital variations (e.g., geostationary) this system will be called upon to operate with.

SIMULATION OUTPUT CHECKLIST

Concept Development	
Concept Verification	X
Procedure Development	
Procedure Verification	X
Algorithm Equation Verification	
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	
Hardware Design Verification	X
ACS Propellant Requirements	
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	X
Ground Operations Operational Impact	X
Communications Impact	
Other ________	
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RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. I4A

FUNCTION TO BE TESTED: Autonomous Target Attitude Determination	
CANDIDATE:	PHASE: Inspection
APPLICABLE TO: / / MANUAL /x / AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to evaluate the capability of the SLR to determine target vehicle attitude over a range of conditions including target axis angular offset, target range, and the vehicles' dynamic status. The basic "T" shaped retroflector arrangement proposed by ITT and baselined in the GDC Avionics study will be evaluated along with scaled down versions that could accommodate closer ranges. Any other cues that can be identified should be evaluated in this test, specifically those that are smaller and more effective at closer ranges. The software algorithms that compute attitude and sequence the sensor for data gathering shall also be verified in this test. Any alternatives to total attitude determination shall also be tested as a part of this test. That is, those schemes that may provide target/Tug coaxial alighment such as an offset tee used for docking port alignment.

b) Reason for Test: In order for the SLR to accomplish an optimum closure with a target and end up facing the docking port, the orientation of the docking port or S/C attitude must be known with reasonable accuracy. It is assumed here that merely locating the docking port is an independent function and provides only the direction and not the attitude of the port. In the ultimate configuration these functions could very well be combined, but for now are best separated.

Docking port (or vehicle) attitude may be information known preflight and stored on board. The ability to make the determination real time and autonomously, however, must be established for several reasons: (1) failure in obtaining the S/C attitude data for one reason or another; (2) to provide a real time cross-check of the S/C attitude; and (3) for assessment of failed S/C retrieval.

Some simulation of the SLR's capability to determine attitude has been done, however, only for one configuration of retroflectors. Parametric data should be generated as well as feasibility of attitude determination at close ranges.

c) Supporting Analytical Studies: An analysis to develop a optical reflecting device that works in conjunction with the SLR for close-in ranging is a possible fruitful effort that should be considered in light of the requirements for close-in station keeping.

d) Related Hardware Development: Development of the optical sensor referred to above will be necessary if it indeed shows potential use. Other possible reflector configuration development may be necessary as well as related sensor (SLR) development to provide attitude data at close ranges.

e) Simulation/Demonstration Test Approach: This test should be configured in conjunction with docking port location tests because of the similarity in objectives and physical requirements. Tug vehicle dynamics should be simulated. A near full scale target cue should be provided with at least a $\pm 60^{\circ}$ motion in one axis. A representative S/C front end should be provided to assess the impact of reflections or tracking.

f) General Facilities Requirements: Dalto Gantry and Flat Floor.

NOTE: Detailed facility utilization will be described in the test procedures under separate cover.

g) Final System Verification Considerations: This function should be included in a final system verification because of its importance as a backup to preflight determination of attitude and its role as a real time cross-check of that attitude determination.

h) Desired Test Outputs: See attached checklist.

i) Justification: This capability is key to autonomous docking and has never been demonstrated under the expected ranges, lighting and dynamic conditions. The task is complex involving considerable new software. Its verification is vital to autonomous system development.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	X
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	X
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	X
ACS Propellant Requirements	
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	
______	
______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. I4M

FUNCTION TO BE TESTED: Manual Target Attitude Determination

CANDIDATE:

PHASE: Inspection/Closure

APPLICABLE TO: /X/ MANUAL /X/ AUTONOMOUS

PREPARED BY:

DATE:

a) Objective: This function shall be tested to evaluate the feasibility of determining vehicle attitude using a TV sensor and the range over which it is effective. Manual techniques of attitude determination shall be considered as well as possible autonomous methods. In conjunction with either method, a number of possible cues or patterns will be evaluated for effectiveness and ease of observation. Both manual and automatic methods of incorporating the derived attitude information into vehicle control laws will be evaluated. The Tug vehicle control function that is of interest in this test is the maneuvers required to align the Tug to a prescribed inertial orientation with respect to the S/C inertial attitude. (That orientation may or may not place the Tug +X axis coincident with S/C docking axis. It will depend on the closure algorithm.)

b) Reason for Test: The closure phase of rendezvous and docking is accomplished on the assumption a prescribed relative attitude has been achieved between S/C and Tug. This is necessary for an optimum closure (e.g., fuel, time). Merely locating the docking port visually does not necessarily define attitude. Relative attitude can be determined manually by observing, as an example, an "offset T" type of pattern. This is the simplest approach to attitude determination, though its only a relative, not an inertial attitude. All maneuvers must be accomplished manually. The eventual vehicles' attitudes are usually such that the docking areas are coincident. Angular offsets to accommodate certain closure algorithms would be difficult to achieve accurately.

Preliminary analyses at MMC have indicated that a TV system has the capability for autonomous attitude determination with little hardware impact other than possibly an additional pattern on the target. This capability should be investigated and data gathered in order to take full advantage of all available components in the final rendezvous and docking subsystem configuration.

c) Supporting Analytical Studies: Control system analysis will be required to develop algorithms for incorporating derived target attitude data into the control laws for automatically accomplishing a specific tug orientation with respect to the S/C.

Analyses will also be required to develop the software algorithms that transform TV image data from a target pattern into the target's attitude (e.g., deriving attitude from an image of a circle on the target that looks oblique because of the skew of the two vehicles).

d) Related Hardware Development: TV sensor hardware development is adequate to accomplish this function, however, system level hardware/software development will be necessary to develop the most promising sensor/pattern/algorithm configurations prior to initiating a major simulation/demonstration evaluation. A small tailored facility (such as MMC's TV simulator) that can evolve workable approaches over longer time spans is felt to be a cost effective approach in developing the automatic function.

e) Simulation/Demonstration Approach: The simulation/demonstration testing should be tailored to extend the automatic TV attitude determination development discussed in Item d) above by validating the most promising approaches under more specific Tug conditions and realistic, ground, target and vehicle dynamic characteristics.

Some target scaling may be utilized, but not at the sacrifice of any pattern or cue fidelity. Realistic lighting is necessary as well as visual scenes that could pose distractions to some of the TV attitude determination schemes (e.g., use of the lighted edges of the target as a pattern). Range simulation beyond the inspection radius (75' to 300') should not be necessary. This test setup should be coordinated with the docking port location test.

f) General Facilities Requirements:

- T27 Space Flight Simulator
- Flat Floor Facility

g) Final System Verification Considerations: Manual determination of target attitude and manual achievement of maneuvers for preclosure relative vehicle attitudes could very well be the primary means of accomplishing the docking, particularly on early flights. Consequently, this function should be tested during the proposed Shuttle flight test in order to achieve the highest fidelity in lighting, dynamics and TV transmission conditions. Accomplishing this test is critical to rendezvous and docking. Previous rendezvous and docking flight experience has indicated great sensitivity to the above factors, therefore, an orderly system verification is of high priority. The automatic capabilities referred to should be verified in-flight, but not necessarily on the Shuttle test flight or even the first operational flights. Again, a stop by stop verification approach is most cost effective since autonomy is not initially required.

h) Desired Test Outputs: See attached checklist.

i) New application (see Test R1M).

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	X
Procedure Development	X
Procedure Verification	X
Algorithm Equation Verification	X
Software Parameter Definition	X
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	
ACS Propellant Requirements	X
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirement	X
Ground Operations Hardware Requirement	X
Ground Operations Operational Impact	X
Communications Impact	
Other ________________	
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RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. I5

FUNCTION TO BE TESTED: Inspection and Commit-to-Dock Algorithm Development	
CANDIDATE:	PHASE: Inspection
APPLICABLE TO: /X/ MANUAL /X/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: The control and decision logic for this function shall be developed for both manual and autonomous performance of the inspection phase.

b) Reason for Test: The algorithms developed in this task are required to support the inspection and abort simulations defined in Tests I1A, I1M, I2A, I2M, I3A, I3M, I4A, I4M and C4A/C4M. Direct support of inspection phase and handover between inspection and closure based on commit-to-date decisions are included.

c) Supporting Analytical Study: Combination of software requirements from other tests must be synthesized into a set or sets for both autonomated and manual candidates.

d) Related Hardware Development Required: None

e) Simulation/Demonstration Test Approach: Simulation/demonstration testing of the algorithms shall be incorporated into the other inspection phase and abort tests. Algorithm performance can be verified analytically prior to the start of the tests for which the algorithms are required to support, as previously defined.

f) General Facility Requirements: Scientific computer processing center.

g) Final System Verification Considerations: Since the developed algorithms are used in support of many phases of the simulation/demonstration testing, the flight software validation will complete the system verification.

h) Desired Test Output: See attached checklist.

i) Justification: This is a new and unique software function that is integral in one form or another with any candidate. Its verification must be conducted to complete an end-to-end system design.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	X
Procedure Development	X
Procedure Verification	X
Algorithm Equation Verification	X
Software Parameter Definition	X
Software Parameter Verification	X
Hardware Concept Verification	
Hardware Design Verification	
ACS Propellant Requirements	
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	X
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	X
Communications Impact	
Other ____________	
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FUNCTION TO BE TESTED: Closure Algorithm Verification	
CANDIDATE:	PHASE: Closure
APPLICABLE TO: /X/ MANUAL /X/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to evaluate potential closure algorithms. Evaluation criteria shall be; ACS usage, TV image availability, software requirements, time to accomplish, sensitivity to initial conditions (e.g., range), sensitivity to loss of sensor data, etc.. The impact on all of the above as a result of automatic vs manual accomplishment shall be assessed as well. Much of the above data should evolve from analytical studies. Consequently, the function of this test shall be aimed at validating the fidelity of those analyses and providing certain data that is not generally an output of an analysis. Much of the objective will be satisfied in performing other tests, specifically the tracking test during closure C2 and C3.

b) Reason for Test: An obvious solution for an algorithm during closure is straight forward line-of-sight translation with the docking axes coincident and velocity at a constant. This is a reasonable solution, particularly suited to manual control. There are, however, variations to the above approach that may be more optimum from a propellant standpoint, or timelines. There is certainly some sort of range rate profile that has advantages over a constant velocity closure. An automated SLR closure is very likely to have a different optimum closure scheme than a TV man-in-the-loop closure. A good deal of the development of good closure methods will be analytical. The purpose of this test is to validate the concepts and obtain credible parametric data that supports the conclusions and definition of the final configuration.

c) Supporting Analytical Studies: Much of the algorithm definition and selection is most efficiently conducted as a software study. A control system analysis should be done to define any closure-peculiar control laws and their software implementation.

d) Related Hardware Development: None

e) Simulation/Demonstration Test Approach: This function's test should be conducted in conjunction with the tests for sensor tracking during the closure phase. In arriving at a test configuration for those tests the following additional factors should be considered in order to meet the objectives of this test as well:

1) Provide for docking axes offsets in tug initial conditions.

2) Incorporate flight representative control laws in the vehicle dynamics models.

3) Provide detailed data on ACS usage and event times.

f) General Facilities Requirements:

- Flat Floor
- Dalto Gantry
- T27 Computation

g) Final System Verification Considerations: This is a low-risk function and no special considerations are necessary. The essential role of the closure algorithms is integral with other more critical closure functions and those tests will more than adequately meet this test's objectives.

h) Revised Test Outputs: See attached checklist.

i) Justification: Autonomous closure and remote manned operation have never been demonstrated. New and more sophisticated algorithms (more than Apollo) will require extensive and careful verification before flight.

SIMULATION OUTPUT CHECKLIST

Concept Development	
Concept Verification	X
Procedure Development	
Procedure Verification	X
Algorithm Equation Verification	X
Software Parameter Definition	
Software Parameter Verification	X
Hardware Concept Verification	
Hardware Design Verification	
ACS Propellant Requirements	X
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	X
Communications Impact	
Other ______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. C2A

FUNCTION TO BE TESTED: Autonomous Target Tracking During Closure	
CANDIDATE:	PHASE: Closure
APPLICABLE TO: [ ] MANUAL [x] AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to verify that the SLR sensor shall provide the required data - LOS, Target attitude, range and range rate - over the range of operation from maximum inspection orbit radius (75' to 300') down to close-in station keeping (3' - 10') and in the presence of anticipated dynamic conditions, maneuvers, propellant slosh, etc. Target attitude determination concepts and capabilities are tested separately in test I6. During this test the selected concept from I6 will be evaluated specifically for its performance in a realistic closure phase environment. Particular attention shall be given to the close-in ranges since SLR capability for attitude determination as well as ranging is somewhat questionable at short ranges.

The ability to maintain "lock" on the target shall be determined. Where necessary reacquisition algorithms will be incorporated and evaluated. The impact of loss-of-lock on closure performance shall be defined.

The optimum utilization of SLR data during a manual closure (using TV) shall be established.

b) Reason for Test: This test shall be performed to determine the capabilities and limitations the SLR has in accomplishing an autonomous closure phase. Though this phase could very well be conducted manually on early flights, there is an inherent capability for an autonomous operation with an SLR. It is important to know and understand this capability before SLR design and development is initiated so that the design specification will be generated to exploit the sensor to the maximum extent possible. The desired result is a system with the greatest growth potential for the minimum additional cost.

A major design goal for autonomous operation is that all functions to be performed must be done very reliably and with a high assurance of success. In addition, automated procedures must be included in the design that provide for safe operation and recovery from anticipated off nominal conditions or failures. No detail study in this area has been done to date.

c) Supporting Analytical Studies: Development of equations for processing the sensor range, range rate, LOS and attitude information into vehicle control system commands must be completed. In addition, reacquisition or other failure backout procedures and algorithms should be defined analytically to the point where straight forward implementation in simulation software can be accomplished.

Potential algorithm shall have been developed and test C1 completed prior to this test.

d) Related Hardware Development: None, other than that already identified for the SLR in test I6 (target attitude determination) and C5 (close-in station-keeping).

e) Simulation/Demonstration Test Approach: Full scale target cue representation is desirable; however, if high fidelity scaled down retroflectors have been built for inspection phase SLR tests I2 and I6, they may be utilized here. Realistic target cues are more important for this test because of the closer ranges.

Good Tug vehicle dynamics (rotation and translation) are necessary. Target S/C dynamics are desirable at close ranges. This test should be laid out with the sensor inspection phase tests in mind. It may be desirable to split the closure phase evaluation into early closure phase tests, which can be accomplished together with inspection phase tests and, near-target tests which can be combined with close-in stationkeeping test. The close-in tests should be full scale but do not require the freedom of motion that early closure phase tests do. The early phase tests may be scaled with little loss in fidelity.

Good sensor hardware performance parameters are necessary from these tests because autonomous closure phase success depends very much on sensor hardware characteristics such as scan rate, track time, reacquisiton times, etc.

f) General Facilities Requirements:

- Dalto Gantry/TMS Combination
- Flat Floor Facility

g) Final System Verification Considerations: Since autonomous operation is not likely for the first flights, the final system verification for this function should be conducted as a special test on one or more of the early operational flights. The baseline manual or hybrid configuration provides a good monitor and failure backup during this mission by mission verification process.

h) Desired Test Outputs: See attached checklist.

i) Justification: Dynamic disturbances have increasingly larger impact as closure approaches docking range. These effects can be determined prior to flight and will impact the system design. It is for these reasons that this test is considered necessary.

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. C2A

Sheet 3 of 3

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	X
Software Parameter Definition	X
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	
ACS Propellant Requirements	
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	
______	
______	

FUNCTION TO BE TESTED: Manual Target Tracking During Closure	
CANDIDATE:	PHASE: Closure
APPLICABLE TO: /x/ MANUAL /_/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to: (1) verify that the vehicle can be controlled along a prescribed closure path manually, via use of TV imaging on the ground and (2) evaluate potential methods of performing this closure automatically or in a hybrid fashion using the TV as a sensor. The above shall be accomplished over the ranges of vehicle dynamics, maneuvers, lighting conditions, visual distractions, target docking axes offsets and all possible closure velocity profiles.

Major emphasis shall be on the ground operations and communications subsystem constraints that impact the TV/man operations and his effectiveness in reliably and safely accomplishing the objectives, specically (1) above.

b) Reason for Test: Simulations, such as GDC is developing, have evaluated a "supervisory" type of closure concept where man is in the loop only to take out bias or drift errors on a periodic basis (once each picture, which is every 16 secs). This concept abides by the rather serious constraint of data rate transmission. Closure algorithms can be postulated, as well as off-nominal visula scenes and dynamic conditions, that will not permit a reliable docking with this supervisory concept. Failures can be conceived that cannot be handled. It appears essential to evaluate other alternate schemes, such as data compression, for example, that permit more "live" TV imaging, and consequently greater manual participation. This results in less complex on-board control schemes and better potential of handling off-nominal situations.

Autonomous TV closure concepts should be considered also. There is a potential capability in the TV to determine range and range rate data at close ranges. See test I2 (autonomous TV inspection). An autonomous closure concept certainly alleviates the image delay problems that are unavailable with the current tug communications baseline.

c) Supporting Analytical Studies: Some analysis for development of the software processing methods that derive range, range rate, attitude, and LOS data from TV imaging will be required. This analysis is common with tests I2 and I7 (autonomous TV inspection functions). Closure phase control system analysis results will also be applied to this task.

d) Related Hardware Development: None

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e) Simulated/Demonstration Test Approach: Some scaling of target size may be feasible in this test, particularly for manual operations. The autonomous operation, however, may have to utilize larger targets in order to achieve the necessary cue fidelity. Vehicle dynamics are important as are lighting and visual effects.

f) General Facilities Requirements:

- T27 Space Flight Simulator
- Dalto Gantry/TMS
- Flat Floor(s)

g) Final System Verification Consideration: The manual TV closure, being the anticipated primary mode on early flights, should be exercised in the shuttle orbit test flight. The automated schemes may be evaluated and verified as part of a phased development approach during the first flights.

h) Desired Test Outputs: See attached checklist.

i) Justification: Manual tracking capability is influenced by lighting, shadowing and dynamics. Uplink/downlink delays also influence these capabilities and the combinations of effects should be simulated.

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. C2M

Sheet 3 of 3

SIMULATION OUTPUT CHECKLIST

Concept Development	
Concept Verification	X
Procedure Development	
Procedure Verification	X
Algorithm Equation Verification	X
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	
Hardware Design Verification	X
ACS Propellant Requirements	
Vehicle Dynamics Data	
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	X
Ground Operations Hardware Requirement	X
Ground Operations Operational Impact	X
Communications Impact	
Other	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. C3M

FUNCTION TO BE TESTED: Manually Achieve and Maintain Close-In Station Keeping	
CANDIDATE:	PHASE: Closure
APPLICABLE TO: / / MANUAL /x/ AUTONOMOUS	
PREPARED BY: R. O. Zermuehlen	DATE: 8-22-75

a) Objective: This function shall be tested to evaluate the capability and methods for manually closing to a predetermined range of less than 10 feet; stopping the relative closing velocity, then maintaining that range for a length of time necessary to accomplish functions such as detail close-in TV inspection, positioning of a servicing arm, or positioning a non-impact docking probe.

This phase shall be evaluated over the range of initial conditions that can be extrapolated from the closure tests, C1 and C3. The more critical conditions to be considered are range, velocities, accelerations, docking axis misalignments, vehicle dynamic states, etc.

The man-in-the-loop responses shall be evaluated carefully under realistic constraints of data rates, image availability, image fidelity, etc. Various concepts for speeding the TV imaging on the ground shall be evaluated.

ACS propellant usage shall be gathered.

b) Reason for Test: One reason for this test is to assess the ability of the baseline subsystem to perform the servicing function. Non-impact docking for servicing requires a stationkeeping position just a foot away from a target vehicle. Specific design for this function is not currently required. One purpose, however, for early development testing is to determine the inherent hardware capabilities and limitations that exist and identify possible additional requirements to be imposed prior to final design that result in a good growth potential and lower overall program costs.

Another reason is to evaluate the control capabilities of utilizing a non-impact docking device. At the time final docking mechanism design selections are made, all aspects of maintaining the necessary relative motion of the two vehicles, including design costs, must be quantatively defined for both impact and non-impact mechanisms in order to make a firm and rational judgement.

c) Supporting Analytical Studies: Some analyses already identified to support test C3 will be applicable to this test as well. It relates to development of imaging concepts that will enable faster response of the man on the ground in commanding necessary vehicle maneuvers. This is more critical for this function than any other.

Some control system analyses will be necessary to define control laws for the fine method translation control that will be necessary at close-in ranges.

d) Related Hardware Development: None

e) Simulation/Demonstration Test Approach: Full scale hardware with realistic dynamics and control capability is desirable for this test. Independent 6DOF motion of at least one vehicle is desirable but not necessarily required. This test setup should be coordinated with the docking mechanism tests. High fidelity of ground operations and man-in-the-loop functions are necessary.

f) General Facilities Requirements:

- T27 (man-in-the-loop evaluation)
- Flat Floor(s)
- 6DOF Motion (good vehicle dynamics)

g) Final System Verification Considerations: Verification of this function will depend on the nature of the docking mechanism. If non-impact, this function will have to be verified on the first shuttle flight. Otherwise, its demonstration can be incorporated into the operational flights as servicing or other needs become identified.

h) Desired Test Outputs: See attached checklist.

i) Justification: New application, see test I1M.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	
Procedure Development	X
Procedure Verification	
Algorithm Equation Verification	X
Software Parameter Definition	X
Software Parameter Verification	
Hardware Concept Verification	
Hardware Design Verification	
ACS Propellant Requirements	X
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	X
Ground Operations Hardware Requirement	X
Ground Operations Operational Impact	X
Communications Impact	
Other ______	
______	
______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. C3A

FUNCTION TO BE TESTED: Automatically Achieve and Maintain Close-In Stationkeeping	
CANDIDATE:	PHASE: Closure
APPLICABLE TO: / / MANUAL /x/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to evaluate concepts for automatically stopping vehicle closure at some predetermined range, then maintaining relative state between the two vehicles indefinitely within a reasonably tight set of limits on velocities, angular rates, translational motion, etc.

Several sensor options shall be evaluated such as a modified SLR, TV or other simple proximity devices. The maximum range of initial conditions that can be derived from the closure phase tests shall be considered. ACS propellant data shall be gathered as well as vehicle motion data.

b) Reason for Test: The capability of a man-in-the-loop close-in stationkeeping concept has not been demonstrated to date. General impressions are that unless the data rate constraints can be relieved on TV imaging updates, it is unlikely such a function can manually be performed accurately. Test C3M will determine these capabilities and limitations. This test will evaluate automatic methods that should be considered alternatives for the manual mode. The testing is also necessary to formulate an achievable autonomous rendezvous and docking subsystem candidate configuration.

TV capability of accomplishing this function should be evaluated, if for no other reason, than that it is already in the baseline. Addition of a simple pattern and some software algorithms may provide the capability in the most cost effective manner.

c) Supporting Analytical Studies: Control system analyses will be necessary to develop autopilot control laws that receive sensor data and automatically provide vehicle control within optimized translational and angular motion deadbands.

Analysis may be required in conjunction with the development of some new proximity devices. An example is development of a corner cube/mirror reflector device that can operate in conjunction with the SLR to provide attitude information with the SLR at close ranges.

d) Related Hardware Development: Some development, possibly in several areas, will undoubtedly be necessary to provide the capability for determining relative vehicle states (attitude and translation) at close in ranges. No developed hardware is currently available to accomplish this function. Typical of such devices are: a light emitting diode (LED) in conjunction with an optical reflector, a modified SLR and a new design retroflector, capacitive or mechanical sensors, TV with special patterns. or cues, etc.

e) Simulation/Demonstration Test Approach: Full scale simulation is desirable. Vehicle dynamic motion simulation is essential, however, large translation or rotational movement is not necessary. Simulated vehicles should be designed for a number of possible sensors and cues and easy interchange of either. Lighting simulation should be available, specifically for the TV options. Good tug vehicle and S/C control system representation is essential since relative motions should be quite low, even for a full scale simulation.

This test may share facilities with the closure phase TV tracking test C3.

f) General Facilities Requirements:

- 6 DOF motion simulators
- Flat Floor(s)

g) Final System Verification Considerations: This function is to be tested for evaluation purposes and has a supporting role in configuration selection. Requirements definition for final system verification is premature at this time. They will be dependent on configuration selections.

h) Desired Test Outputs: See attached checklist.

i) Justification: Autonomous stationkeeping is a new technology concept critical to non-impact docking and servicing. Demonstration of this capability is imperative before flight.

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. C3A

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	X
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	
ACS Propellant Requirements	
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	
______	
______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. C4A

FUNCTION TO BE TESTED: Abort Procedures-Autonomous Closure	
CANDIDATE:	PHASE: Closure
APPLICABLE TO: /_/ MANUAL /x/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to evaluate the capability of the autonomous closure techniques, whether TV or radar, to detect a certain percentage of anticipated anomalous conditions and provide the corrective action necessary to avoid catastrophic impact on target or tug. Several methods that have a high degree of failure detection and correction shall be evaluated and parametric data gathered on ACS usage, timeline impact, reattempt potential, etc.

The methods of reattempting an aborted docking shall also be investigated, with the impact on hardware, ACS usage, etc., defined wherever possible.

b) Reason for Test: Autonomous operation considerably compounds detecting anomalous conditions as opposed to a man-in-the-loop performing that function. Man can make value judgements that can be extremely complex to duplicate in an autonomous configuration. This test will be aimed at determining the capability of the rendezvous and docking hardware (and software) to perform this function autonomously. The strategies themselves that will accomplish the abort will be investigated as a part of Test C4N (manual abort procedures). In order to not duplicate any effort, this test will evaluate only those aspects of the overall strategies that relate directly to the autnomous function.

c) Supporting Analytical Studies: Systems level analysis must precede this test to arrive at potential methods for detecting abort conditions and to arrive at candidate means of implementing them. Tug and S/C failure mode and effects analysis will be necessary to determine the range of anomolous conditions to be anticipated.

d) Related Hardware Development: Some sensor failure detection schemes may require some hardware design effort to determine feasibility and implementation details sufficient for simulation.

e) Simulation/Demonstration Test Approach: This function should be tested in conjunction with the closure tests but should be tested on only the most likely configurations to be selected to avoid excessive runs.

There are unique requirements for this test that should be considered in configuring the other closure tests; the goal being able to accommodate the abort testing within the closure testing with minimal impact. Some of these considerations are:

1) Provide target/tug travel to accommodate abort evasive maneuvers (side translation ≈ tug diameter).

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2) Setup simulation software to accommodate simulation of vehicle maneuvers/ dynamics at maximum rates, attitudes and translations compatible with 1) and failure mode cases.

3) Provide for abort detection and implementation algorithms in flight software.

4) Configure target and tug structural envelope to support evaluation of vehicle collision potential.

f) General Facilities Requirements:

- o Dalto Gantry
- o Test Lab Flat Floor

g) Final System Verification Considerations: The final system verification will be a simulation facility function and logically should be a second phase of the test described herein. It should include flight software and flight hardware versions of any design that may be identified during this test. No in-flight abort testing is anticipated.

h) Desired Test Outputs: See attached checklist

i) Justification: New Technology. See tests C1A and C3A.

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. C4A

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	
ACS Propellant Requirements	X
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	
______	
______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. C4M

FUNCTION TO BE TESTED: Abort Procedures - Manual Closure	
CANDIDATE:	PHASE: Closure
APPLICABLE TO: /X/ MANUAL /_/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to: (1) develop effective, simple methods of avoiding serious impacts in the event of failures during closure; and (2) verify that the most promising methods can provide a safe, minimum-impact recovery from all anticipated failures of Tug, target vehicle, and ground/mission operations functions. A considerable amount of manual abort concepts will be procedural in nature, however consideration must be given to providing the necessary information to the ground for procedural operations and the time responses involved in those actions, both of which may result in hardware impact.

b) Reason for Test: The rendezvous and docking system should be designed such that failures during the rendezvous and docking phase, specifically docking, should not result in any greater impact on either vehicle than would occur to the failed vehicle during any other non-docking phase. In other words, any relatively minor failure on either Tug or spacecraft should not propagate into a major disaster, such as a collision. Consequently, all anticipated failures must be defined and examined for impact. Those that will affect the rendezvous and docking phase success, or jeopardize either vehicle, will require provision for detection and a method of correcting the problem. Other Tug subsystems will be involved such as failure detection circuits in the IGS, or algorithms in the computer software.

Another reason for aborting is sudden recognition on the ground via TV or data of an undesirable situation which may not necessarily be failure induced such as a docking port physical status being other than expected.

c) Supporting Analytical Studies: Tug and spacecraft failure mode and effects analysis will be necessary. Some analysis may be required in support of hardware failure detection design schemes.

d) Related Hardware Development: Some minor hardware development may be necessary if hardware failure detection (or correction) methods are defined.

e) Simulation/Demonstration Test Approach: The comments and criteria presented in Test C6, Autonomous Abort Procedures, are applicable here as well. More emphasis will be placed, however, on procedures and man-in-the-loop reactions and responses for this manual configuration. Closer attention will have to be paid to fidelity of the ground operations, communications links, delays, etc., that impact the manual mode more directly than they do the autonomous.

f) General Facilities Requirements:

- T27 Space Flight Simulator
- Flat Floor Facilities
- Dalto Gantry

g) **Final System Verification Consideration**: See C4A Autonomous Abort Procedures.

h) **Desired Test Outputs**: See attached checklist.

i) **Justification**: New technology application; see Test C3M.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	
Procedure Development	X
Procedure Verification	
Algorithm Equation Verification	
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	
Hardware Design Verification	
ACS Propellant Requirements	X
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	X
Ground Operations Hardware Requirement	X
Ground Operations Operational Impact	X
Communications Impact	X
Other ______	
______	
______	

RENDEZVOUS AND DOCKING SUBSYSTEM
TEST DESCRIPTION NO. D1

FUNCTION TO BE TESTED: Probe and Latch Design and Operation

CANDIDATE:	PHASE: Docking
APPLICABLE TO: /X/ MANUAL /X/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to verify that the selected candidate docking mechanism(s) will capture the target and accomplish hard dock latching under all anticipated extremes of dynamic motion, vehicle lateral offsets, angular errors and velocity mismatches. Specifically, this will be an evaluation of full scale, flight representative hardware. The ability to perform initial capture may be tested independently of latching, depending on the nature of the mechanism. The performance of an extendable step-type of probe can be assessed independent of its ability to make a hard-contact latch.

Sufficient testing should be conducted to arrive at credible predictions of probability of latch.

b) Reason for Test: The Tug docking mechanism will, for all practical purposes, be a new design. Though there will be borrowed technology from other programs wherever possible, new requirements and totally different loading conditions require a complete and thorough hardware test program under the most realistic simulated flight conditions. Simulated flight conditions are the key to this test program. A hardware test program, by itself, cannot provide a credible probability of success since that figure of merit depends entirely on the state of two multi-variable vehicles. A full scale, 6-DOF, realistic vehicle simulation, rather than laboratory test jigs, is required to complete verification of the mechanism design.

c) Supporting Analytical Studies: None required in support of this test. There will, of course, be the routine mechanism design analysis and stress analysis conducted as a part of the design task. Also, sophisticated docking dynamic analyses will be conducted prior to design in order to arrive at the design requirements, both for the mechanism and the Tug vehicle (structure, control system, etc.).

d) Related Hardware Development: This test is really the concluding step in the total mechanism hardware development. Considerable related development will be a part of this total effort, of course, such as the latches, the probes, the supporting structure, the variable diameter accommodation mechanism, the spin adapter, the extendable, steerable probe, etc., etc.

e) Simulation/Demonstration Test Approach: Use of full scale hardware is the only meaningful approach. The stem, or probe, design verification may be considered separately depending on the configuration selected. Testing should be a two-phased approach. The first may use an inexpensive single (possibly two) degree(s) of freedom simulation for initial concept evaluation. Final flight hardware latches, structures, etc., can be credibly evaluated only in a 6-DOF environment.

f) General Facilities Requirements:

- 6-DOF Simulator
- Neutral Buoyancy
- Test Lab Flat Floor

g) Final Systems Verification Considerations: Phase 2 of this test will, in essence, serve as a preliminary final system verification. The ultimate test will be a successful docking on the Shuttle flight test proposed earlier.

h) Desired Test Outputs: See attached checklist.

i) Justification: Probe and latch designs will require the defined test as a normal phase of development program, since all mechanisms are at least partially new designs.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	X
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	X
ACS Propellant Requirements	
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ____________________	
____________________	

FUNCTION TO BE TESTED: Dynamic Effects - Pre- and Post-Latch	
CANDIDATE:	PHASE: Docking
APPLICABLE TO: /X/ MANUAL /X/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to determine the dynamic conditions and control modes that are vehicle induced (prior to contact) and that are both vehicle and contact mechanism generated from initial contact through hard latch, including dynamics of combined vehicles. This test will attempt to quantify the range of vehicle conditions that can exist during this phase and how they impact the contacting device, be it stem or probe or guide. The corresponding effect of the initial contact process on the dynamic conditions shall also be determined. A secondary objective shall be to determine the range of vehicle dynamic conditions that can result prior to, during, and after final hard latch has been accomplished. The purpose here is to determine ACS propellant usage and Tug control system transient data for autopilot design parameter definition. Slosh dynamics and propellant plume impingement are of principal concern.

Note that the final contact and latch design is not the key concern in this test. Test D1--latch operation--addresses that area.

b) Reason for Test: A major driver in any system involving a probe and, in particular, a soft dock or semi-soft dock mechanism that employs a long stem or probe (possibly steerable), is the dynamic motion between the two vehicles this device will have to be designed to take out. This test will deve op that data and at the same time evaluate several such candidate devices. The mechanism structural characteristics, the drive motor and gearing design, the steering requirements and implementations, all depend on those dynamic characteristics of the two flexibly attached vehicles. Slosh effects are a major unknown.

The post-latch dynamic conditions are also desired for reasons already stated above in Item a). This data should be easily gathered from this test with some minor reconfigurations.

c) Supporting Analytical Effort: This test phase will have been preceded by a computer dynamic analysis program designed to identify the initial mechanism design specification. This test is a verification of the resulting designs. Some analysis will be required after these tests to relate results to control system parameters.

d) Related Hardware Development: This test is in direct support of the initial contact mechanism hardware development and design.

e) Simulation/Demonstration Test Approach: Full scale hardware tests are desirable. Complete latch mechanism hardware details may not be necessary, however, the vehicle(s) representation, including slosh, should be realistic, with valid control system representation as well. The initial contact device should be as flight hardware representative as possible.

f) General Facility Requirements:

- o 6 DOF Motion System
- o Neutral Bouyancy Facility
- o Flat Floor Facilities

g) Final System Verification Considerations: Final system verification should be a combined test of the entire docking mechanism design--contact device, latches and structural members. This test setup may be expanded to accomplish this, however, the true test may be best reserved for the proposed Shuttle flight test.

h) Desired Test Output: See attached checklist.

i) Justification: Data gathered for this test will provide specification information for Tug and spacecraft control systems.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	X
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	
Software Parameter Definition	X
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	X
ACS Propellant Requirements	X
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	
______	

FUNCTION TO BE TESTED: Docking Abort Procedures	
CANDIDATE:	PHASE:
APPLICABLE TO: /X/ MANUAL /X/ AUTONOMOUS	
PREPARED BY:	DATE:

a) Objective: This function shall be tested to evaluate the feasibility and methods of accomplishing an abort during the terminal docking phase. Specifically this shall be concerned with undocking after initial contact and undocking after hard latch. The hardware actions required to accomplish these functions under nominal and off-nominal dynamic vehicle conditions shall be evaluated. The impact of autonomous vs manual configurations shall be evaluated with respect to performing an abort.

b) Reason for Test: Conditions will undoubtedly arise where the docking process is desired to be reversed. A failure of the mechanism or S/C may occur that renders further docking impossible or undesirable. An unsuccessful hard docking may have occurred (partial latch-up) and the vehicle may have to be backed up for a retry. The overall mechanism design must consider incorporating the undocks, or abort, capability. This test will determine how this can be accomplished and how effective the candidate designs are.

c) Support Analytical Studies: A failure analysis will be required to identify the failures and/or conditions of Tug and spacecraft that will require undocking. The results of this will be used in designing the means of accomplishing it.

d) Related Hardware Development: Undocking is a requirement directly affecting docking mechanism hardware design. The latches, probe and the sequencing of these devices all must incorporate unique features to provide undocking. This test will aid by providing design criteria for design of these mechanisms. In the second step of a two-step process the resulting designs will be evaluated for effectiveness with essentially the same test conditions.

e) Simulation/Demonstration Test Approach: This function should be tested as a part of the two previous docking tests - latch operation (D1 and contact dynamics (D2). These tests should be designed with the objectives of this test in mind. Certain unique capabilities may be necessary to do that. Vehicle motion reversibility shall be necessary, for example.

f) General Facility Requirements:

- o 6 DOF Motion System
- o Neutral Bouyancy Facility
- o Flat Floor Facilities

g) Final System Verification Considerations: This function can safely be verified in-flight, during the Shuttle test flight, with no real safety or mission success impacts. It is recommended that it be included as the final task in that test.

h) Desired Test Output: See attached checklist.

i) Justification: Refer to Test D1.

SIMULATION OUTPUT CHECKLIST

Concept Development	X
Concept Verification	
Procedure Development	
Procedure Verification	
Algorithm Equation Verification	
Software Parameter Definition	
Software Parameter Verification	
Hardware Concept Verification	X
Hardware Design Verification	X
ACS Propellant Requirements	
Vehicle Dynamics Data	X
Hardware Design Criteria/Parameters	X
Ground Operations Software Requirement	
Ground Operations Hardware Requirement	
Ground Operations Operational Impact	
Communications Impact	
Other ______	
______	
______	

VOLUME III - PROCEDURES AND PLANS

Part IVA - MANUAL SYSTEM TEST PROCEDURES

MANUAL

RENDEZVOUS AND DOCKING SYSTEM

TEST PROCEDURES

CONTENTS

1. INTRODUCTION

This document is a compilation of the functions which should be tested to demonstrate a manual Rendezvous and Docking (R&D) system. A procedural set is included in this report as Part IVB for the autonomous R&D systems. Included are the test procedures which detail the test objectives, test setups, support requirements, and schedules to provide development which is compatible with the STS program. Existing MSFC facility utilization has been maximized to avoid development of new facilities with their resultant costs and schedule problems.

Part III of this Volume contains the test descriptions from which these procedures were developed.

2. MANUAL CANDIDATE DESCRIPTION

The candidate systems are comprised of three subsystems. They are sensors, mechanisms, and strategies or algorithms. The sensor measures range and angular separation which must be reduced to zero to effect docking. The algorithms are designed to reduce these sensed values to some residuals which can be accommodated by the docking mechanism. Subsystem requirements budgets and tradeoffs were used to assist in selecting the candidate subsystems for the manual system described in the following paragraph.

a. SENSORS

The sensors recommended for the manual candidate include a TV camera for inspection, final closure and docking phases, and a RF rendezvous radar for the rendezvous phase. Rationale for this selection, a ranking list of the candidates and the tradeoffs related to the selection process are addressed in

The procedures are general enough to encompass other sensors of a similar type which appear in the ranking lists, and therefore allow flexibility to changing system requirements.

b. MECHANISM

The mechanism ranking highest for the manual docking system candidate was the MDAC square frame concept. It is illustrated in Figure The rationale for selection, other candidates rankings, and tradeoff results are documented in Section III, Volume II of this report.

c. STRATEGIES

The strategies for the candidate manual system are the methods by which inspection, alignment, and docking are accomplished. These include onboard and ground based algorithms for implementing the methods. Algorithms divide into decision, maneuver, sensor utilization and redundancy management categories. The degree to which each category interacts with man-in-the-loop is a function of the system autonomy. The algorithms are developed using standard software development techniques and represent no significant advances in the state of the art.

Note: Estimates of effort and cost associated with each test cannot be used independantly. They assume the cost of some individual tests would increase if others were deleted.

3. TEST PROCEDURES

TEST PROCEDURE R1M
MANUAL ACQUISITION, TRACKING, AND RANGING AT MAXIMUM RANGE

1.0 PURPOSE

The objectives of this test are to establish the docking sensor capability to:

(1) Acquire the target spacecraft at maximum anticipated range;

(2) Perform effective range and LOS angle measurements at acquisition range;

(3) Operate with available light, ascertain wehther target aids and artificial lighting will extend the effective range; and

(4) Utilize the algorithms developed for determination of range and LOS angle data.

2.0 SCOPE

A TV has been baselined on the Tug for inspection purposes as well as a role in manual rendezvous and docking. The capability of the TV as a primary or backup rendezvous sensor for acquisition is investigated in this test. Obviously, the determination of range and LOS angle implies more than just locating the spacecraft. The use of spacecraft pattern recognition techniques and stadian-type ranging with the TV image data will be considered. Lighting requirements and software algorithms (onboard or mission control) for using the image data for determining range and LOS angle will be assessed.

3.0 APPROACH

The requirements for this test necessitate separation of the target spacecraft and tug mounted sensor by $\approx$ 25 n mi range. Since the primary sensor for this test is the TV, the use of spacecraft models and scaling on the T27 simulator appears feasible and cost effective. Alternatives include a Shuttle flight test, aircraft flight test, and a high altitude test using full scale hardware. Because the inspection and closure phases of the test program are planned to utilize the T27, the extension of the system to rendezvous ranges appears feasible and will result in cost savings. However, the option should be kept open to utilize the autonomous candidate approach (high altitude test) if problems arise.

4.0 TEST SETUP

The test shall be performed on the T27 Space Flight Simulator as illustrated in Figure R1M-1. The setup to provide the target spacecraft image data is detailed in Figure R1M-2.

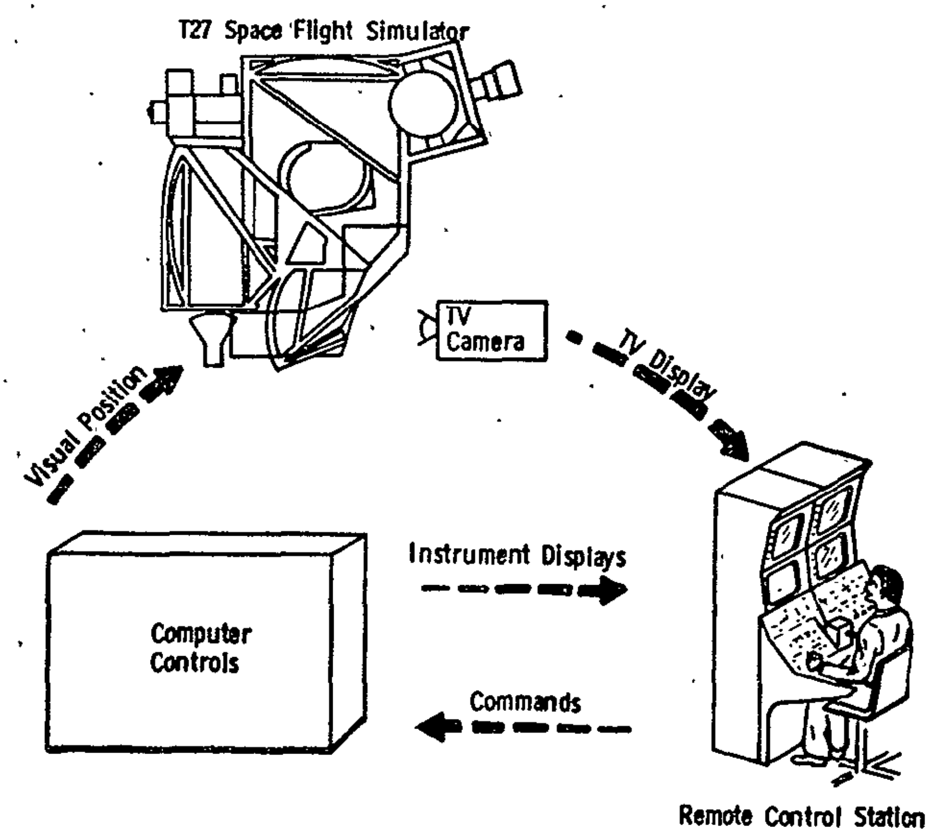

Figure R1M-1 Manual Acquisition, Tracking, and Ranging Test Setup

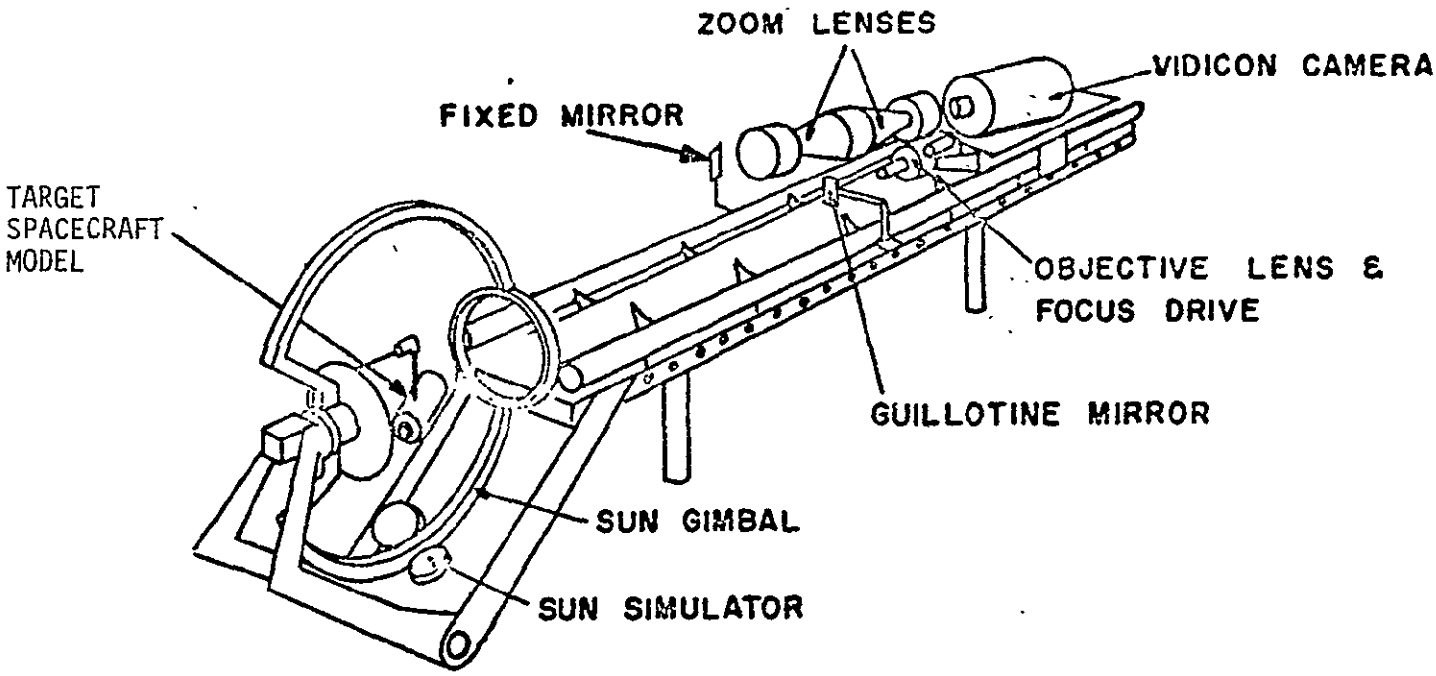

Figure R1M-2 Target Spacecraft Image Generation Model

5.0 TEST DESCRIPTION

Test runs shall be conducted using models of each selected spacecraft while varying the lighting conditions and celestial scenes over anticipated or representative ranges.

Four spacecraft have been selected to represent the retrieval spectrum. Each spacecraft model will be subjected to a series of six (6) runs demonstrating acquisition from each direction along the major axes. These runs will be repeated at simulated ranges of 10, 15, 20, and 25 n mi separation. If the initial set of runs indicates artificial lighting is required, the tests will be repeated using supplemental lighting and subsequent tests will evaluate the lighting needs.

This test scenario uses 96 test runs and the data gathered will include actual versus indicated range and LOS angles (i.e., what the man in the loop considers the range to be versus the simulated range and residual LOS angle error when the operator thinks LOS angles are nulled). The following matrix (Table R1M-1) essentially constitutes a data sheet for recording results. Each test run is estimated to require an average of 5 minutes for the console operator to acquire, track (null LOS) and determine range. Between runs the range or target model attitude will be changed, as well as changing the spacecraft models.

6.0 ANTICIPATED RESULTS

The data derived from this series of tests is anticipated to establish useful range for acquisition and tracking of representative spacecraft. Supplemental lighting requirements and TV pointing constraints are expected to be established and verified. The test results may require imposing of operations constraints on mission planning to preclude approach trajectories resulting in TV pointing within TBD degrees of the sun and moon.

Since the TV has never been used as a backup to the ranging sensor, this test is important to establish the capability of the TV to accomplish this role.

7.0 SUPPORT REQUIREMENTS

A. Test Facilities - The T27 space simulator is considered adequate for the requirements of this test. However, mounting the TV sensor in front of the pilot window, providing display of the composite image, and simulated pointing of the sensor for acquiring the target from the console are new requirements. Also, celestial scenes shall be expanded to encompass geostationary altitude and representative spacecraft models are required.

Table R1M-1 Manual Acquisition, Track and Ranging Data Sheet

		Simulated Range (n mi)											
		10			15			20			25		
S/C	Approach Direction	Measured Range	Offset	Light Required	Measured Range	Offset	Light Required	Measured Range	Offset	Light Required	Measured Range	Offset	Light Required
1	+ X												
	- X												
	+ Y												
	- Y												
	+ Z												
	- Z												
2	+ X												
	- X												
	+ Y												
	- Y												
	+ Z												
	- Z												
3	+ X												
	- X												
	+ Y												
	- Y												
	+ Z												
	- Z												
4	+ X												
	- X												
	+ Y												
	- Y												
	+ Z												
	- Z												

C.2

B. Software - Tug control software and range determination algorithms are required. However, since similar simulations were performed for Apollo rendezvous and docking with the Lunar Module and with Skylab, an adaptation of that software may be feasible. This should be the subject of an analytical study preceding the rendezvous algorithm development test. The rendezvous algorithm becomes part of the Tug control software which is then used in this test.

C. Personnel - Actual test run time for 96 runs at 5 minutes each is approximately 8 hours. In addition to the console operator, a technician is required to change and verify actual ranges, change spacecraft models, and related test setup activity. Additionally, hybrid computer laboratory support is required at a ____ man level. Initial test setup, facility modifications, model building, and software development or modification estimates are tabulated in Table R1M-2.

Table R1M-2 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	300 Hrs
Facility Operations Costs	$ 11,700
Engineering Manpower	3.1 MM
Technician Manpower	9.4 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	3.0 MM
Technician Manpower	3.0 MM
Software Analyst	3.0 MM
Software Programmer	3.0 MM
Facility Modifications	$ 7,500
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.5 MM
Test Reports	$ 500

TEST PROCEDURE R2
RENDEZVOUS ALGORITHM VERIFICATION

1.0 PURPOSE

This test will select the rendezvous scheme best suited for autonomous and/or manual rendezvous methods. The selected algorithms will be used with the other tests of the rendezvous series to ensure they can accomplish the rendezvous under all anticipated conditions. The test is also useful in developing performance criteria feedback into the Tug design, specifically in the areas of timelines, ACS propellant budgets, power profiles, etc.

2.0 SCOPE

The rendezvous algorithm development is not a primary goal in itself, but is in the category of providing a support tool for the rendezvous demonstration. The algorithm development is significant in that it is required prior to performance of the rendezvous simulations, and the software developed will be a prototype for the Tug on-board computer software. Both autonomous and manual rendezvous algorithms are covered by this test.

3.0 APPROACH

A strictly software modeling approach is planned for this test. However, the algorithms developed by this method will be used and refined in the subsequent demonstrations of functions included in the rendezvous phase. Since the software is for both autonomous and manual rendezvous, the capability is developed to autonomously select an efficient closure path while manually or autonomously maintaining line-of-slight tracking of the vehicle.

4.0 TEST SETUP

Computer modeling is utilized for this test and therefore no test setup is required, per se. Use of the MSFC rendezvous and docking laboratory hybrid computers is assumed. Validation of the software encompasses use for the other rendezvous phase tests.

5.0 TEST DESCRIPTION

The test will consist of computer runs simulating rendezvous maneuvers of the tug. The rendezvous system recommended for use is a Proportional Navigation scheme. Inherent in the algorithm will be the application of sensed range and LOS angle data to the Tug control laws.

6.0 ANTICIPATED RESULTS

Results of this test are anticipated to provide a checked out set of software. This software can be used to simulate the tug control system responses to autonomous sensor inputs or remote manned console inputs based on man in the loop visually maintaining LOS pointing.

The rendezvous algorithm for the geostationary application is sufficiently different from Apollo and evaluation is considered essential. Performance of software simulations under anticipated conditions is cost-effective before use of the algorithms for rendezvous phase tests involving hardware.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The support facility requirements are satisfied by use of MSFC rendezvous and docking laboratory existing capabilities

B. Software - A software program must be developed or adapted from existing Apollo programs.

C. Personnel - Software analyst and programmer personnel are required. Approximate manpower requirements are shown in Table R2-1.

Table R2-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	100 Hrs
Facility Operations Costs	$ 2,300
Engineering Manpower	.3 MM
Technician Manpower	1.2 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	1.0 MM
Technician Manpower	- MM
Software Analyst	1.0 MM
Software Programmer	1.0 MM
Facility Modifications	$ -
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.5 MM
Test Reports	$ 500

1.0 PURPOSE

This test will demonstrate RF or SLR rendezvous sensor capability to maintain line of slight (LOS) lock on the target under anticipated rendezvous conditions. Even for the manual candidate, this phase of operations uses autonomous tracking. However, the capability of man in the loop to monitor the LOS tracking and assume control if lock-on is lost is considered a valuable objective and was demonstrated in test R1M.

2.0 SCOPE

This test encompasses the Tug and spacecraft separation ranges from ~ 25 miles to inspection distance (50 - 100 ft) to verify tracking can be maintained during these maneuvers. The inspection series of tests are a sequential phased continuation of this activity. However, due to the ranges involved, scaling would be necessary to simulate this phase with existing facilities. Since scaling is easily accommodated for TV (telephoto zoom lenses), the separation of the tests into a full scale test of the rendezvous radar and a scaled down test of the TV is proposed.

3.0 APPROACH

The RF or SLR rendezvous radar is tested using full-scale target models over the same relative range and using the same test setup as test R1A for maximum autonomous rendezvous range capability.

A result of the previous test is expected to be the specification of useful range for the TV as a backup rendezvous phase sensor.

4.0 TEST SETUP

The test is conducted using a mobile vehicle mounted sensor and a full-size target spacecraft mockup with reflectors. This test is conducted as illustrated in Figure R3M-1.

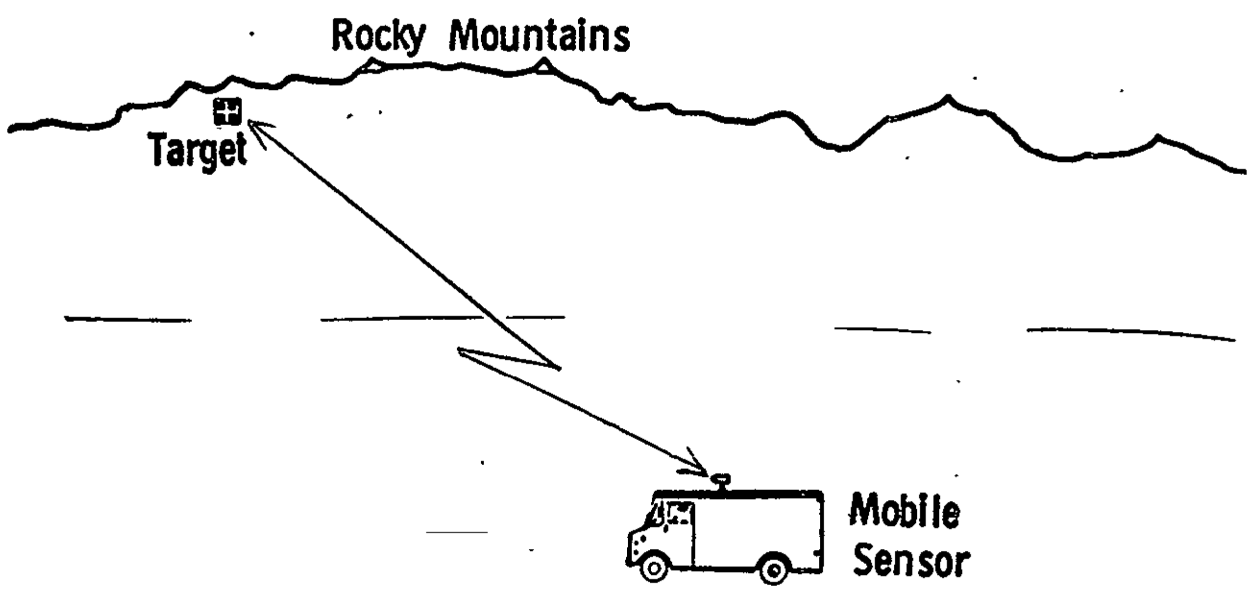

Figure R3M-1 Rendezvous Sensor Tracking Test Setup

5.0 TEST DESCRIPTION

This test will consist of driving the mobile sensor-carrying vehicle over a prescribed course covering the range of variables representing the rendezvous phase. Along the test course, readings will be recorded for measured range and LOS angles for comparison with known values at check points. Table R3M-1 lists the nominal velocity and range profile to be simulated for the initial run.

Table R3M-1 Rendezvous Sensor Tracking Parameter Variation

Closure Velocity	Actual Range (n mi)	Measured Range	Actual LOS	Measured LOS
30 fps (20 mph)	25			
15 fps (10 mph)	12.5			
10 fps (6.7 mph)	5			
5 fps (3.3 mph)	3			

Two additional runs are anticipated to be performed at velocity profiles plus and minus 10% from nominal. The length of the nominal run is approximately three (3) hours which is also the average time for each of the three runs for a total of 9 hours run time.

6.0 ANTICIPATED RESULTS

Results of this test will provide confidence in the rendezvous sensor capability to track the target and maintain LOS lock. Many of the sensors under consideration have never been demonstrated in this role, nor have the techniques and software being considered. It is further anticipated that the combination of rendezvous algorithms, sensor hardware, and target spacecraft mockups will be brought together for the first time during this test. Another expected result will be debugging the interfaces between these elements for the simulations.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The support facilities for this test include a truck for sensor mounting, including a power supply and a mini-computer capable of accommodating the rendezvous algorithm logic and algorithms for applying range and LOS data to the Tug control laws. A full-scale mockup of representative spacecraft is also required, having various sensor reflectors or rendezvous aid mounting capabilities.

B. Software - Software developed in Test R2 will be utilized for this test. Assuring compatibility with the selected mini-computer is the only activity directly related to this test in the software realm. Software estimates for this activity are listed in Table R3M-2.

C. Personnel - Two direct support personnel are required for driving the vehicle and recording test data for the three test runs. Test setup time involves mounting the sensor and its support and data gathering equipment in the vehicle, checkout, and calibration of the system. An estimate of the manpower requirements is summarized in Table R3M-2.

Table R3M-2 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	- Hrs
Facility Operations Costs	$ 800
Engineering Manpower	.8 MM
Technician Manpower	1.5 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	9.0 MM
Technician Manpower	6.0 MM
Software Analyst	6.0 MM
Software Programmer	6.0 MM
Facility Modifications	$ 7,500
DATA REDUCTION/EVALUATION	
Data Analyst	1.5 MM
Engineering	2.0 MM
Test Reports	$ 500

TEST PROCEDURE I1M
MANUAL TARGET TRACKING AT INSPECTION RANGE

1.0 PURPOSE

The purpose of this test is to verify the capability of maintaining line of slight (LOS) tracking of the target at inspection ranges. For this test, the term tracking includes determination of LOS angle and range, and rates of change of these variables and target attitudes determination are the objects of subsequent tests. However, consideration of those requirements and anticipation of those test objectives will allow the test setup to accommodate those requirements, thus reducing costs. The display refresh rate of the TV for use by the console operator becomes more critical as ranges decrease.

2.0 SCOPE

This test covers the use of a TV as a sensor for determining range and range rate while maintaining LOS pointing of the Tug during inspection of the spacecraft. It therefore requires these algorithms be developed and is used for validation and sizing of the Tug software requirements.

3.0 APPROACH

This demonstration utilizes the information obtained from the previous test covering the closure from rendezvous to inspection range. Algorithms for range, range rate and LOS angle/rate TV data will be evaluated and modified as necessary to operate at inspection ranges. Tug vehicle dynamics become more critical as range and the field of view of the TV decrease; therefore the dynamics will be simulated accurately.

4.0 TEST SETUP

This test uses the T27 Space Flight Simulator with remote manned console as illustrated in Figure R1M-1 and -2. No modification to the facility are required with the exception of celestial scene changes previously mentioned.

5.0 TEST DESCRIPTION

Test runs will be made at ranges of 100 ft, 200 ft and 300 ft to verify the console operator capability to measure range and to control LOS pointing of the sensor at the target spacecraft. Lighting effects and various celestial scene impacts on this capability will be verified. Each of the three runs are expected to require approximately 30 minutes.

6.0 ANTICIPATED RESULTS

The test is expected to verify console operator capability for tracking the target spacecraft, maintaining LOS pointing and determining range at inspection distances. Determination of recommended inspection range, lighting requirements, and pointing constraints with respect to sun, moon and stars are also important results. This activity has been performed by a man on-board Apollo. However, demonstration of remote console operator capability, considering data management aspects, has never been performed by the USA.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The T27 Space Flight Simulator portion of the MSFC rendezvous and docking laboratory meets the requirements of this test without modifications.

B. Software - The software used for manual target tracking at maximum range and during rendezvous is anticipated to be adequate for this test. However, some slight changes in stored information for spacecraft tracking at closer ranges may be required.

C. Personnel - The personnel skills required are the same as for the rendezvous phase tests using the T27 space flight simulator. Actual run time totals 90 minutes. Test setup time involves replacing the spacecraft models and changing lighting conditions at each range. The manpower and cost estimates for the test are listed in Table IIM-1.

Table I1M-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	200 Hrs
Facility Operations Costs	$ 7,800
Engineering Manpower	1.7 MM
Technician Manpower	6.6 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	2.0 MM
Technician Manpower	2.0 MM
Software Analyst	2.0 MM
Software Programmer	2.0 MM
Facility Modifications	$ 2,500
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.5 MM
Test Reports	$ 500

TEST PROCEDURE I2M
MANUAL TARGET INSPECTION MANEUVERS

1.0 PURPOSE

This function is tested to evaluate the capability to manually initiate an inspection orbit, to visually maintain acceptable range and to control sensor pointing during the inspection maneuver. Another objective is determination of the ability for measuring LOS angle, range, and their time rates-of-change while maneuvering around the target spacecraft. The TV image refresh rate necessary to support the inspection phase will be determined as an output of this test. It is anticipated that the refresh rate should increase inversely with the range reduction to allow more rapid responses during terminal docking closure.

2.0 SCOPE

This test builds on the results of the previous test by verifying the capability of using the sensed data for control during maneuvers. These tests are performed step-wise to provide for intermediate check points, and improvements in the system as necessary. This allows reduction of variables to manageable sets and solving of problems in one phase before proceeding to the next. Use of range, range-rate and LOS angle/rate data will be evaluated to supplement the visual capability of a console operator to control the range and LOS pointing during inspection "fly-around". Alternate displays of this derived data will be developed to provide the best intelligence to the operator.

3.0 APPROACH

The approach to performance of this test involves a manned console with variable time delays and image transmission rates built into the data system. The TV sensor picks up a composite scene made up of target, lighting, celestial, and earth scene inputs to the T27 infinity image system. The image is digitized for transmission by the Tug PCM data system to a simulated ground processing system for display on the console. Evaluation of data loading of the communication link as a result of the display refresh rate will be assessed to determine whether data compression techniques are required at the inspection range and during the inspection maneuvers.

4.0 TEST SETUP

This test uses the T27 space flight simulator with remote manned console (refer to Figures R1M-1 and -2). The added capability for this test is to preprogram a target rotation and visual scene motion to simulate a "fly-around" maneuver.

5.0 TEST DESCRIPTION

The test will be performed by simulating tug "fly-around" maneuvers at anticipated inspection range and rate (100 ft and 20 minutes for circumnavigation). Runs will be made using 15 and 25 minutes at the 100 foot range to determine ACS usage parametrics and operator capabilities/reactions for the time variations. The range will also be increased to 200 feet and another 20 minute run performed to verify manual capability at the increased range.

6.0 ANTICIPATED RESULTS

This test is anticipated to support the traceoff of ACS propellant consumption versus operator time for the fly-around. Determination or validation of recommended range and maneuver velocities for the inspection maneuver are anticipated outputs, as well as the sensitivity of ACS propellant usage to the variables in manually inspecting the target. Assurance that range measurements can be made adequately and range controlled while maneuvering around the target and maintaining LOS pointing is the prime output of the test; however, the level of operator training required can be qualitatively evaluated, also.

The effects of time delays and console display update rate requirements will be firmed up as a result of this test. This will establish whether some image data compression or limited field transmission is necessary to provide adequate update rates.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The T27 space flight simulator is used for this test. The capability to rotate the target model at preprogrammed rates will be required.

B. Software - The software for the previous test is adequate except for programming the relative motion of the target to simulate fly-around maneuvers.

C. Personnel - The personnel requirements are based on the standard requirements for operation of the T27 facility. Test setup and software development costs are based on the anticipated spacecraft model changing and software modification, previously described. The estimates are summarized in Table I2M-1.

Table I2M-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	200 Hrs
Facility Operations Costs	$ 7,800
Engineering Manpower	1.7 MM
Technician Manpower	6.6 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	2.0 MM
Technician Manpower	2.0 MM
Software Analyst	2.0 MM
Software Programmer	2.0 MM
Facility Modifications	$ 4,500
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.5 MM
Test Reports	$ 500

TEST PROCEDURE I3M
MANUAL DOCKING PORT IDENTIFICATION

1.0 PURPOSE

This test validates the capability for manual use of TV sensor to determine location of the docking port on the spacecraft. Anticipated lighting and visual background conditions for representative spacecraft orbits will be simulated to cover the worst case situations. Procedures for locating the port in those cases where attitude is not known with minimal searching will be developed as an output of this test, using spacecraft recognition cues. Acquiring and maintaining LOS lock on the docking port will be demonstrated using simulated Tug and spacecraft dynamics.

2.0 SCOPE

This test does not have a difficult objective to achieve under most conditions. However, the major thrust is to assure the docking port location can be discerned under worst case lighting conditions.

3.0 APPROACH

During the inspection maneuver, the console operator visually ascertains the spacecraft status. In this process, the location of the docking port should be readily determined. However, the spacecraft symmetry or lighting conditions could be such that easy recognition of the port is precluded. A realistic visual representation of lighting, celestial, and earth scenes is necessary to determine the magnitude of this problem.

4.0 TEST SETUP

This test uses the T27 space flight simulator (refer to Figures R1M-1 and -2) as supplemented by the simulated "fly-around" capability added for Test I2M.

5.0 TEST DESCRIPTION

As opposed to the inspection maneuver test in which optimum lighting was used, this test uses worst case lighting conditions. Analysis of orbital variations in lighting for the entire range of spacecraft under consideration should be performed and the simulation conducted using these conditions. Runs are performed using spacecraft attitudes purposely oriented with the docking port shaded. Spacecraft are selected for this test having symmetrical shapes to verify that 180 degree orientation errors can be avoided. Spacecraft inspection during dark portions of the orbit and during terminator crossings will also be simulated.

6.0 ANTICIPATED RESULTS

This test is expected to confirm whether supplemental lighting is really a requirement. Alternately, an attitude hold mode can be entered as orbital night approaches and determination that the target remains in the field of view until the sunrise terminator is crossed again. Analysis has shown a maximum time in darkness resulting from ± 1 % of a 6900 n mi orbit, or 48.3 minutes, can be anticipated for the representative retrieval spacecraft selected from the mission model. The effects of geostationary altitude on celestial scene confusion factors was never assessed on Apollo simulations. These combined lighting and celestial scene effects are considered as adequate justification for this test.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The T27 space flight simulator portion of the MSFC rendezvous and docking laboratory is used for this test with only those modifications associated with celestial scenes and lighting which is representative of 6900 n mi and geostationary orbits.

B. Software - No unique software is required for this test.

C. Personnel - Personnel to support the T27 facility for test runs covering altitude and inclination variations including 900 n mi at 103 degrees, 6900 n mi at 55 degrees, and geostationary orbits. The lighting variations will be varied during three runs at these simulated orbits for an estimated total run time of 90 minutes. Support for the test runs, test setups, and pre-test analysis is estimated in Table I3M-1.

Table I3M-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	200 Hrs
Facility Operations Costs	$ 7,800
Engineering Manpower	1.7 MM
Technician Manpower	6.6 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	2.0 MM
Technician Manpower	2.0 MM
Software Analyst	1.0 MM
Software Programmer	1.0 MM
Facility Modifications	$ 3,000
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.5 MM
Test Reports	$ 500

TEST PROCEDURE I4M
MANUAL TARGET ATTITUDE DETERMINATION

1.0 PURPOSE

This test is a logical extension of the previous inspection phase series to verify the capability to acquire the final intelligence necessary to perform closure and docking. The target spacecraft attitude is generally known prior to rendezvous and docking activities. However, this test will demonstrate the capability to determine spacecraft attitude offsets using the TV as a sensor. A further objective is to establish whether target-mounted aids or patterns are necessary to determine attitude with adequate accuracy.

2.0 SCOPE

This test is the last in the series of inspection phase tests. It encompasses evaluation of whether spacecraft-mounted cues are required as aids to spacecraft attitude determination. Obviously, the spacecraft developers will be more receptive to the retrieval services if the impacts to their designs are minimized. A goal of this test is therefore to verify that target attitude can be determined without any aids mounted on the target spacecraft.

3.0 APPROACH

Spacecraft pattern recognition algorithms will be used to compare the actual image with that anticipated when target attitude is correct for docking. The simulated spacecraft attitude will be known and the capability for determining attitude based on spacecraft physical features will be assessed. If this does not provide adequate resolution, the use of spacecraft mounted patterns and off-set tee arrangements will be evaluated.

4.0 TEST SETUP

This test uses the T27 space flight simulator (see Figures R1M-1 and -2). Target mounted cues must be added to the spacecraft models. However, initial runs will be performed without aids and the results compared to results obtained using spacecraft patterns.

5.0 TEST DESCRIPTION

This test consists of a series of runs in which known target attitude offsets are established as initial conditions for the test. The capability of the console operator to measure these offsets using the TV as a sensor will be determined at various inspection ranges. Test runs will be conducted at offsets of approximately 2, 5, 10, 20 and 30 degrees and at ranges of 50, 100, and 150 feet simulated vehicle separation.

6.0 ANTICIPATED RESULTS

The capability of a TV sensor to provide the necessary intelligence for the final docking alignment is key to the success of the system. This test will verify whether the target spacecraft attitude can be determined accurately enough to permit docking, both without target-mounted aids and with the aids. At least two types of aids will be evaluated and accuracy of results compared.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The T27 facility located in the MSFC rendezvous and docking laboratory is planned for use during this test with no modifications required. However, scale models of target-mounted aids are required.

B. Software - Software algorithms for pattern recognition based on anticipated "head-on" image versus actual image to derive target attitude offset is required. This software activity is significant for the varied spacecraft shapes and sizes involved.

C. Personnel - Manpower estimates include direct test support, test setup, and change-out of spacecraft models, development and installation of aids, and evaluation of results. The estimates are summarized in Table I4M-1.

Table I4M-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	100 Hrs
Facility Operations Costs	$ 3,900
Engineering Manpower	1.4 MM
Technician Manpower	4.8 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	2.0 MM
Technician Manpower	2.0 MM
Software Analyst	3.0 MM
Software Programmer	3.0 MM
Facility Modifications	$ 2,500
DATA REDUCTION/EVALUATION	
Data Analyst	.5 MM
Engineering	1.0 MM
Test Reports	$ 300

TEST PROCEDURE I5
INSPECTION AND COMMIT-TO-DOCK ALGORITHM

1.0 PURPOSE

The algorithms required to perform inspection phase tests, both onboard and at the mission control center, will be demonstrated via software modeling in this test. Obviously, this presupposes that analyses have been performed and software requirements generated to allow developing the simulation algorithms. The algorithms will be used in support of the inspection phase tests. These tests will, in turn, validate the algorithms over the range of operations they are designed to support.

2.0 SCOPE

This test is limited to the software modeling to develop support algorithms for the other inspection phase tests and the decision algorithm for autonomous commit-to-dock determination. The algorithms developed here will be validated by use during the inspection phase tests for which they were designed. Both manual and autonomous programs are covered in this test.

3.0 APPROACH

The results of analyses to generate software requirements for the inspection and commit-to-dock decision process will be coded into an algorithm for this test. Computer runs will be made to de-bug the program and put it through various simulated sets of conditions prior to inclusion in the other inspection phase tests. Therefore, this test must be successfully completed prior to starting the inspection phase testing.

4.0 TEST SETUP

Since this test constitutes developing software, only the use of MSFC computation laboratory capabilities are required. Therefore, no test setup is necessary.

5.0 TEST DESCRIPTION

This test will consist of computer runs simulating the inspection maneuvers and use of sensed range, LOS angle, and target attitude angle data for control of tug maneuvers.

6.0 ANTICIPATED RESULTS

This is a new and unique software function which is required, to some degree, for autonomous, hybrid, or manual candidate systems. Results of this test are expected to produce a checked-out set of software for this function which is required to support the other inspection phase tests for manual and autonomous candidate systems.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The support facility requirements are satisfied by the MSFC computation laboratory capabilities.

B. Software - New software programs must be developed. The estimated computer costs are listed in Table I5-1.

C. Personnel - Software analyst and programmer skills are required. The estimated manpower is also shown in Table I5-1.

Table I5-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	100 Hrs
Facility Operations Costs	$ 2,300
Engineering Manpower	.3 MM
Technician Manpower	1.2 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	1.0 MM
Technician Manpower	- MM
Software Analyst	1.0 MM
Software Programmer	1.0 MM
Facility Modifications	$ -
DATA REDUCTION/EVALUATION	
Data Analyst	.5 MM
Engineering	1.0 MM
Test Reports	$ 300

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TEST PROCEDURE C1
CLOSURE ALGORITHM VERIFICATION

1.0 PURPOSE

This development of algorithms for control during closure is a prerequisite to simulating the closure phase tests. Potential closure algorithms will be evaluated against a set of criteria including ACS usage, elapsed time, sensor data processing required, sensitivity to loss of data, and sensitivity to initial conditions, for example. Obviously, analyses must precede the algorithm development and the validation of the algorithms is performed during the remaining closure tests.

2.0 SCOPE

This test is limited to software modeling and will select those candidate algorithms to be used in performance of the closure series of tests. Applicability over the expected range of operations and conditions will be verified and algorithm(s) selected which best satisfy the criteria for autonomous and manual systems.

3.0 APPROACH

Analyses must be performed prior to this software modeling task to generate software requirements. Included in this task are the coding and de-bugging necessary to develop an operational program. This program will be run through simulated sets of conditions prior to use in support of the closure phase tests. Successful completion of the closure tests will constitute validation of the software.

4.0 TEST SETUP

Since this task involves software development only, no test setup is required. Use of existing MSFC computation laboratory facilities are assumed.

5.0 TEST DESCRIPTION

This test will consist of computer runs simulating closure phase maneuvers and use of sensed data to control the tug during closure.

6.0 ANTICIPATED RESULTS

This is a new software function for manual, hybrid and autonomous systems. Closure has been demonstrated on Apollo by man on-board using direct visual observations. In the remote case more automation is desired by use of range and LOS data input to tug control loop. The results of this test are anticipated to include checked out software sets for autonomous and manual systems.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The support facility requirements are satisfied by the MSFC computational laboratory capabilities.

B. Software - New software programs must be developed. The estimated manpower is also shown in Table C1-1.

C. Personnel - Software analyst and programmer skills are required. The estimated manpower is also shown in Table C1-1

Table C1-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	100 Hrs
Facility Operations Costs	$ 2,300
Engineering Manpower	.3 MM
Technician Manpower	1.2 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	1.0 MM
Technician Manpower	- MM
Software Analyst	1.0 MM
Software Programmer	1.0 MM
Facility Modifications	$ -
DATA REDUCTION/EVALUATION	
Data Analyst	.5 MM
Engineering	1.0 MM
Test Reports	$ 300

TEST PROCEDURE C2M
TARGET TRACKING DURING CLOSURE - MANUAL

1.0 PURPOSE

This function is tested to demonstrate the target spacecraft can be tracked by manually controlling the tug motion along a prescribed closure path. The TV image data for remote control closure is utilized for control while simulating the range of vehicle dynamics, lighting, visual backgrounds, and spacecraft configurations anticipated.

TV image update rate becomes more critical as the range decreases. For example, at a closure rate of 0.5 fps and an update every 16 seconds (GDC supervisory control system), the range closes by 8 ft between picture updates. This rate may be acceptable for the GDC hybrid-type system, but is considered inadequate for a strictly manual system.

2.0 SCOPE

This test encompasses the ranges which represent the Tug closure from inspection distance to terminal docking. The step-wise performance of tests to this point is designed to reduce uncertainties in the system. Since this is the first test where the errors become critical enough to cause inadvertent contact between the two vehicles, the results of previous phase tests should be analyzed and any required improvements incorporated into the simulations.

3.0 APPROACH

The approach to demonstrating this phase involves use of the T27 moving base simulator with manual control from a simulated mission control center console. A composite TV picture including the target with celestial, lighting, and earth scene dynamic representation will be transmitted from a camera at the T27 pilot's window to the console for display. Various display refresh rates and typical stimuli/response times for network processing and RF propagation uplink/downlink delays will be simulated.

4.0 TEST SETUP

This test utilizes the T27 space flight simulator with remote manned console as illustrated in Figures R1M-1 and -2.

5.0 TEST DESCRIPTION

The test will include runs in which the closure maneuver from inspection range (~ 100 ft) is performed at various closure rates. Since the closure is manually controlled, the image update rate becomes more critical as the range decreases.

Residuals in range, LOS angle, and target attitude angular misalignments will be recorded for each run. Since this test is accomplished using target spacecraft models and the T27 is limited in minimum closure range, the data must be extrapolated to residual errors at docking.

The tests will examine closure rates of 0.25, 0.5, 0.75, 1.0, and 1.25 feet/second. These test runs average approximately 135 seconds per run and will be repeated five times at each rate to obtain average residual errors To reduce the effects of console operator bias the tests will be repeated using another subject at the console. This total test scheme therefore requires approximately two hours run time or one hour per console operator.

6.0 ANTICIPATED RESULTS

This test is critical in that the range is closed to the point that tug and spacecraft dynamics/deadbands enter into the capability of the man at the console to maintain satisfactory angular alignment of the vehicles while closing the range to acceptable residual values for capture. Lighting effects can be extremely critical as the tug begins to shadow the docking port during approach. The need for supplemental lighting is expected to be evaluated and a firm requirement either verified or disproved as a result of this test and test I3M.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The support facility requirements are satisfied by the T27 space flight simulator in the MSFC rendezvous and docking laboratory.

B. Software - No new software programs are anticipated. Modifications to the closure program to accommodate reduced ranges might be required, but are not anticipated.

C. Personnel - The manpower requirements include the direct test support, test setup, and changeout of spacecraft models and evaluation of results. The estimates are listed in Table C2M-1.

Table C2M-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	300 Hrs
Facility Operations Costs	$ 11,700
Engineering Manpower	3.1 MM
Technician Manpower	9.4 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	3.0 MM
Technician Manpower	3.0 MM
Software Analyst	1.0 MM
Software Programmer	1.0 MM
Facility Modifications	$ 3,000
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.5 MM
Test Reports	$ 500

TEST PROCEDURE C3M
MANUALLY PERFORM CLOSE-IN STATIONKEEPING

1.0 PURPOSE

This test is primarily to verify close-in stationkeeping capability for non-impact docking. Servicing of satellite spacecraft appears to be viable option for the rendezvous and docking system and non-impact docking enhances servicing potential. The spacecraft appendages (solar arrays, antennae, etc) may be left extended since the spacecraft is not subjected to docking dynamics, propellant slosh forces, etc, and the spacecraft must be left operational after servicing. Results of the test are anticipated to include whether automated stationkeeping algorithms are required, or if the console operator control capability is adequate. A stationkeeping attitude hold mode appears very desirable for troubleshooting and recovery from mis-docking. Although the manual candidate mechanism is an impact docking device, the non-impact option should be kept open for new requirements and developments.

2.0 SCOPE

The test covers the capability of the manual candidate system to establish and maintain a close-in (< 10 ft) stationkeeping stable attitude between sensor and target vehicles. This capability is not a requirement for the impact docking mechanism selected for the manual candidate. However, it is considered to be a valuable capability for servicing growth and a necessary capability for abort of mis-docking recovery schemes.

3.0 APPROACH

Since close-in stationkeeping, if required, would logically be performed during this phase of the docking sequence, its demonstration is therefore planned in the test schedule at a comparable point. The approach is to provide the console operator with the standard image data available for the other phases (i.e., no special sensors or aids for stationkeeping) to determine whether the capability for stable stationkeeping is inherent in the selected candidate.

4.0 TEST SETUP

This test utilizes the test setup illustrated in Figures R1M-1 and -2. However, software changes are required to establish attitude hold capability while stationkeeping.

5.0 TEST DESCRIPTION

Test runs will be performed in the manner of test C2M for closure, but will vary the closure rate profile. The closure rate is reduced to zero at stationkeeping separation distances, and must be accomplished gradually to reduce overshoot and impact potential. Stationkeeping distances for the test are established by articulation range of the extendable stem, non-impact docking device or servicing mechanism. This range is anticipated to be in the 5 ft regime, and therefore tests will be conducted at 3, 5, and 7-foot separations. The ability of the console operator to maintain stable stationkeeping attitude will be evaluated.

6.0 ANTICIPATED RESULTS

This test is very important to the manual system to provide assurance that close-in stationkeeping can be accomplished for abort or for analyses of problems occuring during closure. The image data update rate is critical to the manual stationkeeping capability and establishing a requirement for image display refresh rate is an anticipated result of this test.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The T27 space flight simulator facility located in the MSFC rendezvous and docking laboratory meets the requirements of this test.

B. Software - The primary difference in the software is the elimination of a programmed constant closure rate and replacement with a closure profile that reduces the rate to zero (attitude hold mode) until maneuver commands are input from the operator's console.

C. Personnel - The manpower requirements include the direct test support, test setup, and changeout of spacecraft models and evaluation of results. The estimates are listed in Table C3M-1.

Table C3M-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	200 Hrs
Facility Operations Costs	$ 7,800
Engineering Manpower	1.7 MM
Technician Manpower	6.6 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	2.0 MM
Technician Manpower	2.0 MM
Software Analyst	2.0 MM
Software Programmer	2.0 MM
Facility Modifications	$ 3,500
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.5 MM
Test Reports	$ 500

TEST PROCEDURE C4M
CLOSURE ABORT PROCEDURES - MANUAL OPERATIONS

1.0 PURPOSE

Since retrieval and servicing are offered to spacecraft users, assurance should be provided that no damage occurs to the spacecraft during the process. This function is necessary to verify that an abort can be initiated in the event an anomalous condition occurs during closure. Implicit in this function is verification of instrumentation available for the detection of the anomalous condition and development of preplanned actions to correct the anomaly.

2.0 SCOPE

This test encompasses performance of aborts at various closure ranges and verification that rationale for an abort decision is available, adequate and conclusive. Demonstration of stationkeeping ability is not a stringent predecessor requirement for abort, but will provide more confidence in the success of the abort capability. It is therefore recommended that stationkeeping be successfully demonstrated prior to this test.

3.0 APPROACH

The approach to this problem will involve numerous runs initiating abort procedures at progressively closer ranges and monitoring the miss distances. From these runs, an abort range limitation for a given tug thruster capability and approach velocity will become evident. The data obtained might result in recommending increased thrust levels or reduced approach velocities to permit abort action at closer ranges.

4.0 TEST SETUP

This test utilizes the test setup illustrated in Figures R1M-1 and -2. The T27 space flight simulator is instrumented to determine miss distances for abort runs.

5.0 TEST DESCRIPTION

The test is more open ended than the others in the series. Since aborts can be instigated at any time in the closure phase, the abort test run duration is more difficult to predict. It is not considered necessary, for example, to start the run from the full inspection range. However, the actual starting range for the runs can best be determined from results of initial abort test runs. A significant number of runs should be made, on the order of 20, using more than one operator. For estimating purposes ten runs of 30 minutes duration each for two operators will be assumed.

6.0 ANTICIPATED RESULTS

The most significant results from the test are expected to be the demonstration of abort capability and establishing the range at which aborts are feasible. During the Apollo program, numerous failures to latch-up were experienced. In one case, at least, soft docking was attempted numerous times before latch-up was achieved. The capability for a remotely controlled docking system to recover from a missed docking attempt has not been proven and is critical to system development.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The T27 space flight simulator facility located in the MSFC rendezvous and docking laboratory meets the requirements of this test.

B. Software - No changes in software are anticipated, assuming the tug returns to an attitude hold mode when the console control's are returned to neutral.

C. Personnel - The manpower requirements include direct test support (2 operators), test setup, spacecraft model changes, and evaluation of results. The estimates are listed in Table C4M-1.

Table C4M-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	200 Hrs
Facility Operations Costs	$ 7,800
Engineering Manpower	1.7 MM
Technician Manpower	6.6 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	2.0 MM
Technician Manpower	2.0 MM
Software Analyst	1.0 MM
Software Programmer	1.0 MM
Facility Modifications	$ 2,000
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.5 MM
Test Reports	$ 500

TEST PROCEDURE D1
LATCH DESIGN AND OPERATIONS VERIFICATION

1.0 PURPOSE

The docking mechanism is designed to operate within a range of lateral and angular offsets as well as a range of velocity variations. This test is to simulate those variations and demonstrate that the mechanism does, in fact, operate as specified. Full scale flight representative docking system hardware is required with faithful vehicle dynamics representation simulated.

2.0 SCOPE

For the manual candidate system, the MDAC square frame mechanism, or a derivative, is selected. Since this is a new design, the test will validate that the specifications are met by the mechanism. For the autonomous candidate, the square frame mechanism was selected. For the hybrid or best-mix candidate, the same mechanism was chosen. All candidate impact docking mechanisms are subjected to a similar set of runs based on their corresponding sensor characteristics.

3.0 APPROACH

The approach selected uses full scale flight prototype hardware and simulated vehicle dynamics. Numerous runs are performed at various closing velocities, angular offsets and lateral offsets. These values will be increased until capture no longer occurs to establish limits on the misalignment and velocity parameters. There are at least two options available using existing MSFC facilities. These are the Neutral Buoyancy Tank and the 6 DOF motion simulator.

The selected approach uses the 6 DOF motion system as described in the Test Setup. The selection was influenced by the commonality with the following test (D2) requirements.

4.0 TEST SETUP

This test makes use of the 6 DOF motion system. The selected docking mechanism is mounted on the moving base system and the target is attached to the ceiling of the building.

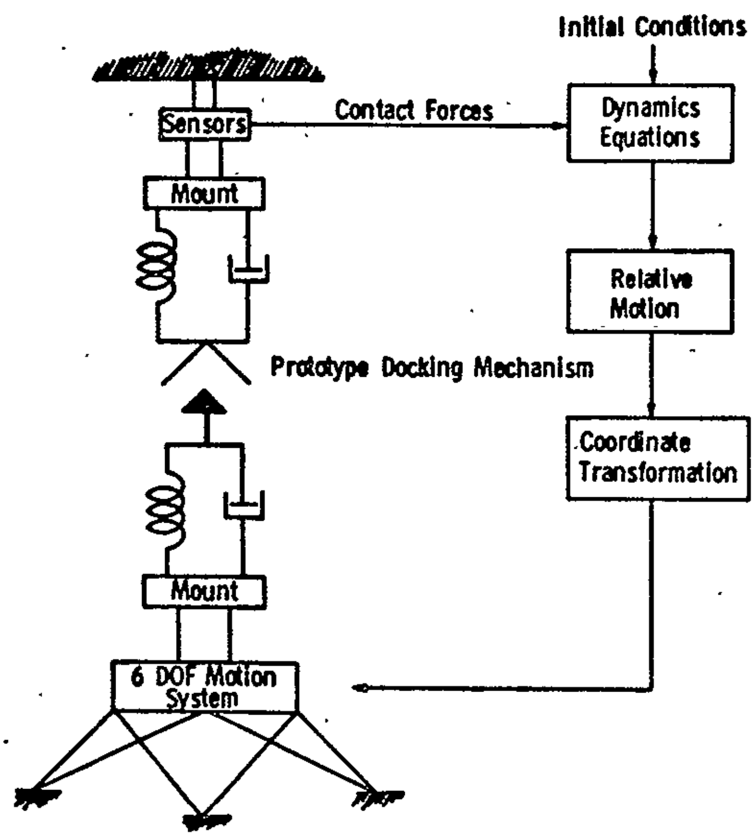

Figure D1-1: Docking Test Set-Up

5.0 TEST DESCRIPTION

Test runs will be performed to evaluate latching capability with the impact docking mechanisms at the approach velocities, lateral offsets, and angular offsets indicated in Table D1-1. Measured values include docking

Table D1-1 Impact Docking Parametric Variations

Run Nos.	Velocity	OFFSETS Lateral (ft)	Angular (deg)	Lateral (ft)	Angular (deg)	Lateral (ft)	Angular (deg)	Lateral (ft)	Angular (deg)
1 - 4	0.25 fps	0	0	0.2	0	0.4	0	0.6	0
5 - 8	0.50 fps	0	0	↓	0	↓	0	↓	0
9 -12	0.75 fps	0	0	↓	0	↓	0	↓	0
13-16	1.00 fps	0	0	↓	0	↓	0	↓	0
17-20	1.25 fps	0	0	0.2	0	0.4	0	0.6	0
21-24	0.25 fps	0	1.25	0	2.5	0	3.75	0	5
25-28	0.50 fps	0	↓	0	↓	0	↓	0	↓
29-32	0.75 fps	0	↓	0	↓	0	↓	0	↓
33-36	1.00 fps	0	↓	0	↓	0	↓	0	↓
37-40	1.25 fps	0	1.25	0	2.5	0	3.75	0	5
41-44	0.25 fps	0.2	1.25	0.4	2.5	0.6	3.75	0.6	5
45-48	0.50 fps	↓	↓	↓	↓	↓	↓	↓	↓
49-52	0.75 fps	↓	↓	↓	↓	↓	↓	↓	↓
53-56	1.00 fps	↓	↓	↓	↓	↓	↓	↓	↓
57-60	1.25 fps	0.2	1.25	0.4	2.5	0.6	3.75	0.6	5

forces at spacecraft interface and at tug interface to verify attenuation provided by the mechanism. These data will be gathered via strip chart recordings to provide dynamic force and damping data from strain gage instrumentation.

The non-impact mechanism capabilities to capture and draw the vehicles together for hard-latch should be demonstrated. The parametric variations are tabulated in Table D1-2, for recommended ranges of vehicle separation, lateral offsets, and axial offsets. Instrumentation for the test should determine stem loads in tension, torsion, buckling to demonstrate stem design, and assess rates of stem retraction using good representation of vehicle masses, c.g.'s, and dynamic characteristics.

Although a non-impact docking mechanism was not ranked best for the current set of requirements, the flexibility should be retained to simulate/demonstrate a non-impact system. For example, the requirements could change to favor non-impact by emphasizing servicing. The following test description is provided for the non-impact mechanism tests.

Approach velocity will be reduced from some finite value to zero (stationkeeping) for the non-impact case. The test setup remains essentially the same. However, the instrumentation is provided for different parameters.

6.0 ANTICIPATED RESULTS

The results of this test are expected to be concept verification of a new design. (All mechanisms under consideration are at least major modifications to existing designs.) The results will also establish the limits on misalignment (lateral and angular) that can be accommodated by the mechanism. These data verify the specification values which the sensors and algorithms must meet. Potentially, the requirements on the sensors could be

Table D1-2 Non-Impact Docking Parametric Variation

Run Nos.	Séparation	OFFSETS							
		Lateral (ft)	Angular (deg)	Lateral (ft)	Angular (deg)	Lateral (ft)	Angular (deg)	Lateral (ft)	Angular (deg)
1 - 4	6 feet	0	0	0.2	0	0.4	0	0.6	0
5 - 8	4 feet	0	0	0.2	0	0.4	0	0.6	0
9 - 12	2 feet	0	0	0.2	0	0.4	0	0.6	0
13-16	6 feet	0	1.25	0	2.50	0	3.75	0	5
17-20	4 feet	0	1.25	0	2.50	0	3.75	0	5
21-24	2 feet	0	1.25	0	2.50	0	3.75	0	5
25-28	6 feet	0.2	1.25	0.4	2.50	0.6	3.75	0.6	5
29-32	4 feet	0.2	1.25	0.4	2.50	0.6	3.75	0.6	5
33-36	2 feet	0.2	1.25	0.4	2.50	0.6	3.75	0.6	5

relaxed or might need to be made more stringent. Other important results are in the area of specifying the docking loads imparted to the spacecraft and verification that the mechanism attenuation of these loads is as advertised. The data channels will be recorded to provide a time history of the forces resulting from the docking impacts.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The facility requirements for this test include the 6 DOF motion system located in the MSFC rendezvous and docking laboratory. Modifications to the facility are necessary to accommodate the test requirements. These include mounting a simulated spacecraft docking interface to the laboratory ceiling and instrumenting the mount and the mechanism for measuring forces. Additionally, simulation of tug control capability must be included in the 6 DOF system.

B. Software - The software must be developed to accurately simulate tug and spacecraft dynamics and tug motion to bring the mechanism into contact with the spacecraft interface and effect capture. This software must have the capability to accommodate various initial conditions (misalignments, closure velocities, etc) inputs for the test runs.

C. Personnel - The manpower requirements include direct test support to operate the facility and test result recording equipment. Preparation of support software, test setup, and facility modifications are necessary pre-test activities. Estimates for these activities as well as post-test analysis of results are included in Table D1-3.

Table D1-3 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	600 Hrs
Facility Operations Costs	$ 23,400
Engineering Manpower	4.2 MM
Technician Manpower	18.8 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	8.0 MM
Technician Manpower	12.0 MM
Software Analyst	8.0 MM
Software Programmer	4.0 MM
Facility Modifications	$ 25,000
DATA REDUCTION/EVALUATION	
Data Analyst	2.0 MM
Engineering	3.0 MM
Test Reports	$ 1,000

TEST PROCEDURE D2
DYNAMICS EFFECTS, PRE- AND POST-LATCH

1.0 PURPOSE

This function is tested for a two-fold purpose: to determine (1) the vehicle induced effects, and (2) the control modes required for an impact docking system from initial contact through hard latch. This includes dynamics of the combined vehicles and tug propellant slosh effects. Obviously, the vehicle dynamics simulations must be realistic and high fidelity to provide assurance that a latch-up can be achieved under anticipated conditions. The selection of a non-impact system would negate the requirement for this test.

2.0 SCOPE

This test expands on Test D1 in the area of tug-induced dynamics effects. Propellants remaining in the tanks at docking create slosh dynamics which are significant for some acceleration profiles. The tug attitude control system (ACS) control modes which result in the least damaging spacecraft acceleration profiles will be developed from this test. It may be necessary, for example, to inhibit the ACS control just prior to impact and re-enable the ACS with new gains after latch-up. The mechanisms for autonomous, manual, and hybrid candidates will be subjected to this test program.

3.0 APPROACH

This test differs from D1 primarily in the software complexity. Tug control mode variations and the capability to simulate combined vehicle dynamics must be added to the control logic.

The test could be performed in the Nuetral Buoyancy Tank or using the 6 DOF moving base simulator. Since the damping effects of water in the NB tank are unknown, the most realistic simulation of the dynamics available is via software modeling and therefore the 6 DOF system was chosen. Also, a realistic simulation of the Tug control system implies water jets or propeller units with questionable minimum impulse bit reproduction capability.

4.0 TEST SETUP

This test setup is the same as that illustrated in Figure D1-1. However, the software is more complex in that propellant slosh dynamics are included.

5.0 TEST DESCRIPTION

Results of the previous test (D1) shall be factored into the requirements for this test in selecting parametric variations. This screening process is anticipated to significantly reduce the number of runs required. Anticipated test run parametric variations are tabulated in Table D2-1, but are subject to revision based on Test D1 results.

6.0 ANTICIPATED RESULTS

Dynamics effects of tug propellant slosh, damping characteristics of the docking mechanisms, and tug control mode requirements are anticipated to be developed from this test. Data gathered from the previous test will be used to establish whether the tug control gain changes are required or whether the tug control system should be deactivated during major docking transients. The incorporation of additional tug control modes will be

Table D2-1 Dynamic Effects Test Parameter Variations

Run Nos.	Approach Velocity	Propellant Mass Residuals	Offsets Lat.	Ang.	Lat.	Ang.	Lat.	Ang.
1 - 3	0.5 fps	0.5 full	0	0	TBD	TBD	TBD	TBD
4 - 6	1.0 fps		0	0	TBD	TBD	TBD	TBD
7 - 9	0.5 fps	0.7 full	0	0	TBD	TBD	TBD	TBD
10-12	1.0 fps		0	0	TBD	TBD	TBD	TBD
13-15	0.5 fps	0.3 full	0	0	TBD	TBD	TBD	TBD
17-18	1.0 fps		0	0	TBD	TBD	TBD	TBD

incorporated in the software if required. Strip chart recordings of the data are required to provide time history of force excursions.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The 6 DOF motion system located in the MSFC rendezvous and docking laboratory, as modified for test D1, meets the requirements for this test by inclusion of software modifications.

B. Software - Incorporation of tug propellant slosh simulations and changes to tug control mode software are required for this test.

C. Personnel - The personnel requirements for this test include direct test support, test software modification, and test result evaluation. The support estimates are tabulated in Table D2-2.

Table D2-2 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	300 Hrs
Facility Operations Costs	$ 11,700
Engineering Manpower	2.0 MM
Technician Manpower	9.4 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	8.0 MM
Technician Manpower	12.0 MM
Software Analyst	8.0 MM
Software Programmer	4.0 MM
Facility Modifications	$ 25,000
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.5 MM
Test Reports	$ 500

TEST PROCEDURE D3
DOCKING ABORT PROCEDURES

1.0 PURPOSE

This function is a continuation of the closure abort procedures to examine feasibility of performing an abort during terminal docking. The decision for abort in this close proximity of the target spacecraft must consider plume impingement (thruster braking) damage versus potential impact damage if abort is not initiated. The capability for recovery from a mis-docking is also an objective of this test, as is demonstration of undocking after hard latch is achieved.

2.0 SCOPE

This test will evaluate the abort capabilities for both autonomous and manual systems or combinations thereof (hybrid system). Abort in this sense is only applicable to an impact docking system. Since the closure abort test interface with this test is somewhat arbitrary, the major emphasis will be development of recovery from aborts, second attempts and undocking verification.

3.0 APPROACH

The approach to this demonstration will include runs with differing missed docking initial conditions to determine the capability for recovery.

Attitude sensing instrumentation or console operator visual cues will be utilized for autonomous and/or manual candidates, as available. Combinations of these cues may be required to effect recovery and docking after some mis-docking situations. The extent to which this capability is available and the difficulty for providing the capability will be an output of this test.

4.0 TEST SETUP

The test setup for this test is the same as illustrated in Figure D1-1. Abort decision software is added as an increased complexity building block or growth module for this test. An attitude hold or stationkeeping mode is also required to be included in the control software.

5.0 TEST DESCRIPTION

The test will include test runs covering a range of approach velocities and separation distances at which the abort is initiated. The range of variables to be simulated are listed in Table D3-1.

Table D3-1 Docking Abort Parameter Variations

Test Runs	Approach Velocity (fps)	Distance at Start of Abort					
		50'	25'	20'	15'	10'	5'
1 - 6							
7 -12	1.25						
13-18	1.0						
19-24	0.75						
25-32	0.5						
33-38	0.25						

6.0 ANTICIPATED RESULTS

The results of this test are expected to verify the capability of the system to recover from a missed docking attempt, and to perform aborts in the terminal closure phase. Undocking for a mission abort to jettison a failed spacecraft and return the tug to the orbiter is an option. The demonstration of undocking and the dynamics of separation of a "dead" spacecraft are expected to provide usable results.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The 6 DOF motion system of the MSFC rendezvous and docking laboratory as used for test D2, adequately meets the requirements of this test.

B. Software - Slight software modifications are anticipated to permit the tug to "back-off" and reinitiate a docking closure maneuver.

C. Personnel - The manpower requirements for this test include direct test support, test software modification, and test result evaluations. The support estimates are listed in Table D3-2.

Table D3-2 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	400 Hrs
Facility Operations Costs	$ 15,600
Engineering Manpower	2.7 MM
Technician Manpower	12.4 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	8.0 MM
Technician Manpower	12.0 MM
Software Analyst	8.0 MM
Software Programmer	4.0 MM
Facility Modifications	$ 25,000
DATA REDUCTION/EVALUATION	
Data Analyst	2.0 MM
Engineering	2.0 MM
Test Reports	$ 500

VOLUME III - PROCEDURES AND PLANS

Part IVB - AUTONOMOUS SYSTEM TEST PROCEDURES

AUTONOMOUS

RENDEZVOUS AND DOCKING SYSTEM

TEST PROCEDURES

CONTENTS

I. INTRODUCTION

This document is a compilation of the functions which should be tested to demonstrate an autonomous Rendezvous and Docking (R&D) system. A separate procedural set is prepared for the manual and hybrid R&D systems. Included are the test procedures which detail the test objectives, test setups, support requirements, and schedules to provide development which is compatible with the STS program planning. Existing MSFC facility utilization has been maximized to avoid development of new facilities with their resultant costs and schedule problems.

II. AUTONOMOUS CANDIDATE DESCRIPTION

The candidate systems are comprised of three subsystems. They are sensors, mechanisms, and strategies or algorithms. The sensor measures range and angular separation which must be reduced to zero to affect docking. The algorithms are designed to reduce the sensed values to some residual amount which can be accommodated by the docking mechanism. Subsystem requirements budgets and tradeoffs were used to assist in selecting the candidate subsystem for the autonomous system described in the following paragraphs.

A. Sensors - The autonomous candidate sensors which ranked best in the study were the GaAs Scanning Laser Radar (SLR) first, and the Dual Mode RF Radar second. Both these sensors transmit a beam of energy and use retroreflectors on the target spacecraft to provide intelligence regarding target attitude and better accuracy in range and line-of-sight (LOS) angle measurements. Delay lines are included in the RF reflectors to allow separation of retroreflector returns from those reflections from other parts of the spacecraft. The sensed parameters are range, LOS angle and target (spacecraft) attitude. Computed parameters are time rates of change of these sensed values. The sensed/computed data are used by the Tug control system on-board software to reduce these values to zero.

B. Mechanism - The autonomous candidate mechanism ranking highest was the McDonnell Douglas (MDAC) square frame which was also selected for the manual candidate. This mechanism was rated against Multi-Mission Support Equipment (MMSE) Spider beam with centrally located Apollo-type probe-drogue and a new design non-impact system having an extendable stem which captures the spacecraft while the Tug is stationkeeping. The stem is used to draw the vehicles together for hard-latch on the periphery to support the Shuttle imposed loads for retrieval. This new design meets the requirements well, but is not as well developed as the other designs.

C. Strategies/Algorithms - The strategies for the candidate autonomous systems are the methods by which inspection, alignment, and docking are accomplished. These include primarily on-board algorithms for implementing the methods. The algorithms divide into decision, maneuver, sensor utilization, and redundancy management categories. The degree to which each category interacts with man-in-the-loop is a function of the system autonomy. For the autonomous candidate this interaction is minimal and the man is in a "monitor only" role. The algorithms are developed using standard software development techniques and represent no significant advances in the state of the art.

TEST PROCEDURE R1A
AUTONOMOUS ACQUISITION, TRACKING, AND RANGING AT MAXIMUM RANGE

1.0 PURPOSE

The purpose of this test is to establish that the autonomous sensor (SLR, RF, or TV) can acquire target, maintain track, and provide range, range-rate, line-of-sight (LOS) angle and angular rate data for rendezvous initiation range (25 n mi). Spacecraft conditions (lighting, orientation, dynamics) as well as Tug conditions (vehicle control deadbands, etc) which have a bearing on this capability will be considered and accounted for in the test.

The manual candidate rendezvous sensor (RF radar) is also subjected to this test as referenced in the test R1M procedure.

2.0 SCOPE

This test initiates the rendezvous phase and the range requirement is derived from the tug placement and spacecraft location uncertainties. Analysis has established a specific range (≈ 20 - 25 n mi) at which target spacecraft acquisition and tracking must be established to achieve an optimum rendezvous within allocated ACS budget.

3.0 APPROACH

Three alternatives for this simulation appear to meet a reasonableness test. Obviously, the facilities requirements for the test are stringent, in that actual ranges of ≈ 25 n mi and flight configuration hardware are highly desirable. Another factor involves reducing atmospheric effects. The three options include Shuttle flight test, aircraft flight test and high altitude demonstrations, in descending order of fidelity and costs. Since the test requires sizable sensor and target separation, the test could be conducted with the target mounted on the free-flying teleoperator (FFTO) if the shuttle flight test approach is taken. For the aircraft flight test approach, two aircraft are desirable--one for sensor and another for target. However, a ground-mounted target could be used to simulate the spacecraft. The Convair 990 program might provide one aircraft and the Earth Resources sensor aircraft used by JSC the other. However, the third and lowest cost approach can meet the requirements, although the atmospheric attenuation will be greater at 10,000 ft altitude than in the aircraft program at 30,000 feet. Due to costs, the initial tests are recommended to be conducted using the latter method. The Rocky Mountain area, west of the Martin Marietta-Denver plant, provides a range of elevation from 10,000 to 14,000 feet and very low humidity (typically less than 20% RH). The proposed test setup includes a fixed target and mobile (vehicle-mounted) sensor as described in the following test setup description, Section 4.0. Of course, the vehicle (road-induced) dynamics are imposed on the sensor and these effects produce a more severe environment on the test.

4.0 TEST SETUP

The test utilizes a full-scale spacecraft mockup which may be of low-fidelity, having accurate representation of target reflector aids, and their geometric layouts. A mobile base is provided for the sensor and its ancillary support equipment, which includes a power supply and a mini-computer. The sensor test setup will be breadboarded for easy installation in and removal from the mobile base, currently envisioned as a rental truck. The target is placed in the high country west of Martin Marietta-Denver plant in a location visable from considerable distances as illustrated in Figure R1A-1.

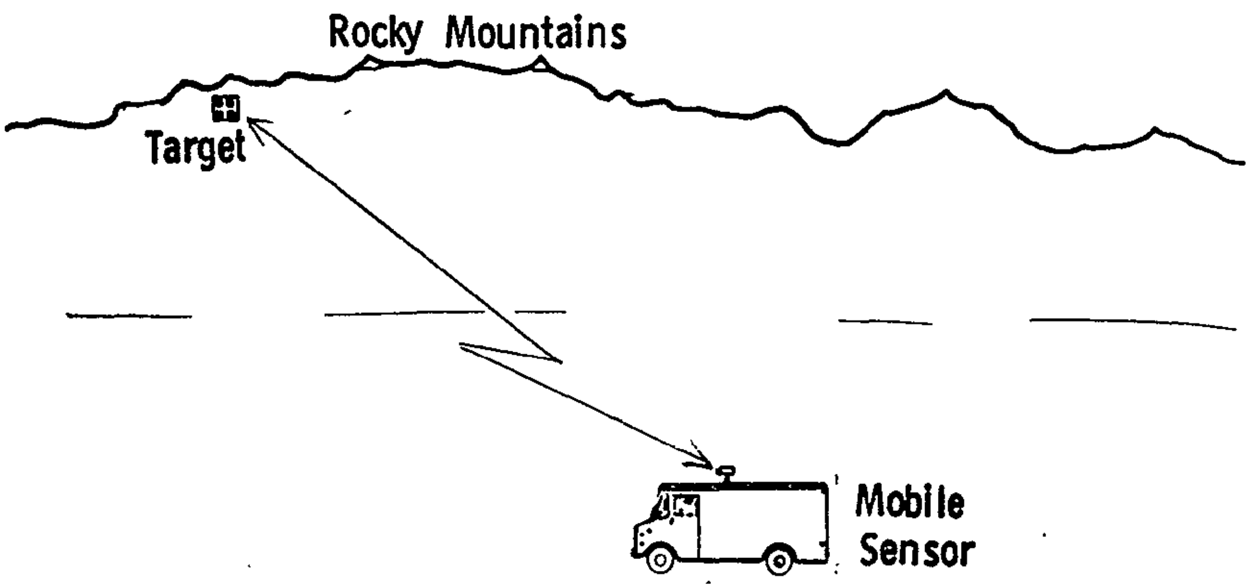

Figure R1A-1 Autonomous Acquisition, Tracking, and Ranging Test Setup

5.0 TEST DESCRIPTION

Test runs will be performed by driving the truck perpendicular to the centerline of the target reflector mockup at approximately 25 miles separation range and recording measured range and LOS angle at predetermined checkpoints. (It may be necessary to stop the vehicle at each checkpoint if road-induced vibrations result in loss of lock.) These results will be compared with actual values. Runs will be performed when the weather is clear and dry both in daylight and darkness to assess the lighting effects and requirements for the SLR or TV sensors. The RF sensor is not considered susceptible to lighting variations. At least four runs will be performed, one in darkness, one in early morning, one near noon, and one in late afternoon. Each run is anticipated to require approximately one hour.

6.0 ANTICIPATED RESULTS

Since the density and humidity of the air at the test site are significantly lower than sea-level, the results are anticipated to be acceptable for extrapolation to deep space. The capability of the autonomous sensor to track the target, when vehicle dynamics and lighting variations are accurately simulated, is expected to be proven or disproven for rendezvous range by this test.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The facility requirements for the high altitude test include a small build-up area for the test setup and supporting equipment for mobile installation. The actual test performance will require rental of a truck or use of a government furnished vehicle.

B. Software - The software for the mini-computer used for simulating tug motion is no different than that required for the other tests if the machines are compatible.

C. Personnel - The manpower requirements include build-up of the sensor pointing and control system for mobile base (or aircraft) mounting, actual test support including vehicle driver, and test data reduction and analysis. These support requirements are listed in Table R1A-1.

Table R1A-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	- Hrs
Facility Operations Costs	$ 800
Engineering Manpower	.8 MM
Technician Manpower	1.5 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	9.0 MM
Technician Manpower	6.0 MM
Software Analyst	6.0 MM
Software Programmer	6.0 MM
Facility Modifications	$ 7,500
DATA REDUCTION/EVALUATION	
Data Analyst	1.5 MM
Engineering	2.0 MM
Test Reports	$ 500

Refer to Manual Candidate Procedures

(Same as Test R2)

TEST PROCEDURE R3A
AUTONOMOUS RENDEZVOUS SENSOR TRACKING

1.0 PURPOSE

This test will demonstrate the autonomous sensor (SLR, RF, or TV) capability for maintaining line-of-slight (LOS) lock on the target under anticipated rendezvous conditions. The sensor measures LOS angles/rates, range and range-rate and the Tug guidance and navigation system control loop uses the sensor data in performing the rendezvous maneuvers. The Tug control laws will make use of the rendezvous and docking sensor data in addition to the normal inertial guidance and navigation data for control.

2.0 SCOPE

This test encompasses Tug and spacecraft separation distances from a maximum anticipated rendezvous range (≈ 25 n mi) to minimum inspection range (75 - 100 ft). The test is performed in conjunction with the previous test (R1A) which had the same basic objectives but was only concerned with maximum range.

3.0 APPROACH

The rendezvous tracking at maximum range could have been performed most effectively using test aircraft. However, closure to 75 - 100 ft separation with aircraft is not as desirable and the selected high altitude test becomes more adaptable to the objectives of this test.

4.0 TEST SETUP

This test uses the test setup illustrated in Figure R1A-1, with no modifications required. The sensor is located so as to be visible at all ranges considered from the flat land in the South Park area of Colorado.

5.0 TEST DESCRIPTION

The test runs will be similar in nature to Test R1A, except for varying the range. The truck-mounted sensor will be driven along at least three (3) approach paths beginning 25 miles from the target and terminating the test at approximately 75 feet from the target. The range and LOS angle data will be recorded at predetermined checkpoints along the route. (It may be necessary to stop the vehicle at each checkpoint if road-induced vibrations result in loss of lock by the sensor.) Duration of each run is anticipated to be approximately one hour.

6.0 ANTICIPATED RESULTS

The results of this test are expected to verify capability of the sensor to track at ranges from 25 miles down to 75 feet. The test is important since this function has never been performed using the sensors under consideration in space flight. Further, the software/hardware techniques being considered have never been demonstrated as a system.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The facilities requirements are identical to test R1A, with no modifications anticipated.

B. Software - The software requirements are the same as test R1A, with exception of range at which tracking is performed. However, this requirement does not impose any modifications to the software.

C. Personnel - Since this test is basically a continuation of test R1A, only actual test support is costed. Refer to Table R3A-1 for estimates.

Table R3A-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	- Hrs
Facility Operations Costs	$ 800
Engineering Manpower	.8 MM
Technician Manpower	1.5 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	3.0 MM
Technician Manpower	2.0 MM
Software Analyst	- MM
Software Programmer	- MM
Facility Modifications	$ -
DATA REDUCTION/EVALUATION	
Data Analyst	1.5 MM
Engineering	2.0 MM
Test Reports	$ 500

TEST PROCEDURE I1A
AUTONOMOUS TARGET TRACKING DURING INSPECTION

1.0 PURPOSE

The purpose of this test is to verify that the Space Tug mounted autonomous sensor (SLR, RF, or TV) can effectively maintain line-of-sight (LOS) tracking of the target spacecraft at minimum inspection ranges (~ 50 ft). This will be accomplished by putting the sensor LOS angles, ranges, and rates in the simulated Tug control loop to maintain an acceptable relative orientation and separation of the two simulated vehicles (Tug and spacecraft). It is assumed the spacecraft attitude is known from spacecraft telemetry prior to Tug approach.

2.0 SCOPE

This test is the first in a series to demonstrate the required functions in the inspection phase. The plan is to perform each succeeding test by upgrading the test setup to allow verification of inspection maneuvers, locating docking port and tracking during closure. This step-wise approach permits analysis of results and incorporation of newly acquired knowledge into the next test.

3.0 APPROACH

Several approaches to the problem are available. For example, the simulation could be performed using software modeling of the entire problem. However, the success of the subsequent operations hinge on proper location of spacecraft recognition aids (retroreflectors). Therefore, the use of full-scale target (spacecraft) recognition aids which are appropriate for the sensor frequency appears necessary. For cost effectivity, the intermediate step of only software modeling will be eliminated. This test requires a faithful reproduction of the Tug control responses and dynamics, in addition to full-scale spacecraft mockup layouts of docking aids. Since subsequent inspection maneuver demonstrations will be "fly-around" of the target, a planar dynamic simulation capability is considered adequate.

4.0 TEST SETUP

The spacecraft mockup is mounted on the Dalto gantry (Figure 1) with provision for 3-axis translation and 3-axis attitude freedom (pitch, roll, and yaw). However, only the spacecraft attitude deadband is simulated for this test. The sensor will be mounted in the Target Motion Simulator (TMS) with 1-axis translation and 3-axis attitude motion available.

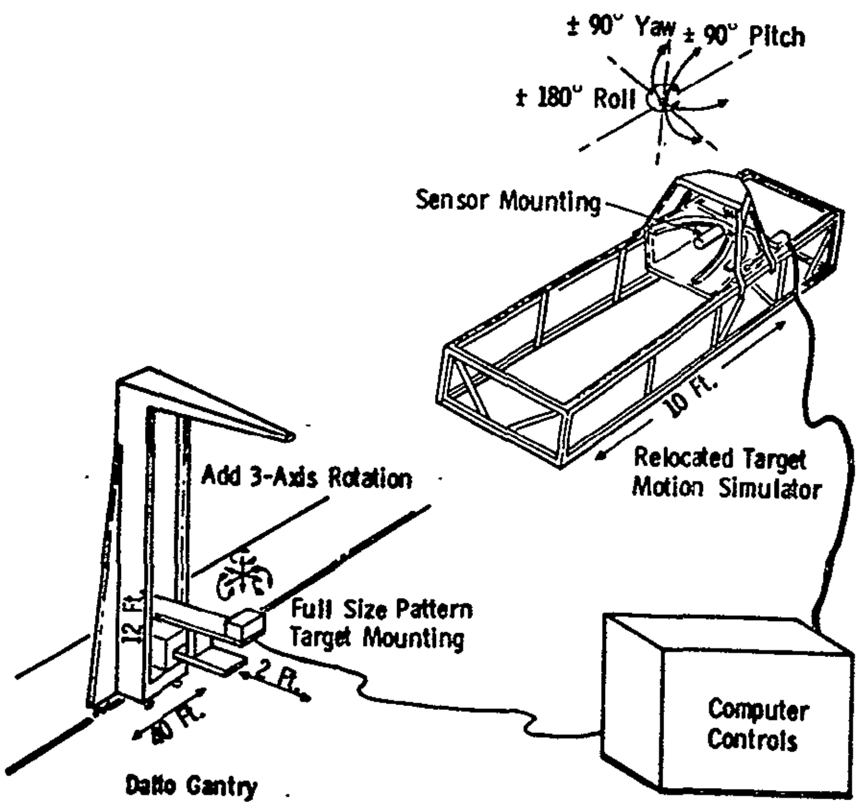

Figure I1A-1 Test Setup

5.0 TEST DESCRIPTION

The test will consist of runs at ranges 25 to 50 feet with the target spacecraft attitude control deadbands simulated but spacecraft attitude oriented for optimum signal return. The test is performed using various layouts of retroreflectors mounted on a full-size mockup spacecraft. Sensor intelligence for LOS angle, range, and rates will be used by the computer to control the sensor (Tug) attitude and measure relative separation of the vehicles. The system will be verified to maintain lock at inspection distances.

6.0 ANTICIPATED RESULTS

The results of this test are anticipated to pick up where the rendezvous phase tests leave off. A new facility (Dàlto gantry and TMS) is used and separation capability of the facility is 50 feet, maximum. The results are anticipated to be demonstration of the sensor tracking capability at the reduced range before introducing the complications of simulating tug "fly-around" maneuvers.

7.0 SUPPORT REQUIREMENTS

A. Facilities - This test uses the Dalto Gantry/TMS facility with 3-axis rotational motion added to the target model mounted on the Dalto Gantry. Facility modification requires moving the TMS and conversion of the Dalto Gantry to the application as illustrated in Figure IlA-1. This capability is not strictly necessary for this test, but will be needed for subsequent tests. Spacecraft deadbands could be included in the software for relative motion between the vehicles.

B. Software - Software algorithms to close the loop between the Dalto Gantry and TMS are required for this test. Much of this software already exists at MSFC and the modification and upgrading of this software to validate its use for this application is required.

C. Personnel - Manpower requirements for this test include moving the TMS and test setup activities. The removal of the TV camera and associated support equipment from the Dalto gantry as well as fabrication and installation of a lightweight spacecraft model (approx. 5 ft diameter) having target aids accurately spaced and aligned are activities which must precede testing. Support of checkout and test runs is also required, as is data reduction and analyses. Estimates for these activities are listed in Table IIA-1.

Table IIA-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	200 Hrs
Facility Operations Costs	$ 7,800
Engineering Manpower	2.7 MM
Technician Manpower	7.6 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	2.0 MM
Technician Manpower	2.0 MM
Software Analyst	3.0 MM
Software Programmer	3.0 MM
Facility Modifications	$ 4,000
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.0 MM
Test Reports	$ 500

TEST PROCEDURE I2A
AUTONOMOUS TARGET INSPECTION MANEUVERS

1.0 PURPOSE

The purpose of this test is to verify that the Space Tug mounted autonomous sensor (SLR or RF) can maintain line-of-sight (LOS) tracking while the space tug circumnavigates the target spacecraft. This will be accomplished by putting the sensor LSO angles, ranges, and rates in the simulated Tug control loop during the execution of a preprogrammed fly-around maneuver. The test will verify the ability of the system to maintain adequate relative separation and orientations to accomplish inspection of the spacecraft to determine a go/no-go for docking.

2.0 SCOPE

This test continues where the autonomous target tracking test (I1A) left off, in that it demonstrates the capability of the sensor to maintain tracking during the inspection maneuver (fly-around) after achieving closure to inspection range. Upgrading of the test setup from I1A to provide for this test involves provisions of rotating and reindexing the target spacecraft through various attitudes to simulate fly-around schemes. The purpose of the fly-around is to inspect the spacecraft to determine its status for retrieval or servicing, as applicable.

3.0 APPROACH

The approach includes an expansion of the test capability to incorporate ro-ation of the target spacecraft to provide additional relative motion between the simulated Tug and spacecraft. A secondary objective of this test is to determine the number and locations of retroreflectors on the spacecraft to maintain tracking during inspection maneuvers. In anticipation of the next test in the series, the development of methodology for finding the docking port during the inspection maneuvers is considered during the performance of the spacecraft inspection. From an autonomous inspection, the Tug computer memory should be programmed to store the locatin of the docking port based on cues obtained during inspection maneuvers.

4.0 TEST SETUP

The test setup is the same as for IlA (see Figure IlA-1) except for software controls. The capability to rotate the spacecraft mockup through 360 deg about a vertical axis to simulate circumnavigating the spacecraft is required. Additionally, the capability to re-index and change spacecraft attitude to simulate fly-arounds in various planes is necessary. An additional capability is required to be added for the laser and TV sensors to simulate celestial scenes. This is necessary to verify laser sensor capability for target separation from stellar objects and to determine solar pointing constraints and illumination effects.

5.0 TEST DESCRIPTION

The test will consist of runs in which the tug/sensor circumnavigates the target spacecraft at 25 and 50 ft inspection ranges and various rates. The tug control logic used for directing the maneuver is resident in the computer control and is verified as a result of the test. Although the actual inspection range may be greater than 50 feet, the capability of inspection at 50 feet is considered adequate for 100-200 feet ranges.

Alternate control logic schemes may be required to perform the maneuver using simulated thruster firing schedules to remove normal accelerations induced by inspection orbit maneuvers. A faithful reproduction of Tug dynamics is required to assure sensor tracking if the target is maintained. Eight test runs are planned to obtain satisfactory results. Three runs at the 25 foot range and four at the 50 foot range will be conducted performing circumnavigation in times of 10, 20, and 30 minute duration at each range. Range, range-rate, LOS angle, and angle rate measurements will be recorded for each run.

6.0 ANTICIPATED RESULTS

The completion of this test is critical in verifying that tracking can be accomplished while maneuvering the tug around the spacecraft for inspection. Verification of the "commit-to-dock" decision algorithms developed in test I5 are anticipated results of this test. However, verification is not complete until the results of docking port identification (Test I3A) and target attitude determination (Test I4A) are factored into the decision algorithm.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The facilities required for this test are the Dalto Gantry/Target Motion Simulator, as described in Test I1A, and located in the MSFC rendezvous and docking laboratory.

B. Software - Software to support this test is that developed under Tests I1A and I5. Only that modification and upgrading of software to validate its use for this application is required.

C. Personnel - Manpower requirements for this test include only direct test support and data reduction and analysis. These requirements are based on support of the Dalto Gantry and Target Motion Simulator and are listed in Table I2A-1.

Table I2A-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	300 Hrs
Facility Operations Costs	$ 11,700
Engineering Manpower	4.1 MM
Technician Manpower	11.4 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	3.0 MM
Technician Manpower	3.0 MM
Software Analyst	3.0 MM
Software Programmer	3.0 MM
Facility Modifications	$ 5,000
DATA REDUCTION/EVALUATION	
Data Analyst	3.0 MM
Engineering	3.0 MM
Test Reports	$ 1,000

TEST PROCEDURES I3A
AUTONOMOUS DOCKING PORT IDENTIFICATION

1.0 PURPOSE

The purpose of this test is to verify the space tug mounted autonomous sensor (SLR or RF) can provide adequate intelligence to the tug computer to allow location of the docking port on the spacecraft. This intelligence is gathered during the tug circumnavigation inspection maneuver(s) about the target spacecraft. For the normal operational case the attitude of the spacecraft is known prelaunch; and therefore the location of the docking port is known. However, the capability to locate the docking port for unknown spacecraft attitudes is highly desirable.

2.0 SCOPE

This test continues in sequence following inspection of the spacecraft and is obviously required for the onboard autonomous commit-to-dock decision algorithm. Prior to final closure maneuvers, it is necessary to determine target spacecraft attitude. Both tug and spacecraft docking axes must be aligned within certain tolerances to affect docking. The determination of target attitude angular misalignment requires reflector patterns on the spacecraft and this test verifies those angular measurements can be made accurately enough to reduce the errors to acceptable values.

3.0 APPROACH

The docking port identification may be a by-product of the inspection maneuver in the nominal case. However, this test will examine cases where the initial inspection orbit is not in the plane of the docking axis. Test runs involve changing the reflectors and reflector configurations which are utilized to locate the docking port and simulating "fly-arounds" in several plans to locate the port autonomously.

4.0 TEST SETUP

The test uses the combined Dalto Gantry and TMS (refer to Figure I1A-1) as supplemented by the simulated "fly-around" and target indexing provisions on the Dalto Gantry.

5.0 TEST DESCRIPTION

The test runs will consist of performing "fly-arounds" by rotating the target 360 degrees, re-indexing by 60 degrees, and repeating the 360 deg rotation maneuver twice. This sequence assures that one of the three inspection orbit planes is within a maximum offset of 30 degrees from the docking axis at worst case. An average inspection orbit time is 20 minutes which therefore results in a one-hour run for each configuration or set of target mounted cues. Four configurations are proposed to cover the expected range of variables.

Figure I3A-1 illustrates the cue configurations with reflector arrangements and dimensions for the autonomous candidate.

6.0 ANTICIPATED RESULTS

The results are anticipated to establish ACS propellant usage for inspection as well as spacecraft mounted cue requirements. Optimum reflector cue locations, number of reflectors, and recommended separation distances are anticipated to be an outpu- of this test.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The facility requirements for this test are satisfied by the Dalto Gantry/TMS facilities located in the MSFC rendezvous and docking laboratory and described in Test I1A.

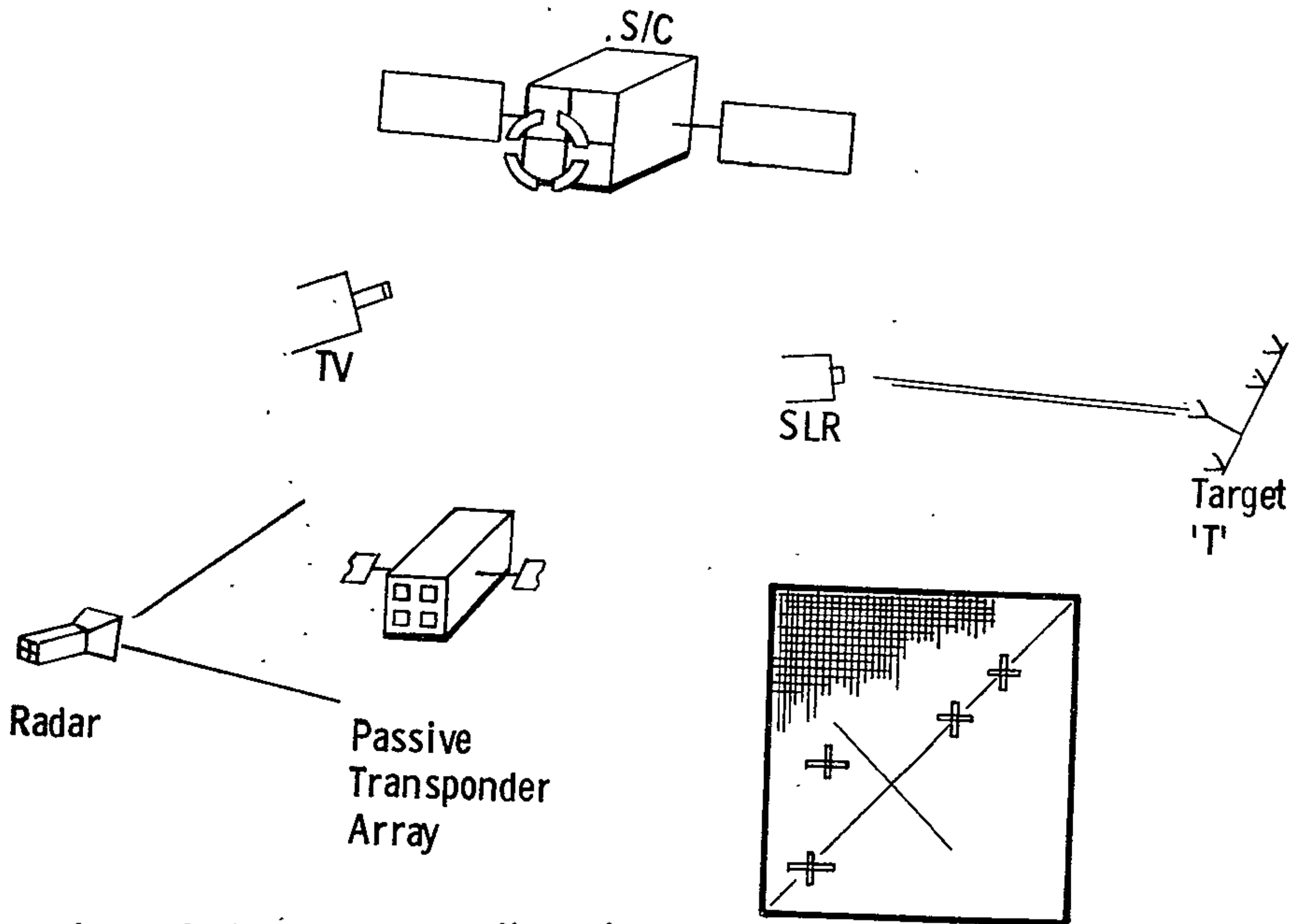

Figure I3A-1 Target Cue Configurations

B. Software --Software to support this test is that developed under test I5 and validated by the other inspection phase tests in the series, of which this test is a part.

C. Personnel - Manpower requirements for this test include only direct test support, data reduction, and analyses of results. The support estimates are listed in Table I3A-1.

Table I3A-1 Test Cost Estimates

ACTUAL TEST SUPPORT		
Computer Hours	100	Hrs
Facility Operations Costs	$ 3,900	
Engineering Manpower	1.3	MM
Technician Manpower	3.8	MM
PREPARATION AND TEST SETUP		
Engineering Manpower	1.0	MM
Technician Manpower	1.0	MM
Software Analyst	1.0	MM
Software Programmer	1.0	MM
Facility Modifications	$ 2,000	
DATA REDUCTION/EVALUATION		
Data Analyst	.5	MM
Engineering	.5	MM
Test Reports	$ 300	

TEST PROCEDURE I4A
AUTONOMOUS TARGET ATTITUDE DETERMINATION

1.0 PURPOSE

The purpose of this test is to determine the capability of sensing spacecraft attitude using the passive aids mounted on the target spacecraft. This is the final test in the inspection series before entering the closure phase. Figure I4A-1 illustrates the information necessary to reduce misalignments to acceptable values for docking.

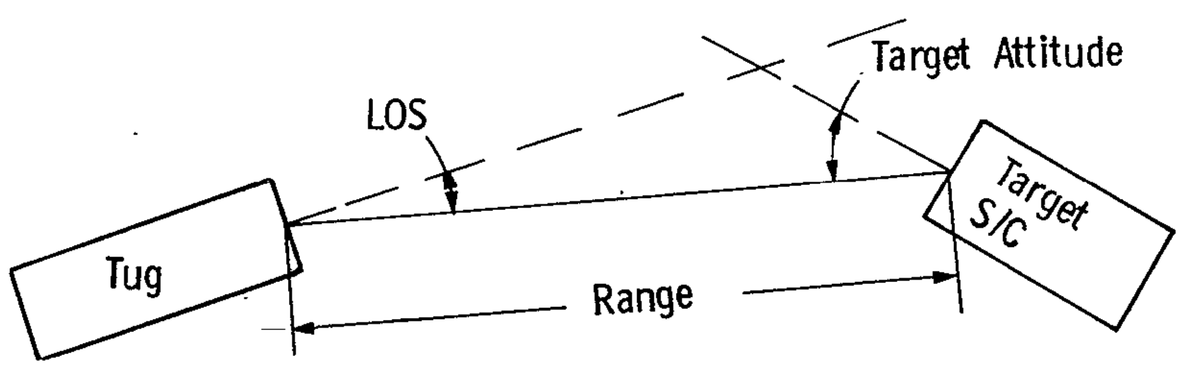

Figure I4A-1 Geometry of Sensed Measurements

These three measurements and their time rates of change provide the necessary intelligence to perform docking.

When these six parameters are known within acceptable limits, the problem becomes one of reducing these measured values to zero. This is accomplished by algorithms designed to operate on sensed values (errors) to reduce the error sources to residuals which can be accommodated by the docking mechaism design.

2.0 SCOPE

This test encompasses evaluation of spacecraft mounted cues as aids to spacecraft attitude determination. Obviously, the spacecraft developers are willing to pay some penalty for the services provided, but the goal is to minimize these penalties. Of special concern is weight, size, and alignment complexity of the spacecraft mounted aids.

3.0 APPROACH

The use of spacecraft mounted aids will be verified for autonomously measuring target attitude angles. The sensed values (range, LOS angle, and target attitude angle) will be applied to the tug control system logic with the resultant goal to reduce all these values to near zero (within the accommodation capability of the docking mechanism).

One approach to demonstrating this capability uses off-set "T" arrangement for reflectors mounted on the target spacecraft. This arrangement is illustrated in Figure I4A-2.

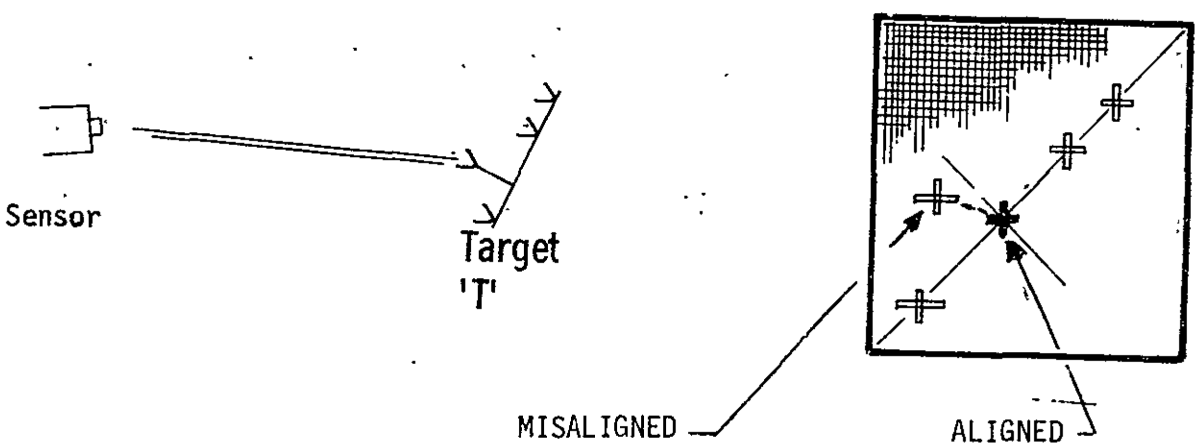

Figure I4A-2 Target Aids for Attitude Determination

The offset "T" arrangement of reflectors provides a recognizable signature in the tug computer logic when properly aligned, as illustrated in the figure. Also, the quantity of angular misalignment is a function of the distance and direction the offset reflector is from the nominal signature, in addition to the separation range of the vehicles. This test uses flight configuration hardware and software to determine the capability and accuracy of the system in measuring the target attitude angle and reducing it to an acceptable residual value for docking.

4.0 TEST SETUP

This test uses the Dalto Gantry/TMS facilities of the MSFC rendezvous and docking laboratory as illustrated in Figure IIA-1.

5.0 TEST DESCRIPTION

Test runs will be performed at various initial conditions to demonstrate the capability to bring the measured angular offsets in target attitude into acceptable residuals for docking. This is accomplished by simulated tug maneuvers to place the sensor in position for closure maneuvers along the axis of the target docking port. Offsets of approximately 2, 5, 10, 20, and 30 degrees will be used as initial conditions for test runs at 50, 40, and 30 foot separation ranges. This requires a total of 15 test runs of 2 to 5 minutes duration each, for the candidate target reflector aids under evaluation.

6.0 ANTICIPATED RESULTS

The capability of the sensor to determine target attitude accurately and for the tug control system to make use of the sensed data to effect docking are key results anticipated from this test. Proceeding to the closure series of tests requires more precise control of the vehicle's relative positions as the potential for collision increases. Successful completion of this test should be verified before proceeding.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The Dalto Gantry/TMS facilities located in the MSFC rendezvous and docking laboratory as described in Test I1A is considered adequate for this test.

B. Software - Software to support this test was developed under test I5 and the algorithms specifically designed to determine target attitude and close the control loop around the sensed data are validated by this test.

C. Personnel - Only the manpower required for direct support of this test, data reduction, and analysis of results is shown in Table I4A-1.

Table I4A-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	100 Hrs
Facility Operations Costs	$ 3,900
Engineering Manpower	1.4 MM
Technician Manpower	3.8 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	1.0 MM
Technician Manpower	1.0 MM
Software Analyst	1.0 MM
Software Programmer	1.0 MM
Facility Modifications	$ 2,000
DATA REDUCTION/EVALUATION	
Data Analyst	.5 MM
Engineering	.5 MM
Test Reports	$ 300

TEST PROCEDURE I5
INSPECTION AND COMMIT-TO-DOCK ALGORITHM VERIFICATION

Refer to Manual Candidate Procedures

(Same as Test I5)

TEST PROCEDURE C1
CLOSURE ALGORITHM VERIFICATION

Refer to Manual Candidate Procedures

(Same as Test C1)

TEST PROCEDURE C2A
TARGET TRACKING DURING CLOSURE - AUTONOMOUS

1.0 PURPOSE

This function is tested to demonstrate the target spacecraft can be tracked by autonomously controlling the tug motion along a prescribed closure path. This is accomplished by using the sensor LOS and range data in the tug control laws to effect the closure. The range of vehicle dynamics, lighting (SLR), and spacecraft configurations anticipated will be simulated.

2.0 SCOPE

This test encompasses the tug to spacecraft separation distances from approximately 50 feet to terminal docking. Step-wise performance of tests to this point permits the reduction of uncertainties prior to operating in the range where collisions are possible. The results of previous tests should be assimilated and required improvements to the system be incorporated in the simulations.

3.0 APPROACH

The approach to demonstrating this phase involves the use of the Dalto Gantry for mounting the full-scale target with aids and the TMS for mounting the sensor. The computer control of the motion between the two simulated vehicles incorporates the closure algorithm and modeling of the tug control laws and dynamics of both vehicles (ACS rates and deadbands). The sensed data is used to close the loop on the tug control system, with the logic designed to reduce range, LOS angle, and target attitude angles to essentially zero at controlled rates.

4.0 TEST SETUP

This test uses the Dalto Gantry and TMS facilities of the MSFC rendezvous and docking laboratory as illustrated in Figure I1A-1.

5.0 TEST DESCRIPTION

The test will consist of runs with closure from approximately 50 feet to a minimum range at which the sensor field-of-view loses capability for measuring all control parameters. This range is determined by target reflector spacing, sensor field-of-view, etc. The closure rates will be varied for each run and angular misalignment residuals at a range where the mechanism can effect soft-dock will be measured. Four runs are planned at rates of 0.25, 0.5, 1.0, and 1.5 ft/sec closures, for each set of target mounted reflectors.

6.0 ANTICIPATED RESULTS

The results of the test runs are anticipated to verify the capability of the hardware and software to measure the parameters, close the loop and control the closure parameters. This is the most critical phase of the impact docking system and has never been demonstrated in space.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The Dalto Gantry/TMS facilities located in the MSFC rendezvous and docking laboratory as described in Test I1A meet the requirements for this test.

B. Software - Software to support this test was developed under Test I5 and the algorithms specifically designed to control closure rates are validated in this test.

C. Personnel - Only that manpower required for direct support of this test, data reduction, and analysis of test results is included in Table C2A-1.

C.3

Table C2A-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	200 Hrs
Facility Operations Costs	$ 7,800
Engineering Manpower	2.7 MM
Technician Manpower	7.6 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	2.0 MM
Technician Manpower	2.0 MM
Software Analyst	3.0 MM
Software Programmer	3.0 MM
Facility Modifications	$ 4,000
DATA REDUCTION/EVALUATION	
Data Analyst	1.0 MM
Engineering	1.0 MM
Test Reports	$ 300

TEST PROCEDURE C3A
AUTOMATICALLY PERFORM CLOSE-IN STATIONKEEPING

1.0 PURPOSE

This test is primarily to verify autonomous stationkeeping capability for non-impact docking. Servicing of satellite spacecraft appears to be a viable option for the rendezvous and docking system and non-impact docking enhances servicing capability. Since the spacecraft appendage (e.g., solar arrays, antennae, etc) may be left extended since the spacecraft is not subjected to docking dynamics, propellant slosh forces, etc and the spacecraft must be left operational after servicing.

2.0 SCOPE

This test covers the capability of the autonomous candidate system to establish and maintain close-in (less than 10 feet) stationkeeping stable attitude between sensor and target vehicles. The requirement for this capability is dependent on the docking mechanism selected for the autonomous candidate.

3.0 APPROACH

The verification of the autonomous capability for stationkeeping has two real advantages. This capability supports non-impact docking and provides a "hold" mode for abort and "commit-to-dock" decision questions. The approach uses the software logic for attitude hold based on sensed LOS angle and range values. The test is also useful for validating the commit-to-dock decision algorithm.

4.0 TEST SETUP

This test uses the Dalto Gantry and TMS facilities of the MSFC rendezvous and docking laboratory as illustrated in Figure IIA-1.

5.0 TEST DESCRIPTION

This test will consist of test runs in which closure is not performed at a constant rate, but the rate is gradually reduced to zero at stationkeeping distance. This distance is varied for each run, with tests conducted at 3, 5, and 7 ft final stationkeeping separations, and initial closure rates of 0.25, 0.5, and 1.0 ft/sec. This set of nine runs will utilize a linear rate reduction beginning with the initial rate at a separation of 50 feet and reducing to zero at the final separation distance.

6.0 ANTICIPATED RESULTS

This test is considered important for two reasons. The autonomous stationkeeping capability is crucial to servicing and attitude hold for abort analysis and decisions. Since this capability has never been demonstrated, it is important before proceeding to the closure abort test.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The Dalto Gantry/TMS facilities located in the MSFC rendezvous and docking laboratory as discussed in Test I1A meets the requirements for this test.

B. Software - Software to support this test was developed under Test I5 and the algorithms to provide closure rate profiles for stationkeeping are validated by this test.

C. Personnel - Only that manpower required for direct support of this test, data reduction, and analysis of test results is included in Table C3A-1.

Table C3A-1 Test Cost Estimates

ACTUAL TEST SUPPORT	
Computer Hours	200 Hrs
Facility Operations Costs	$ 7,800
Engineering Manpower	2.7 MM
Technician Manpower	7.6 MM
PREPARATION AND TEST SETUP	
Engineering Manpower	2.0 MM
Technician Manpower	2.0 MM
Software Analyst	4.0 MM
Software Programmer	4.0 MM
Facility Modifications	$ 4,000
DATA REDUCTION/EVALUATION	
Data Analyst	2.0 MM
Engineering	2.0 MM
Test Reports	$ 500

TEST PROCEDURE C4A
CLOSURE ABORT PROCEDURES - AUTONOMOUS OPERATIONS

1.0 PURPOSE

The primary purpose for this test is to determine whether an autonomous abort capability is feasible, to ascertain acceptable ranges for aborts, and to define the intelligence necessary for an autonomous abort decision by the tug computer or a rendezvous and docking system mini-computer.

Abort for an autonomous system relies on sensed data analyzed by the tug computer to make the abort decision. This test therefore requires software development to simulate an anomalous condition instigating an abort. Further, the test should be preceded by a functional failure modes and effects analysis (FMEA) to define the top-level functions, the loss of which are justification for abort.

2.0 SCOPE

The test will ascertain the limits on range at which aborts can be successfully initiated by varying the ranges at which aborts are performed during closure. Demonstration of autonomous stationkeeping to provide for a "hold" mode is considered highly desirable before entering the abort testing.

3.0 APPROACH

The test is considered best performed in steps which increase in complexity. Initially the aborts will be initiated by preprogrammed command at specified ranges to verify the range at which aborts are feasible. The results of FMEAs will be expanded to include necessary cues (measurements) which are required to tell the tug computer to initiate an abort. This phase of the test program is begun with simple cases and expanded to some reasonable level defined in the analyses preceding the test.

4.0 TEST SETUP

The Dalto Gantry and TMS facilities of the MSFC rendezvous and docking laboratory as illustrated in Figure IIA-1 are used for this test. A test-peculiar monitor is added to determine miss distance of the simulated vehicles, and to halt relative motion when collision is indicated.

5.0 TEST DESCRIPTION

Closure abort runs are performed at decreasing ranges, beginning at 30 feet separation and decreasing in 5 feet increments until collision of the tug with the target is indicated. After this phase is completed, sensed data which indicate an abort decision should be made will be introduced and the decision algorithms of the tug computer. Verification of instigation of an abort, if separation distance is adequate, will constitute satisfactory test completion. Entering a stationkeeping mode, if the distance is too close for other abort maneuvers, will also be verified.

6.0 ANTICIPATED RESULTS

The results of this test are anticipated to determine whether the capability to autonomously initiate an abort is feasible. Some doubt exists that this capability is worth the cost in complexity. Further, anticipating the total gamut of failures before they occur and preprogramming corrective actions for them may be beyond the memory capability of the computer. Based on previous programs, the unexpected failure is the most likely to occur.

7.0 SUPPORT REQUIREMENTS

A. Facilities - The test requirements are met by the Dalto Gantry/TMS facilities of the MSFC rendezvous and docking laboratory as illustrated in Figure IIA-1.

B. Software - Software modifications are required for this test to accommodate the increased complexity for detection of failures and initiation of aborts. The estimated computer support is listed in Table C4A-1.

C. Personnel - Manpower requirements for this test include direct test support, test software modification, data reduction, and evaluation of results, as shown in Table C4A-1.

Table C4A-1: *Test Cost Estimates*

ACTUAL TEST SUPPORT		
Computer Hours	300	Hrs
Facility Operations Costs	$ 11,700	
Engineering Manpower	4.1	MM
Technician Manpower	11.4	MM
PREPARATION AND TEST SETUP		
Engineering Manpower	3.0	MM
Technician Manpower	3.0	MM
Software Analyst	6.0	MM
Software Programmer	6.0	MM
Facility Modifications	$ 8,000	
DATA REDUCTION/EVALUATION		
Data Analyst	3.0	MM
Engineering	3.0	MM
Test Reports	$ 1,000	

TEST PROCEDURE D1
LATCH DESIGN AND OPERATIONS VERIFICATION

TEST PROCEDURE D2
DYNAMICS EFFECTS, PRE- AND POST-LAUNCH

TEST PROCEDURE D3
DOCKING ABORT PROCEDURES

Refer to Manual Candidate Procedures

(Same as Tests D1, D2, and D3)

VOLUME III - PROCEDURES AND PLANS

Part V - SIMULATION/DEMONSTRATION FACILITY MODIFICATION PLAN

RENDEZVOUS AND DOCKING SYSTEM
SIMULATION/DEMONSTRATION
PLAN

1.0 FACILITY USAGE OVERVIEW

The facilities now in existance at MSFC were evaluated for applicability to the simulatin/demonstration test program defined in this study. A tour of the MSFC facilities was performed and previous documentation describing facility characteristics and capabilities was reviewed. The results of this assessment, which was conducted early in the study, is summarized in Table V-1.

Table V-1: MSFC Facility Assessment Results

FACILITY	SUITED TO	APPLICATION TO REND & DOCK S/S DEV	CONCERNS
T27 Space Flight Simulator Bldg 4663	• Visual Simulation • Man-In-the-loop • Scaled Down Scenario • 2 Independent Moving Bodies • Lighting Effects/Celestial Scene • Full Circumnavigation	• TV Inspection • TV Closure • TV Rendezvous (Acquisition)	• Fidelity for Camera Evaluation • TV Operational Problem Simulation
Target Motion Simulator Bldg 4663	• Scaled Down System • Man-In-the-loop • Visual Simulation • T27 Provided Celestial Scenes	• Selected TV Operations • SLR Close-In Stationkeeping	• No Target Circumnavigation
Dalto Gantry Bldg 4663	• Terrain Traverse • 3 Axes of Translation Plus Sensor Head Rotation • Full Scale Hardware Possible	• Closure Phase Sensors and Algorithms • Docking Port Locator Cue Evaluation	• Modification Required • 1 Axis of Translation Is Limited
6 DOF Motion Simulator Bldg 4663	• Full Scale Hardware • 6 DOF Dynamic Evaluation	• Docking Mechanism Evaluation (Loads, Latches) • Close-In Sensor Evaluation	• Computer Generated Vehicle Dynamics • Facility Modifications
Teleoperator Flat Floor Bldg 4705	• 5 DOF • Semi Scaled Down Hardware	• Final Closure Concepts • Target Cues Evaluation • Close-In Sensor Evaluation	• Instrumentation • Control System Fidelity
Test Lab Flat Floor Bldg 4711	• Full Scale Hardware • 75' Vehicle Range • 3 DOF Minimum	• Inspection Phase Sensors And Algorithms • Docking Mechanism Evaluation	• Instrumentation • Vehicle Motion Fidelity
Neutral Buoyancy Bldg S4706	• Full Scale Hardware • Close-In Operations	• Docking Mechanism Evaluation • Latch Vehicle Dynamics • Stationkeeping Control-Close-In	• Fluid Damping Effects On Vehicle Dynamics • Sensor Signal Attenuation
Concept Verification Test Facility Bldg 4708	• Space Tug Avionics Development	• Interface Verification • Tug Software • Communications Links	

In the development of the test procedures an attempt was made to select the facility which best met the requirements while necessitating the least modification. The results of matching the facility capabilities with test requirements is illustrated by test phase in Figure V-1.

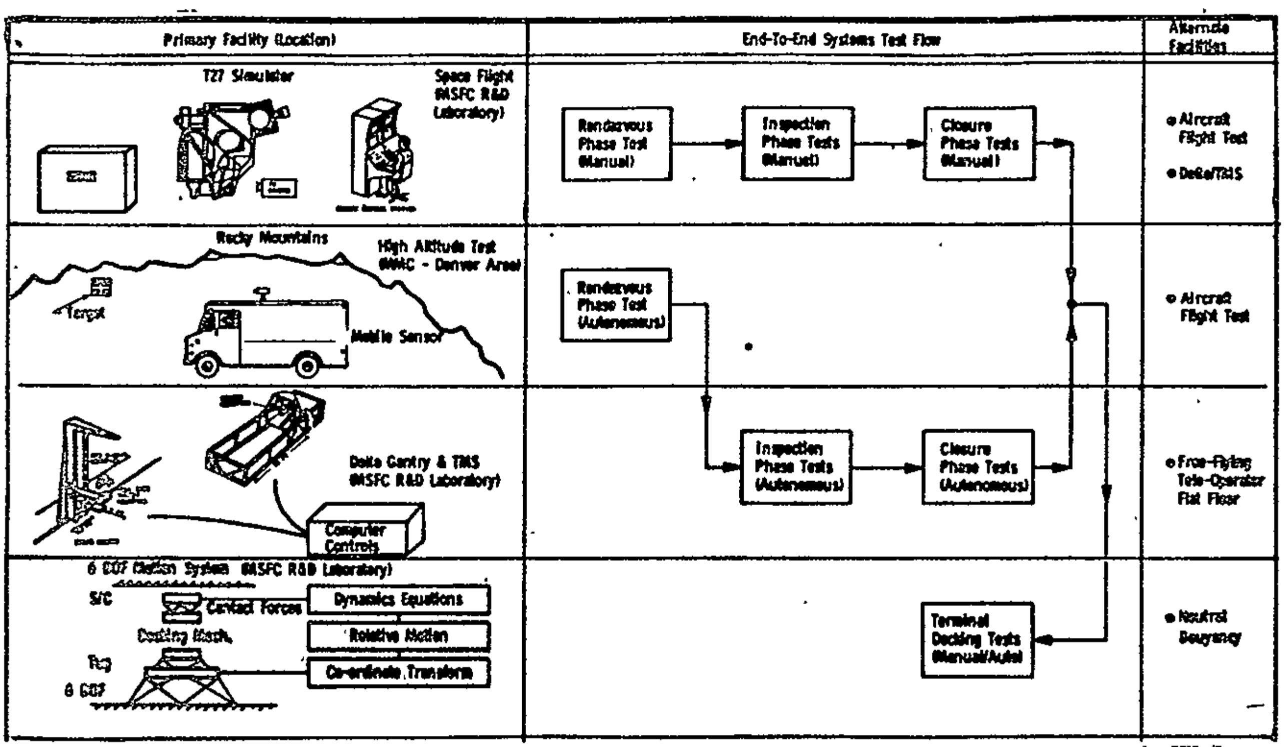

Figure V-1: Facility Usage by Test Phase

The hybrid computer capability resident in the MSFC Rendezvous and Docking Laboratory provides the capability to simulate vehicle dynamics and control systems responses accurately. The necessary facility modification to provide a thorough and comprehensive simulation test program are discussed for the autonomous and hybrid candidate systems in the following sections. Those unique to each candidate are discussed first, followed by the tests having common facility requirements.

2.0 MANUAL CANDIDATE SYSTEM UNIQUE FACILITIES

The T27 Space Flight Simulator is the only facility which is uniquely suited to manual candidate tests. As previously illustrated, it is used for man al rendezvous, inspection and closure phase tests. The test setup for utilizing this facility is illustrated in block diagram form in Figure V-2, with the areas where modification or tailoring to the rendezvous and docking application highlighted.

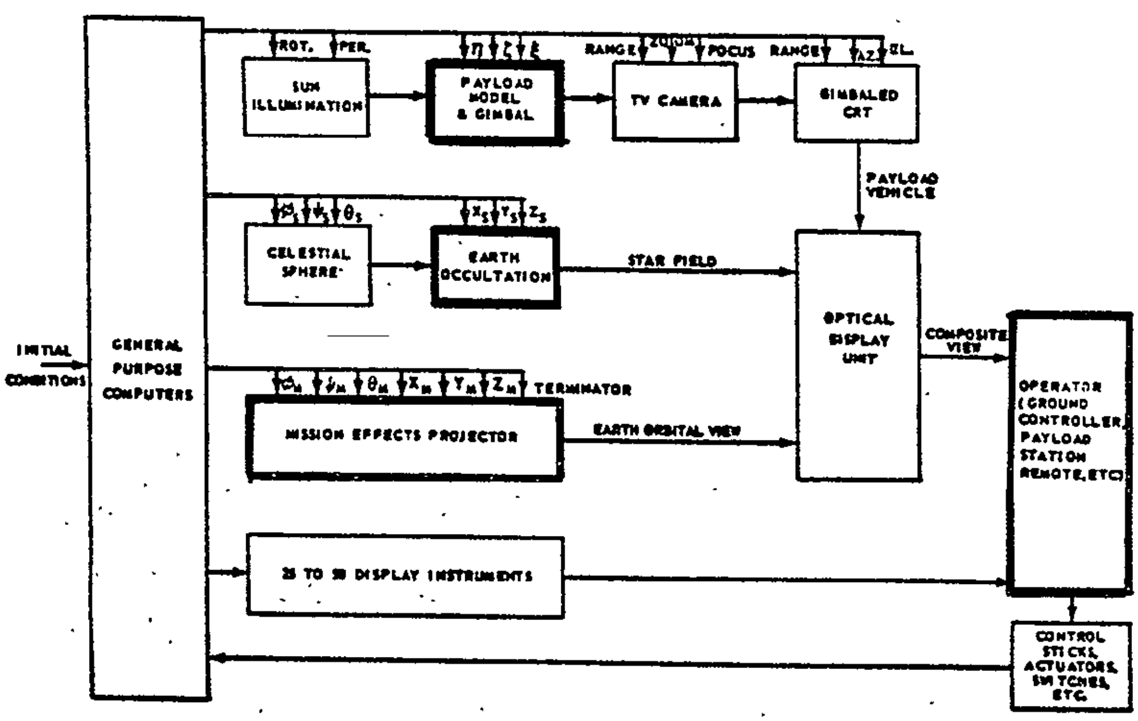

Figure V-2: T27 Space Flight Simulator Functions Requiring Modification

The celestial sphere, earth occultation and mission effects projector functions currently only simulate orbital altitudes and inclinations approximating Skylab missions (~200 miles and 50 degrees). Modifications to these functions are necessary to simulate the range of altitudes and inclinations covered by the current study. Reference spacecraft selected have orbital altitude variations from 900 n mi to geostationary and inclinations from zero to 105 degrees. An area where further tailoring of the facility is required to the current study requirements is in the area of spacecraft models. Accurate representation of spacecraft fidelity is required for use in measuring range, line-of-sight angle and target attitude using image data.

Another area of modification for a manual candidate is illustrated by use of Figure V-3. A variable time delay is required to simulate the delays inherent in the STDN/TDRSS data system.

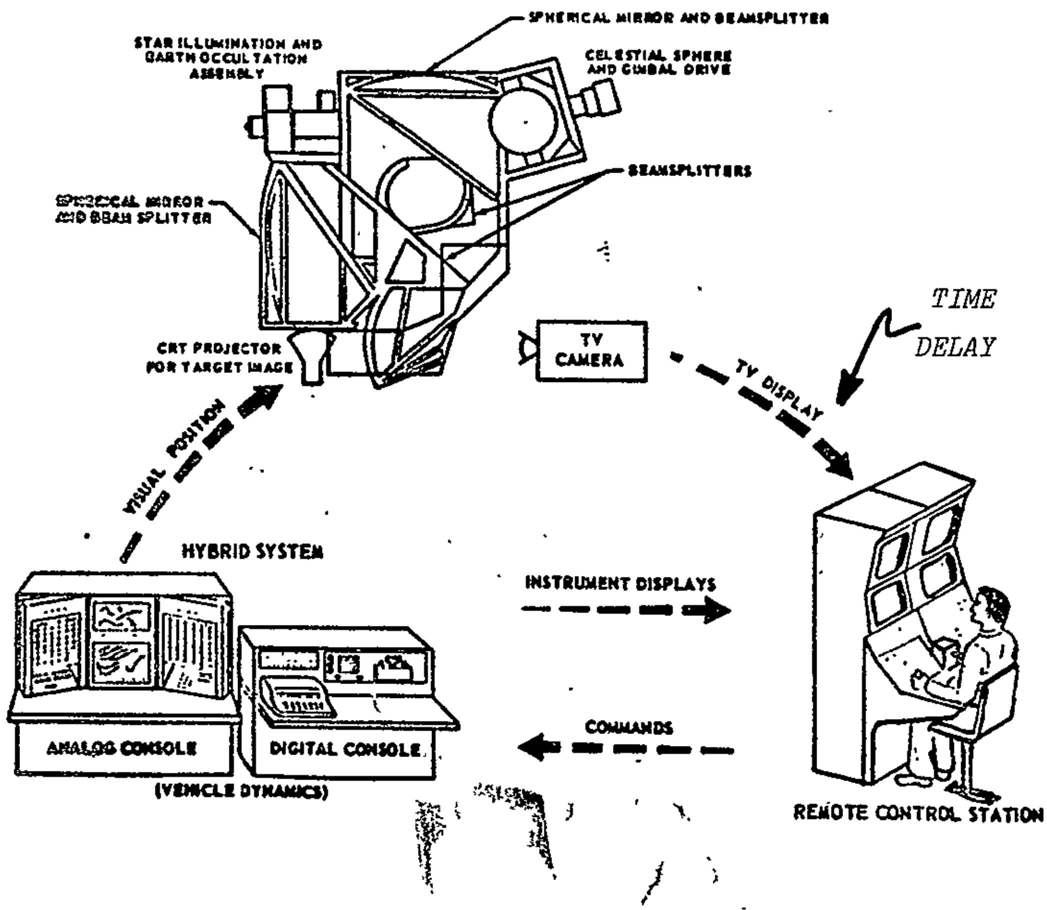

Figure V-3: T27 Space Flight Simulator Test Set-Up

3.0 AUTONOMOUS CANDIDATE UNIQUE FUNCTIONS

The autonomous rendezvous phase tests can best be accomplished in an aircraft or Shuttle flight test program. However, due to costs, another method was recommended in which a high altitude area near Martin Marietta-Denver is used. This test setup requires a vehicle mounted sensor and is described in the Test Procedures, Part IV, Test R1A of this volume.

The test facility recommended for the autonomous inspection and closure phase tests is illustrated in Figure V-4.

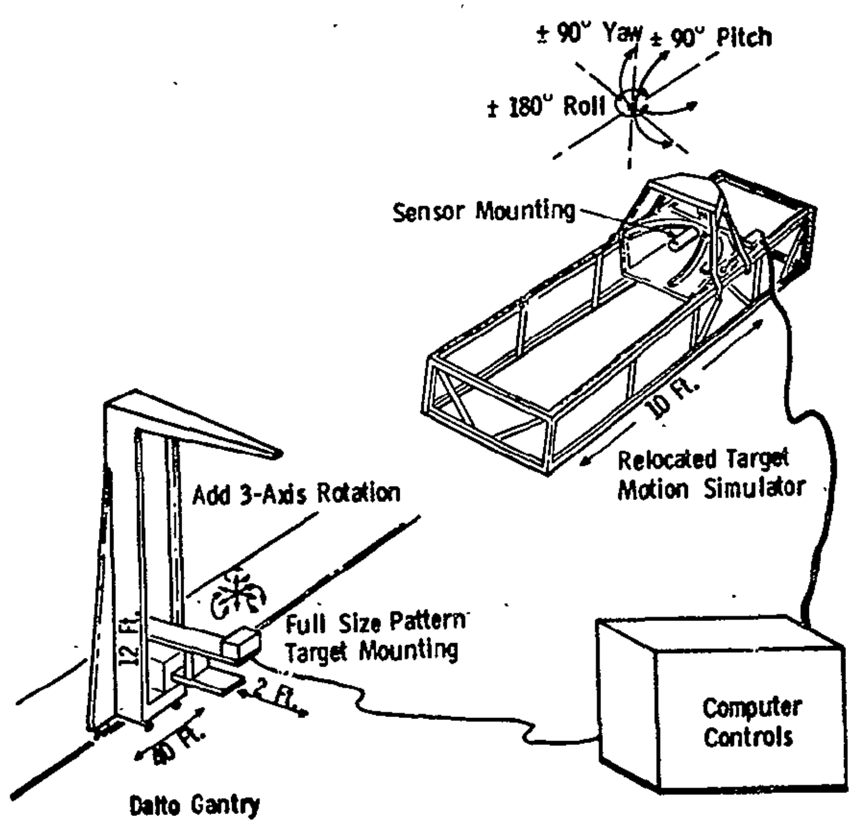

Figure V-4: Autonomous Use of Dalto Gantry/TMS, Facilities

The modifications to accommodate this test include moving the Target Motion Simulator (TMS) to align with the Dalto Gantry track. This provides a combined range capability of 50 feet. A target mock-up having full-size retro-reflectors with actual spacing is mounted in place of the TV camera on the gantry.

Since 3-axis translation and one-axis rotation is currently available for the Dalto Gantry the tests can be performed without added degrees of freedom. However, adding the other two axis rotational capability and expanding transverse translation motion will allow more realistic simulation capability.

The capability to program rotation of this mock-up is required to simulate the fly-around inspection maneuvers.

4.0 AUTONOMOUS AND MANUAL CANDIDATE COMMON FUNCTIONS

The docking phase tests for the autonomous and manual systems involve dynamics at contact and post-latch. These tests are primarily mechanism oriented and, therefore, independent of whether the vehicles were brought together manually or automatically.

The test setup recommended for the docking phase tests uses the 6 DOF motion system as illustrated in Figure V-5.

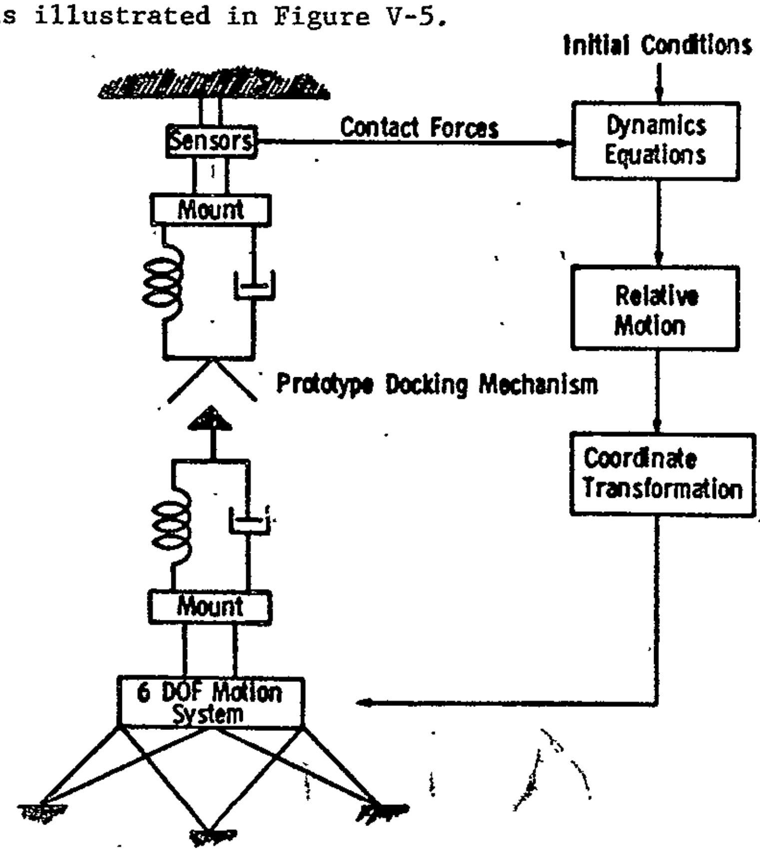

Figure V-5: Docking Phase Test Facilities

The 6 DOF motion system use requires mounting the active vehicle portion of the docking mechanism in the position normally used for aircraft cockpit installation. The passive or target spacecraft portion of the mechanism must be suspended from the ceiling of the building. Instrumenting the mechanisms to measure dynamic responses, as well as developing the dynamics and control software for the system, is required.

5.0 SUMMARY

The facility modifications are summarized in Table V-1, which tabulates those modifications recommended by candidate system.

Table V-2: Facility Modification Summary

Manual System

- T27 Mission Effects Expanded To Include Geostationary Altitudes
- Software Added To Simulate Tug Control Laws, Tug & SC Dynamics
- Built-In Data Processing & Transmission Time Delays Between T27 And Remote Console

Autonomous System

- Move TMS To Mount Sensor In Alignment With Dalto Gantry Track
- Add Indexing Or Additional 2 Axis Rotation To Camera Mount
- Expand Translation Capability Of Dalto Gantry In Transverse Axis
- Software To Simulate Tug Control, Tug & SC Dynamics

Both Manual & Autonomous

Rendezvous - Develop Mobile Sensor Mount
- Develop Full-Scale Mockup Of Target With Aids

Docking - Add Ceiling Mounted Target And Associated Dynamics And Control Software To 6 DOF Motion System