

ESMRO STUDY PROGRAM FINAL REPORT

Volume I Summary

Prepared for

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER

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BALL BROTHERS RESEARCH CORPORATION
 SUBSIDIARY OF BALL BROTHERS COMPANY INCORPORATED
 BOULDER, COLORADO

EXPERIMENTS FOR SATELLITE AND MATERIAL RECOVERY FROM ORBIT

STUDY PROGRAM

F67-05

FINAL REPORT

VOLUME I
SUMMARY

Prepared for

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

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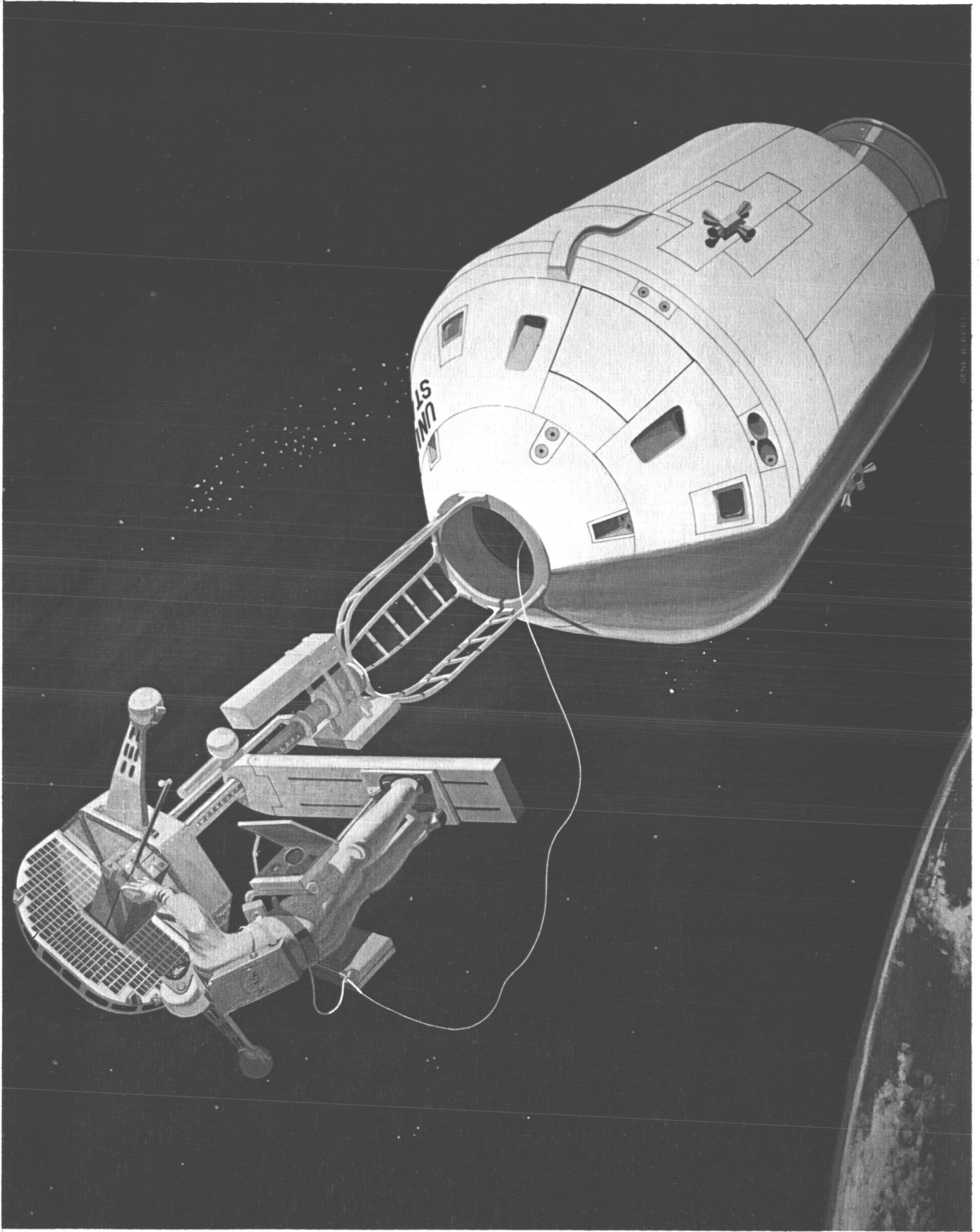
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SATELLITE CAPTURE WORK PLATFORM / APOLLO

BALL BROTHERS RESEARCH CORPORATION



PREFACE

This ESMRO study program final report is submitted per NASA Contract No. NAS8-18119. The report consists of the following three volumes:

- Summary
- Technical
- Experiment Missions

Volume I summarizes the entire study; Volume II is a detailed compilation of study results; and Volume III presents the Apollo experiments on NASA form 1138's.



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GLOSSARY

AAP	Apollo Applications Program
ATM	Apollo Telescope Mount
BBRC	Ball Brothers Research Corporation
CM	Command Module
CSM	Command Service Module
CWP	Capture Work Platform
ΔV	delta velocity
EE	Emerson Electronic Company of St. Louis
ESMRO	Experiments for Satellite and Material Recovery From Orbit
EVA	extra vehicular activity
GSFC	Goddard Space Flight Center
HCO	Harvard College Observatory
IBM	International Business Machines
LEM	Lunar Excursion Module
MOT (stellar)	manned orbiting telescope (stellar)
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSO	mission support operation
NASA	National Aeronautics and Space Administration
NRL	Naval Research Laboratory
OASF	Orbiting astronomical support facility
OSO	Orbiting Solar Observatory
P	primary objective
S	secondary objective
SLA	spacecraft LEM adapter
SM	Service Module
SPS	service propulsion system
UV	ultraviolet



Section 1
INTRODUCTION

Automatic earth orbiting satellites are being used in ever increasing numbers to investigate scientific and weather phenomena, to advance communication, and to further development of earth resources. The comprehensive tasks that these satellites have been designed to perform are comparable to those of major ground based laboratories and facilities. The design approach of these satellites has been to provide maximum reliability for design lifetimes spanning six months to two years. Useful operation beyond these somewhat limited design lifetimes is fortuitous but is not yet planned. With the advent of the manned spacecraft programs, methods are now available to service the automatic satellites, to repair malfunctions and/or improve their performance, and to extend their useful lifetimes.

This report covers a seven month study program of the methods of manually servicing a scientific satellite. This volume presents a summary of the study program results. The major purpose of this study is to define the three experiment missions, evolutionary in complexity, that would lead toward accomplishment of the following objectives:

- (1) Development of extra vehicular activity (EVA) operational techniques, and equipment for rendezvous and capture of a noncooperative object in earth orbit
- (2) Retrieval of valuable materials technology data from an Earth orbiting satellite
- (3) Application of in-orbit repair, refurbishment and checkout techniques to an expanding satellite program

The identification of long range application of these techniques and related satellite design implications is also anticipated. Previous NASA studies have selected the Orbiting Solar Observatory (OSO) as the most promising satellite for the initial manned servicing missions (Federal Systems Division, IBM, Contract NAS1-4667) for the following reasons:

- (1) Its relatively low altitude and orbital inclination, 300 nautical miles and 33 degrees, does not present a significant radiation problem for EVA work.
- (2) Its altitude and inclination are close to that of the planned AAP missions, and efficient orbit transfers can be made to match the Apollo Command Service Module (CSM) orbit to the nearly circular orbit of the OSO.

- (3) The OSO is a progressive satellite program due to the availability of future OSOs for appropriate design modification as required to accomplish in-orbit refurbishment.

A typical OSO is shown in Fig. 1-1.

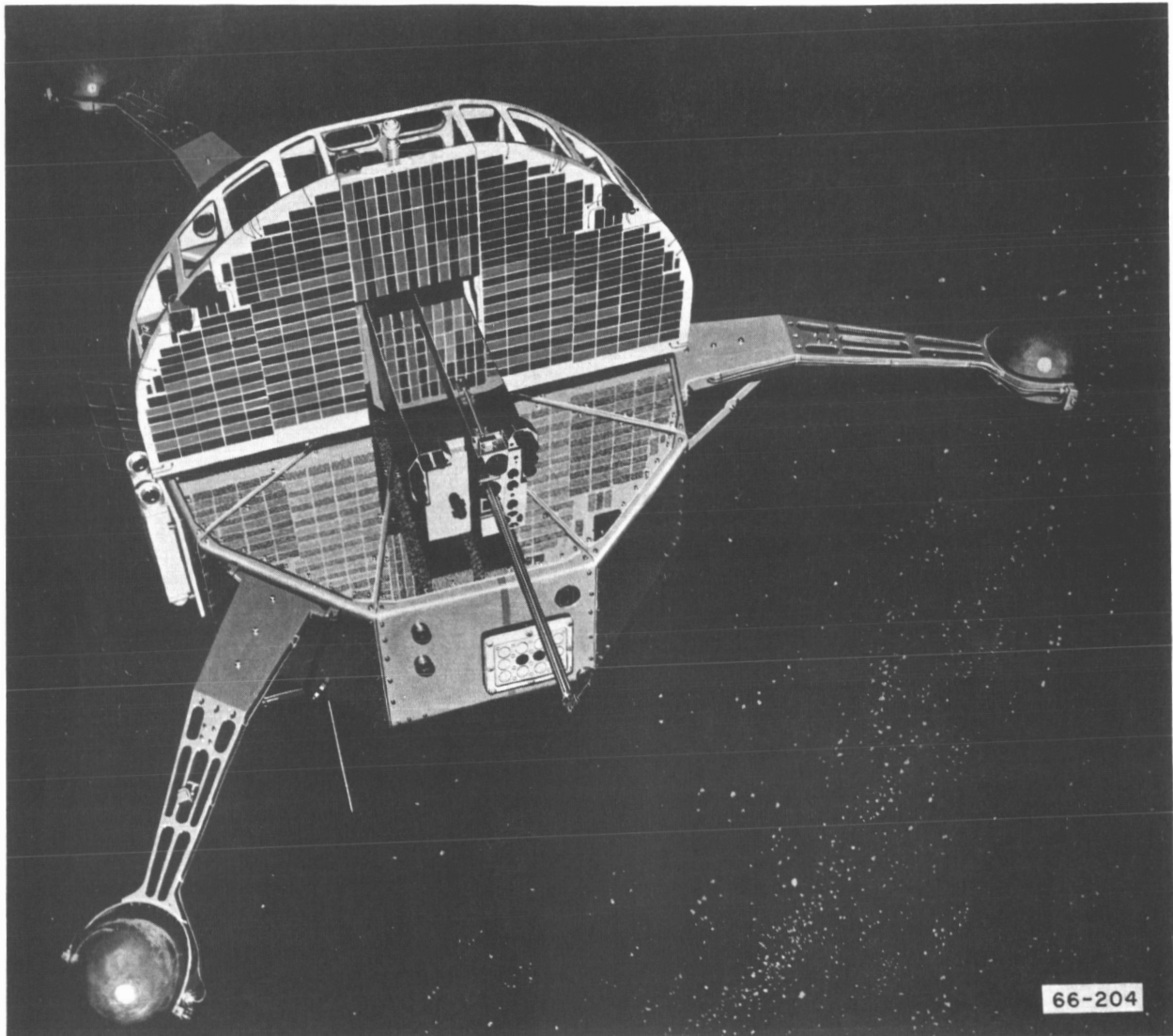


Fig. 1-1 OSO General Configuration

This study program, defined as Experiments for Satellite and Material Recovery from Orbit (ESMRO), has been conducted by the Ball Brothers Research Corporation, Boulder, Colorado, and its subcontractor, the Emerson Electric Company of St. Louis, St. Louis, Missouri, for the Marshall Space Flight Center under contract No. NAS8-18119.



Scientists from the Marshall Space Flight Center (MSFC) and the Goddard Space Flight Center (GSFC), as well as other NASA centers and universities, have been consulted about the experiment program. In addition, the Manned Spacecraft Center (MSC) Astronaut Office has provided valuable review of the concepts developed, as has the GSFC-OSO Project Office.

The major goal of this study program has been to develop three ESMRO missions for the rendezvous and capture of an OSO satellite; these proposal missions are evolutionary in nature with respect to material retrieval, refurbishment, and the conduct of useful EVA work. The three missions are defined in NASA form 1138s (included in Volume III of this report). The technical studies presented in detail in Volume II of this report, have been conducted in two major phases:

- Experiment conception phase
- Experiment mission definition phase

The major criteria and guidelines, established in the study program plan approved by MSFC, are:

- (1) The Apollo CSM is to be used for the rendezvous spacecraft. Initially, the CSM should be in a parking orbit at 370 kilometers (200 nautical miles) altitude and an inclination of 28.5 degrees. An alternate inclination angle of 32.85 degrees, which is the OSO inclination, is to be considered. The eccentricity of the CSM orbit is considered to be 0.00024 ± 0.00021 .
- (2) The target satellite is OSO, which is to be in an orbit of 555 ± 92 kilometers (300 ± 50 nautical miles) altitude and an inclination of 32.85 ± 0.1 degrees. The eccentricity of the OSO orbit is considered to be 0.0004 ± 0.002 .
- (3) The maximum delta velocity (ΔV) assumed available for accomplishing rendezvous maneuvers must not exceed 762 mps (2,500 fps); this is based on conservative estimates of the Saturn I B launch vehicle available payload weight.
- (4) The target satellite (OSO) is to be noncooperative.
- (5) Capture of the OSO must not be destructive.
- (6) After the target OSO is captured, the material retrieval and refurbishment effort is to be performed by EVA.
- (7) Refurbished OSO's are to be returned to normal orbital operating condition following the useful work activities.



The functional requirements of performing the ESMRO missions have been determined by detailed analyses of each phase. Trade-off analyses were conducted to determine the recommended approach to rendezvous, capture, useful work, and release. Technical studies have resulted in a conceptual configuration identified in this report as the Capture Work Platform, (CWP). EVA analysis was conducted to determine detailed timelines for each mission. The significant results of this study program are summarized in the next section, followed by recommended future effort for accomplishment of long range goals and the estimated schedule and cost of conducting the three missions.

Section 2
 RESULTS

The major mission phases that have been analyzed are (1) rendezvous, (2) capture/release, and (3) useful work. The trade-off and technical studies conducted in each area are presented here, followed by a summary mission plan for the three missions.

2.1 RENDEZVOUS PHASE

The rendezvous maneuvers involve: (1) the transfer of the CSM from its parking orbit to the vicinity of the target OSO; (2) terminal closure of the CSM to the OSO; and (3) station keeping of the CSM with the OSO. The major items analyzed have been: (1) type of orbit transfer trajectory; (2) type of terminal guidance; and (3) method of station keeping.

2.1.1 Orbit Transfer

The major alternatives considered in performing the orbit transfer are defined on the following page:

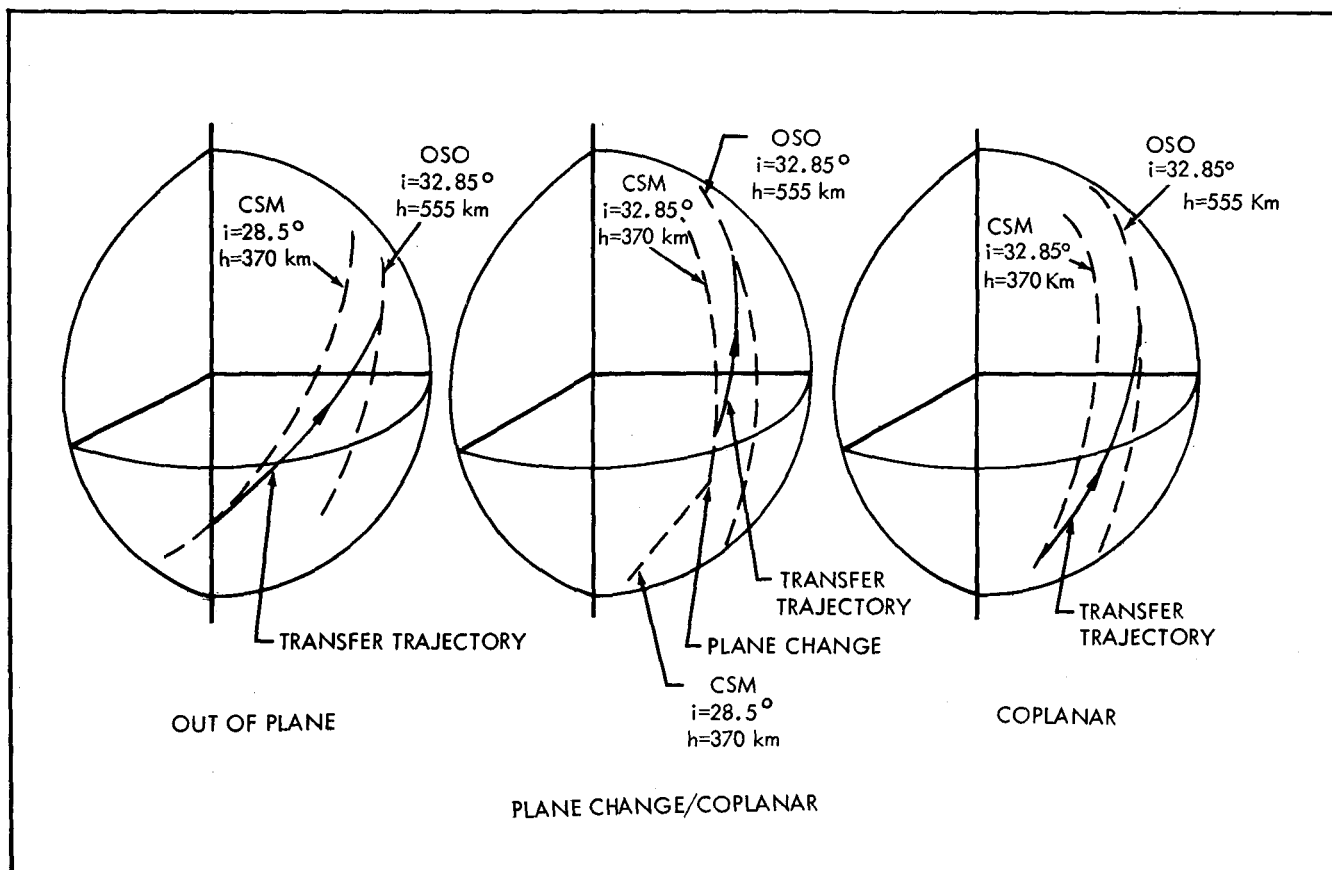


Fig. 2-1 Rendezvous Approaches



- (1) Out of plane: Rendezvous by means of out of plane orbit transfer combines the orbit transfer and plane change of the CSM to the OSO orbit with two impulse burns of the CSM service propulsion system (SPS) engine.
- (2) Plane change/coplanar: Rendezvous by means of plane change/coplanar orbit transfer requires a plane change of the CSM at the 370 kilometer parking altitude, followed by a coplanar transfer of the CSM to the OSO orbit.
- (3) Coplanar: Rendezvous by means of a coplanar orbit transfer requires that the CSM orbit inclination be the same as OSOs and that the orbit transfer be initiated when the longitude of the ascending node of the CSM orbit is the same as that of the OSO orbit.

Digital computer calculations have determined the delta velocity required to perform each of the three alternative orbit transfers. The calculations were limited to delta velocities that could be obtained by the CSM departing from the 370 kilometer altitude parking orbit with an estimated payload configuration. The ΔV assumed was 762 mps (2500 fps); this is proportional to a typical payload configuration.

The results for the out of plane orbit transfer, including nominal values for the CSM and OSO orbital elements, are shown in Fig. 2-2. Out of plane orbit transfer can be accomplished within the 762 mps ΔV limit for differences in the longitude of the ascending nodes of the CSM and OSO orbits of up to about 3 degrees and for the nominal CSM and OSO inclination of 28.5 and 32.85 degrees respectively. For no difference in the longitude of the ascending nodes at the start of the orbit transfer, about 610 mps is required for the minimum energy transfer.

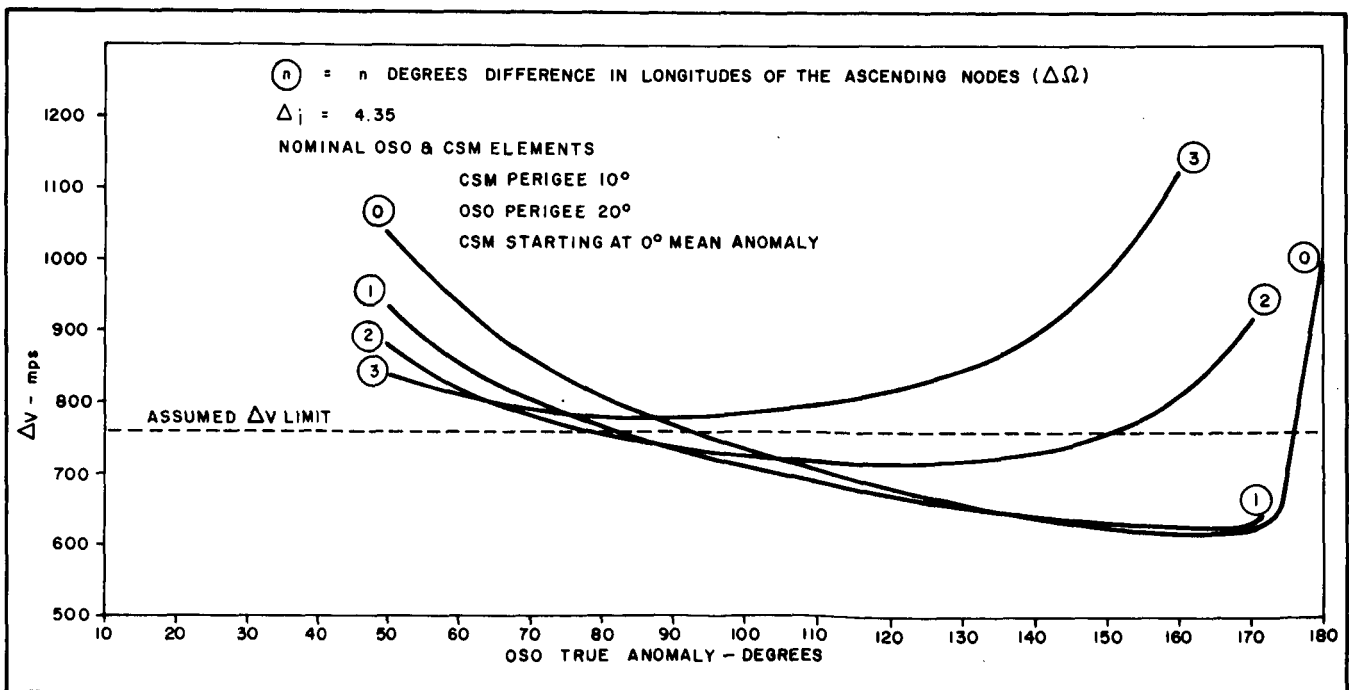


Fig. 2-2 Out of Plane ΔV Requirements

The ΔV required to perform orbit transfer as a function of differences in the longitudes of the CSM and OSO ascending nodes and in orbital inclination angles is given in Fig. 2-3. These data show that the major consumption of ΔV occurs when the plane change is performed due to difference in orbital inclination. It is therefore recommended that the CSM be placed in its parking orbit at an inclination the same as that of the OSO. Similarly, to minimize the ΔV required, the difference in the longitude of the CSM and OSO ascending node should be small at the initiation of orbit transfer. This can be controlled by establishing the launch of the CSM from the surface at a time when the CSM orbit precesses into the OSO orbit, early in the 14 day mission period. Since the CSM orbit plane approaches the OSO orbit plane from an eastward direction at a rate of 1.01 degrees per day, a nominal 10 day surface launch window period allows for the CSM ascending node longitude being up to 10 degrees east of the OSO ascending node longitude; this still permits the ESMRO mission to be conducted within the 14 day mission.

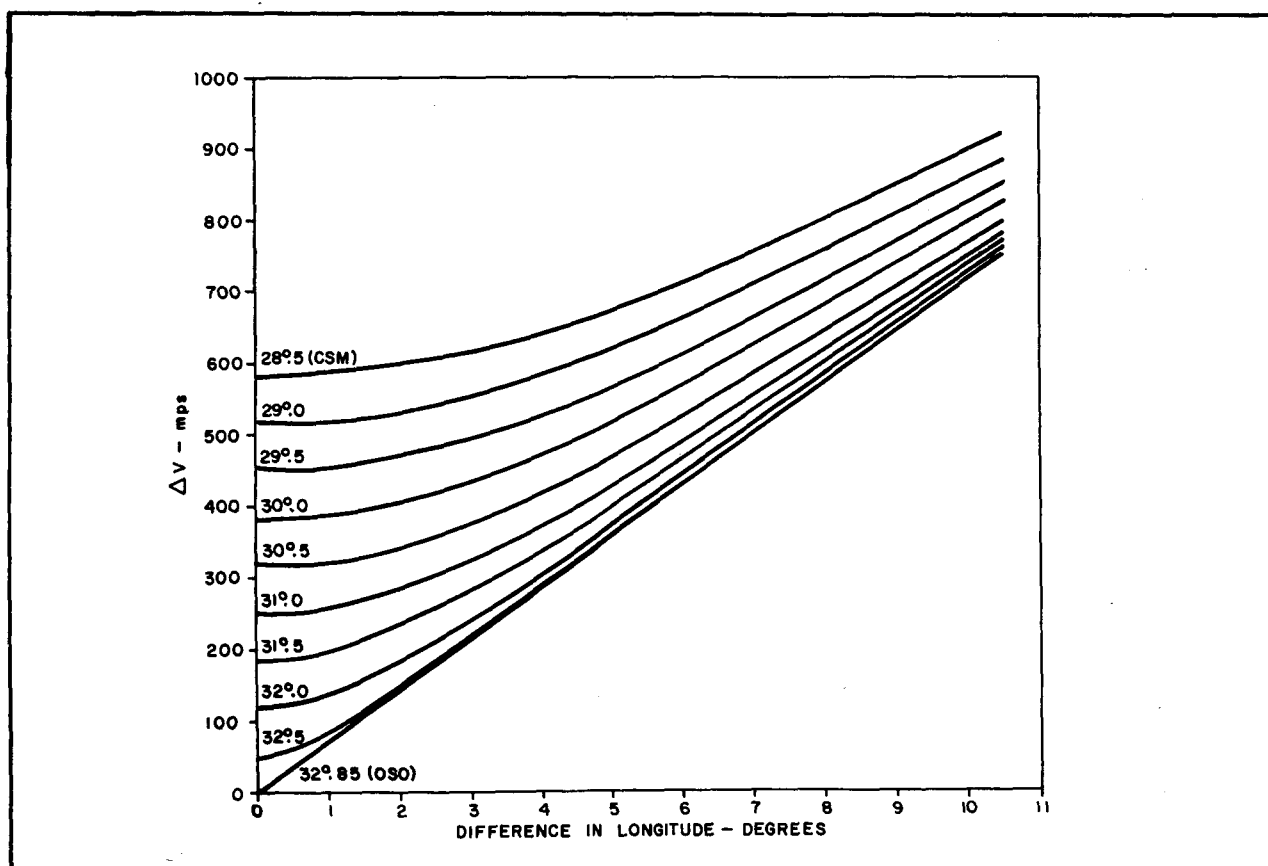


Fig. 2-3 ΔV Requirements as a Function of Plane Change

Calculated data for the coplanar orbit transfer are shown in Fig. 2-4. The minimum ΔV of 115 mps occurs for a transfer over an angle of 180 degrees. This ΔV represents the minimum requirement for performing the orbit transfer, and such a coplanar transfer is recommended for the ESMRO missions.

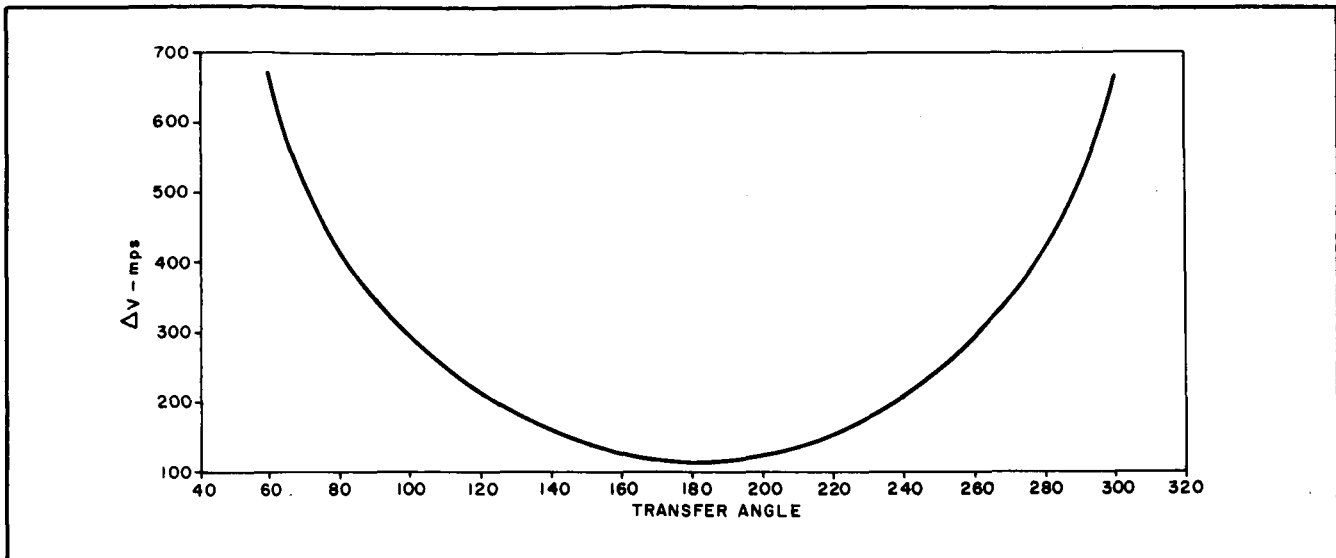


Fig. 2-4 In-Plane Minimum Energy Transfer

Additional calculations have determined the effect of varying the eccentricities and inclinations for both the CSM and OSO orbits on the delta velocity requirements. The variation in these orbital elements from the nearly circular orbits of the CSM and OSO has a minor effect on the total ΔV required for orbit transfer.

2.1.2 Terminal Guidance

The terminal closure maneuvers must correct for possible errors in the known positions of the CSM and OSO as well as in the transfer orbit errors due to thrust impulses. An error analysis shows that the coarse rendezvous maneuver should be within an error ellipsoid of a 20 kilometer major axis and a 10 kilometer minor axis. At 10 kilometers, a sunlit OSO will be brighter than a visual magnitude of minus 2. At 5 kilometers, the sunlit OSO will have a visual magnitude of minus 4, i.e., about as bright as Venus. Analysis of various terminal closure trajectories with the CSM forward and below the OSO indicates that the line of sight to the sunlit OSO and its apparent motion against a star background will make it easily detectable by the astronaut crew. Therefore, it is concluded that the terminal guidance can be performed visually by the crew with the aid of a simple reticle sight to determine range rate data. Further analysis of the possible approach trajectories has shown that an intercept (collision) course terminal maneuver is the most efficient, requiring as little as 73 mps (240 fps) of ΔV .

2.1.3 Station Keeping

Two station keeping modes are required for the ESMRO missions to conduct precapture inspection: (1) nighttime, and (2) daytime circumnavigation. Analysis has shown that a minimum distance of 60 meters (200 feet) between the CSM and OSO can readily be maintained during orbital night by two programmed thrusts of the CSM. Similarly, the daytime circumnavigation at approximately 30 meters (100 feet) can also be maintained by programmed thrusts. The total ΔV required for two nighttime and one daytime station keeping modes is less than 8 mps (25 fps).

2.2 CAPTURE/RELEASE PHASE

The capture phase of an ESMRO mission involves the use of a capture mechanism to contact and contain the OSO until its spin angular momentum and translation momentum are nullified. The release phase is virtually the reverse of capture; i.e., the OSO must be spun up and separated from the CSM. The major items that have been analyzed are: (1) method of coupling the OSO to the CSM during capture; (2) method of capturing the OSO; and (3) the method for despin and spin-up of the OSO.

A study program constraint is the capture of a noncooperative satellite. The OSO dynamics have been examined to determine the spin characteristics of both active and inactive OSO's. The spin rate of an OSO without spin control is expected to decay at about 2 percent per month. This decay rate will result in a spin momentum reduction to about 80 percent of nominal after a year of no spin rate corrections. After 4 years without spin control, an OSO is expected to be spinning at 10 rpm or greater; thus, it will still act as a relatively rigid gyro.

2.2.1 CSM/OSO Coupling

The major alternative methods for coupling the OSO to the CSM during the capture operation are the following:

- Free: A small maneuvering vehicle that would be operated remotely from the CSM, and would apply virtually no capture forces into the CSM.
- Rigid: A rigid structure attached to the CSM that would apply the capture forces directly into the CSM.
- Semirigid: A partially flexible structure attached to the CSM that would decouple the capture forces from the CSM.
- Tethered: A completely flexible tether line with limited control. Capture forces would be applied to the CSM when the line becomes taut.

The coupling trade-off analysis has shown that the semirigid capture mechanism has significant advantages over the others, as shown in Table 2-1. Also, it is the most compatible for converting to the desired work station configuration. Table 2-1 lists nine criteria items which best compare alternate coupling methods. A rating or scale factor from 0 to 10 was used to judge each criterion; zero represents the worst (or least desirable), and 10 represents the best (or most desirable).



Table 2-1
COUPLING TRADE-OFF EVALUATION^(a)

Criteria	Free	Tethered	Rigid	Semirigid
Maximum safety to CSM and crew	10	4	8	8
Least system complexity	0	10	10	7
Least forces applied to OSO and CSM	10	7	0	8
Least possibility of damage to OSO	5	2	4	6
Evolutionary capability	10	6	5	8
Ease of operation	4	0	10	8
Ease of ground simulation and test	5	1	10	10
Minimum development time	0	10	10	8
Minimum development cost	0	10	8	7
TOTAL	44	50	65	70

(a) The largest score is the most desirable

2.2.2 Attachment Head

A variety of attachment heads have been considered for the capture mechanism, such as an enveloping net, a net over OSO pressure spheres, a grapple, a remote manipulator, a fly-in funnel, an encircling tape (Bolas), an adhesive, a yoke, and a rigidized tether. The adhesive and yoke have the most advantages. The adhesive head is bonded around the OSO attachment flange on the bottom of the wheel, while the yoke arms slip between the three OSO arms and secure them. Laboratory high vacuum bonding tests (conducted by Emerson Electric Co. per Contract AF33(615)-2540) of various adhesives have shown that bonds with tensile strengths of 10 psi are possible less than one minute after application. Both the adhesive and yoke heads could be used to capture the OSO, and could be interchangeable components on the same basic capture mechanism. The adhesive head is shown in the frontispiece and other figures in this report.

2.2.3 Capture Mechanism Configuration

The semirigid capture mechanism conceived during this study is illustrated in Fig. 2-5 and the frontispiece. The main features consist of a central boom with LEM type docking collar on one end and the attachment head on the other end. The capture mechanism could be stored either in Sector I of the Service Module (SM) or in the spacecraft LEM adapter (SLA) section. The latter is recommended, since the CSM could dock with it just as it does in the LEM docking operations; this eliminates any need for EVA assembly. Locating the capture mechanism on the CSM docking adapter provides good crew visibility for capture operations, similar to CSM/LEM docking.

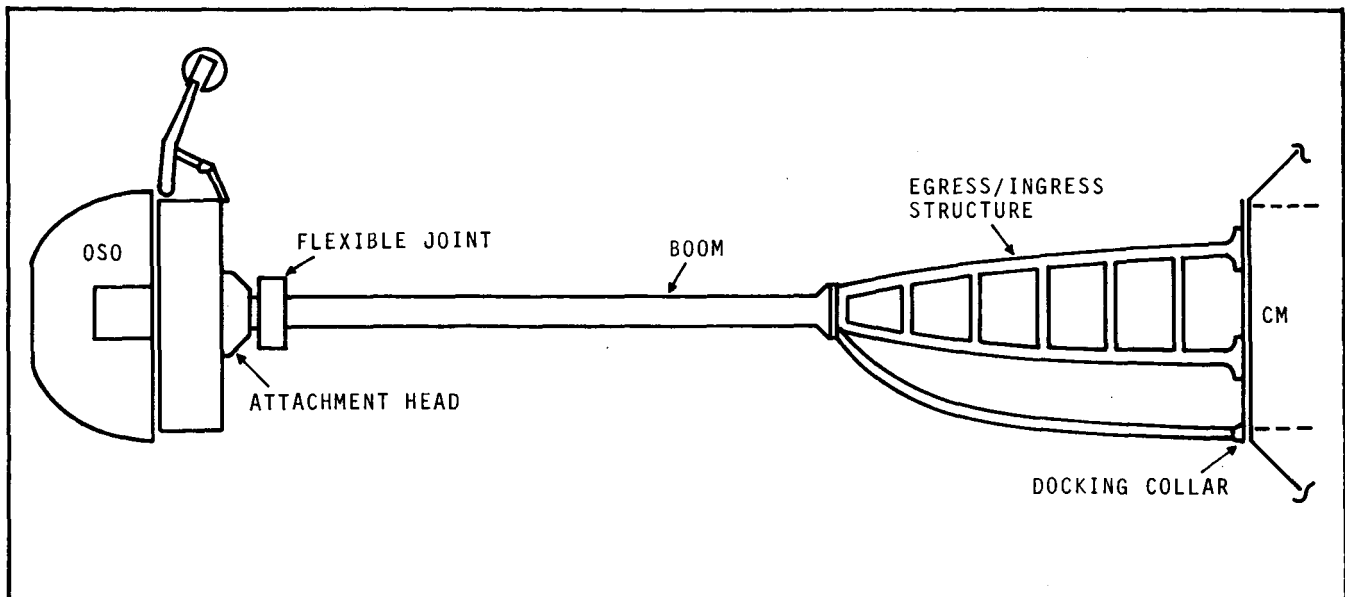


Fig. 2-5 Semi-Rigid Capture Mechanism Concept

The capture technique aligns the CSM along the OSO spin axis, prespins the attachment head to approximately match the OSO spin rate, and maneuvers the CSM with attached capture mechanism into contact with the bottom of the OSO. A flexible joint would be included in the capture mechanism to correct for any misalignment between it and the OSO. Since the spinning OSO acts like a gyroscope, any off-center contact causes precession and nutation; thus, off-center movement capability would be incorporated into the design of the attachment head. The translation forces resulting from contact between the CSM and OSO should be absorbed in a compression spring in the boom by means of a ratchet locking device which stores the energy; this energy storage is effected by locking when the spring reaches its extreme compression. The OSO spin angular momentum is nullified by despinning the attachment head and the OSO by means of a torque motor or friction brake. The adhesive head is then heated to release the adhesive bond, and a centering mechanism centers the OSO attachment flange on the capture mechanism spin axis. Following the useful work phase, the OSO is released into operation by spinning it up and releasing the restraining mechanism from the OSO attachment flange.

2.3 USEFUL WORK PHASE

The useful work phase of the ESMRO mission involves the conduct of the material retrieval and refurbishment experiments on the captured OSO. The major items that have been analyzed are: (1) the location of the OSO during the performance of the useful work; and (2) the location of the EVA astronaut with respect to the OSO. The major study effort has developed ESMRO experiments in the following categories: (1) inspection, (2) material retrieval, and (3) refurbishment. A program plan has been developed for three ESMRO missions which are evolutionary in nature with respect to material retrieval and the conduct of useful EVA work.



2.3.1 Performance of Useful Work

One major motivation for locating the capture mechanism on the CSM front end is that the captured OSO is then in the most advantageous location for work performed on it. Astronaut egress and ingress can be made through the CSM forward hatch directly to the OSO. Furthermore, the OSO is firmly attached to the CSM by rigidizing the capture mechanism flexible joint; this positions it in full view of the astronauts in the Command Module (CM), through the forward viewpoints.

The results of the Gemini program have shown that astronaut EVA work can be performed if the astronaut is properly fixed with respect to the work area. A work platform has been conceived to provide the EVA astronaut with fixity. The work platform attaches to the capture boom and is erected to the working position near the OSO, as shown in Fig. 2-6 and the frontispiece. The work platform moves up and down for work at various levels on the OSO, and in and out for clearance of the OSO arms when the OSO is rotated for access to various parts. The EVA astronauts are to be fixed to the work platform with waist restraints and/or foot restraints. The tools, cameras, lighting and parts storage are to be located on the work platform for easy access. The combined capture mechanism and work platform is referred to as the Capture Work Platform (CWP).

2.3.2 Inspection

A large number of experiment tasks have been developed and evaluated for each category proposed. Many of these are prerequisite to the mission. These include precapture inspection of the OSO to determine the spin rate and general condition. The major inspection experiment tasks involve: (1) examination of the OSO; (2) documentation (visual and photographic) of the OSO condition; and (3) investigation of specific OSO features and surfaces. Each of these tasks as well as the following tasks are specifically described in Volume II of this report.

2.3.3 Material Retrieval

The material retrieval experiment tasks include recovery of materials, components, and assemblies for analysis in the following areas: (1) environmental effects on materials and optics; (2) environmental effects on mechanisms; and (3) failure analysis of OSO hardware. Specific experiment tasks were reviewed, and it has been determined that the OSO II satellite launched on 3 Feb 1965, should be used for the material retrieval mission. The material to be retrieved from OSO II is presented in Table 2-2. It can be seen that the items selected can provide a variety of information. Typically, a large amount of data can be obtained on long term emissivity properties, and micrometeorite data can be obtained for the flux region from 10^{-5} to 10^{-9} impacts per square meter per second that has not been covered to date.

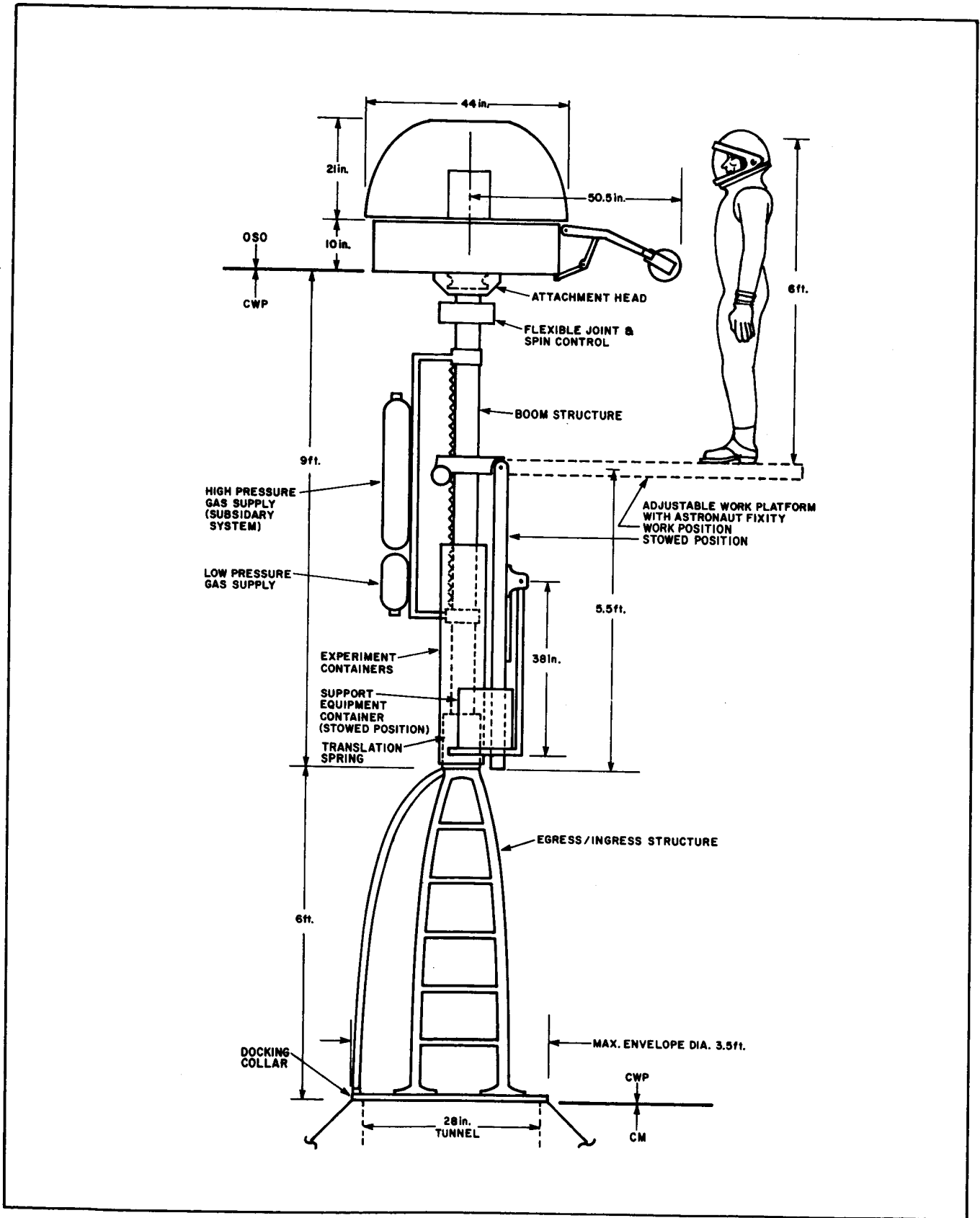


Fig. 2-6 Capture Work Platform Conceptual Configuration



Table 2-2
MATERIAL RETRIEVED FROM OSO II, MISSION 1

Retrieval Item	Environmental Effects on Material & Optics	Environmental Effects on Mechanical Analysis	Failure Analysis
NRL coronagraph occulting disk	X		
Pointing control sun sensor assembly	X		
Right hand solar array panel	X		
HCO ultraviolet spectrometer	X	X	X
Ames emissivity sensor plate	X		
U. of Minn. zodiacal light telescopes	X		
GSFC UV azimuth indexer	X	X	X
U. of New Mexico gamma-ray telescope foil	X		

One of the major design problems encountered in development of space scientific experiments has been that of the operation of exposed high voltage systems in the space environment. Arcing has occurred in several space experiments and has caused severe noise interference problems; in one case, a total failure of a major experiment occurred. This failure was in the OSO II-HCO experiment and occurred at the initial instrument turn on. This unexplained failure has caused considerable design review of similar systems in other experiments, but corrective designs may require direct examination of the failed instrument.

Analysis of the other items retrieved, such as the pointing control sensors, the solar array, and exposed wiring, should lead to improved spacecraft designs. Similarly, retrieval of other OSO II experiment components, such as the University of Minnesota telescope and the GSFC ultraviolet spectrophotometer azimuth indexer, can provide an opportunity to analyze the effects of the space environment on optics and mechanisms.

2.3.4 Refurbishment

The refurbishment experiment tasks include: (1) replacement of expendables; (2) correction of degradation effects; (3) preventative or corrective maintenance; and (4) improvements. Specific experiment tasks have been analyzed, and the selected tasks are shown in Table 2-3 for the two refurbishment missions. The refurbishment tasks cited are typical operations that could be accomplished on the OSO satellite in orbit if a failure or degradation in the satellite system occurred. The tasks selected provide a variety of servicing techniques and are conceived to extend the useful lifetime of the OSO satellite. Specifically, the lifetime of OSO's currently in orbit have been limited primarily by the consumption of the expendables and degraded subsystem performance due to the space environment. For example, radiation degraded the solar array output below minimum operating levels on OSO I within approximately six months after launch. Unpredictable interaction between the OSO II and the earth's magnetic field caused the pitch gas supply to be completely depleted within approximately nine months after launch. It would be desirable to obtain scientific data from an OSO for several years.

Table 2-3
 REFURBISHMENT TASKS ON MISSIONS 2 AND 3

Experiment Task	Replace Expendables		Correct Degraded Subsystems		Corrective Maintenance		Improvements	
	Mission 2	Mission 3	Mission 2	Mission 3	Mission 2	Mission 3	Mission 2	Mission 3
Replenish pitch gas supply	X	X						
Replenish spin gas supply	X	X						
Add new battery supply			X	X				
Add new solar array panel			X	X				
Add new tape recorders			X	X				
Maintain nutation damper locking system					X	X		
Maintain arm locking system					X	X		
Add stabilization magnets							X	X
Calibrate magnetometer							X	X
Replace pointing control electronics						X		X
Replace pointing control sensor								X
Replace experiment optics or sensors						X		X
Add stabilization torquing coils								X

The Mission 2 refurbishment tasks can be accomplished with virtually no modification to the OSO by taking advantage of existing external brackets and connectors. The more sophisticated refurbishment tasks on Mission 3 can also take advantage of existing external brackets, but would require some new wiring and electronics in the OSO to optimize the interface design and prepare in advance for in orbit servicing.

2.3.5 Support Equipment

The tool and support equipment requirements have been analyzed. A common power drive tool with adaptive heads is recommended, since the EVA astronauts are to have good fixity on the work platform. Lighting is a requirement since the work sessions are to extend through orbital night. Retrieved parts are to be placed in sealed containers for return to the earth's surface.

2.3.6 Extra Vehicular Activity (EVA)

The EVA requirements have been analyzed for performing the useful work tasks, and time lines have been generated for each mission; these are presented in Volumes II and III of this report. The timelines were developed based on detailed procedures derived for each experiment task. The entire work sequence for each mission has been divided into work sessions as presented in Tables 2-4, 2-5, and 2-6.



Table 2-4
MISSION 1 TIME LINE SUMMARY

Operation/Event	Experiment Priority	EVA (Min)	IVA (Min)	Accrued Mission Time (EVA + IVA) (Min)
I Rendezvous Operations				
CSM/CWP Docking	MSO		25	25
CSM Orbit Transfer	MSO		44	69
Close Rendezvous Maneuvers	MSO		9	78
Night Time Station Keeping	MSO		31	109
Circumnavigation	MSO		6	115
Pre-Capture Inspection	MSO		60	175
Night Time Station Keeping	MSO		31	206
OSO Capture Maneuvers	MSO		6	212
Sub Total			212	
II Work Session No. 1				
Start EVA-Egress Fwd Hatch	MSO	5	5	222
Prepare Equipment and OSO Inspection	MSO	27	27	276
Astronaut Rest Period		5		281
Mount EVA Cameras	P	3	3	287
Expr. Preparation and Radiation Meas.	MSO	36		323
Satellite Centering	MSO	21		344
Astronaut Rest Period		6		350
Wheel Power Bus Removal	MSO	7		357
Mech. Freedom and Damage Evaluation Photos	P	26		383
Removal Coronagraph Occul. Disk and Photos	S	14		397
Astronaut Rest Period		6		403
Removal Control Sun Sensor Assembly and Photos	P	19		422
Astronaut Rest Period		6		428
Stow Exprs.-Return to CM	M	47	47	522
Sub Total		228	82	
III Astronaut 8 Hour Rest Period				1002
IV Work Session No. 2				
Start EVA-Egress Fwd Hatch	MSO	5	5	1012
Prepare Equip. Reposition Platform	MSO	27	27	1066
Remove Ames Emissivity Plate and Photos	P	26		1092
Astronaut Rest Period		6		1098
Remove Zodiacal Light Telescope and Photos	S	22		1120
Astronaut Rest Period		5		1125
Remove R.H. Solar Panel and Photos*	P	120		1245
Astronaut Rest Period		8		1253
Stow Exprs. Return to CM	M	47	47	1347
Sub Total		266	79	
V Astronaut 8 Hour Rest Period				1827
VI Work Session No. 3				
Start EVA-Egress Fwd Hatch	MSO	5	5	1837
Prepare Equip. Reposition Platform	P	27	27	1891
Remove HCO Expr. and Photos*	P	111		2002
Remove Gamma-Ray Telescope Foils and Photos	S	36		2038
Astronaut Rest Period		6		2044
Remove U.V. Azimuth Indexer and Photos	S	34		2078
Replenish Pitch Gas	S	25	8	2111
Prepare Expr. Stowage Containers	MSO	8		2119
Astronaut Rest Period		5		2124
Stow Exprs. Return to CM	MSO	47	47	2218
Sub Total		304	87	
VII Release Operations	MSO		23	2241
Mission 1 Totals		798	483	

NOTES:

*With Astronaut Rest Periods as Applicable

MSO - Mission Support Operation, P - Primary Objective, S - Secondary Objective



Table 2-5
MISSION 2 TIME LINE SUMMARY

Operation/Event	Experiment Priority	EVA (Min)	IVA (Min)	Accrued Mission Time (EVA + IVA) (Min)
I Rendezvous Operations				
CSM/CWP Docking	MSO		25	25
CSM Orbit Transfer	MSO		44	69
Close Rendezvous Maneuvers	MSO		9	78
Night Time Station Keeping	MSO		31	109
Circumnavigation	MSO		6	115
Pre-Capture Inspection	MSO		60	175
Night Time Station Keeping	MSO		31	206
OSO Capture Maneuvers	MSO		6	212
Sub Total			212	
II Work Session No. 1				
Start EVA-Egress Fwd Hatch	MSO	5	5	222
Prepare Equip. & OSO Inspection	MSO	27	27	276
Astronaut Rest Period		5		281
Mount EVA Cameras	P	3	3	287
Expr. Preparation & Radiation Meas.	MSO	36		323
Astronaut Rest Period		6		329
Satellite Centering	MSO	21		350
Power Bus Removal & Umbilical Connect	MSO	12		362
Astronaut Rest Period		6		368
Mech. Freedom & Damage Evaluation & Photos	P	32		400
Read Magnetometer	S		32	432
Add Stabilization Magnets	S	21		453
Astronaut Rest Period		6		
Stow Equip.-Return to CM	MSO	47	47	553
Sub Total		227	114	
III Astronaut 8 Hr. Rest Period				1033
IV Work Session No. 2				
Start EVA-Egress Fwd Hatch	MSO	5	5	1043
Prepare Equip. Reposition Platform	MSO	27	27	1097
Astronaut Rest Period		5		1102
Add Tape Recorders & Photos*	P	80	15	1197
Astronaut Rest Period		6		1203
Correct Nutation Damper Lock	P	25	15	1243
Astronaut Rest Period		6		1249
Add Solar Array Panel & Photos	P	39	15	1303
Astronaut Rest Period		6		1309
Stow Equip.-Return to CM	MSO	47	47	1403
Sub Total		246	124	
V Astronaut 8 Hr. Rest Period				1883
VI Work Session No. 3				
Start EVA-Egress Fwd Hatch	MSO	5	5	1893
Prepare Equip. Reposition Platform	MSO	27	27	1947
Correct Arm Locking System and Photos*	P	105	15	2067
Astronaut Rest Period		6		2073
Add Batteries & Photos*	P	74	15	2162
Astronaut Rest Period		6		2168
Replenish Pitch Gas	P	25	8	2201
Replenish Spin Gas	P	16	8	2225
Astronaut Rest Period		6		2231
Stow Equip.-Return to CM	MSO	47	47	2325
Sub Total		317	125	
VII Release Operations	MSO		36	2361
Mission 2 Totals		790	611	

NOTES:

*With Astronaut Rest Periods as Applicable

MSO - Mission Support Operation, P - Primary Objective, S - Secondary Objective



Table 2-6
MISSION 3 TIME LINE SUMMARY

Operation/Event	Experiment Priority	EVA (Min)	IVA (Min)	Accrued Mission Time (EVA + IVA) (Min)
I Rendezvous Operations				
CSM/CWP Docking	MSO		25	25
CSM Orbit Transfer	MSO		44	69
Close Rendezvous Maneuvers	MSO		9	78
Night Time Station Keeping	MSO		31	109
Circumnavigation	MSO		6	115
Pre-Capture Inspection	MSO		60	175
Night Time Station Keeping	MSO		31	206
OSO Capture Maneuvers	MSO		6	212
Sub Total			212	
II Work Session No. 1				
Start EVA-Egress Fwd Hatch	MSO	5	5	222
Prepare Equipment and OSO Inspection	MSO	27	27	276
Astronaut Rest Period		5		281
Mount EVA Cameras	P	3	3	287
Expr. Preparation and Radiation Meas.	MSO	36		323
Astronaut Rest Period		6		329
Satellite Centering	MSO	21		350
Power Bus Removal and Umbilical Connect	MSO	12		362
Astronaut Rest Period		6		368
Mech. Freedom and Damage Evaluation and Photos	P	32		400
Replace Expr. Optics/Sensors and Photos	S	24	15	439
Astronaut Rest Period		6		445
Replace Control Sensor Assembly and Photos	S	32	15	492
Astronaut Rest Period		6		498
Stow Equip.-Return to CM	MSO	47	47	592
Sub Total		268	112	
III Astronaut 8 Hour Rest Period				
				1072
IV Work Session No. 2				
Start EVA-Egress Fwd Hatch	MSO	5	5	1082
Prepare Equip. Reposition Platform	MSO	27	27	1136
Astronaut Rest Period		5		1141
High Resolution Photography*	S	76		1217
Astronaut Rest Period		5		1222
Satellite Emissivity Meas.*	S	50		1272
Astronaut Rest Period		5		1277
Correct Nutation Damper Lock and Photos	P	25		1302
Astronaut Rest Period		6		1308
Add Solar Panel and Photos	P	39	15	1362
Astronaut Rest Period		6		1368
Stow Equip.-Return to CM	MSO	47	47	1462
Sub Total		296	94	
V Astronaut 8 Hour Rest Period				
				1942
VI Work Session No. 3				
Start EVA-Egress Fwd Hatch	MSO	5	5	1952
Prepare Equip. Reposition Platform	MSO	27	27	2006
Read Magnetometer	S		16	2022
Add Stabilization Elec/Mag. Coils and Photos	S	22		2044
Astronaut Rest Period		6		2050
Correct Arm Locking System and Photos*	P	105		2155
Astronaut Rest Period		6		2161
Add Batteries and Photos*	P	74	15	2250
Stow Equip.-Return to CM	MSO	47	47	2344
Sub Total		292	110	
VII Astronaut 8 Hour Rest Period				
				2824
VIII Work Session No. 4				
Start EVA-Egress Fwd Hatch	MSO	5	5	2834
Prepare Equip. Reposition Platform	MSO	27	27	2888
Add Tape Recorders and Photos*	P	80	15	2983
Astronaut Rest Period		6		2989
Replace Pointing Control Elec. and Photos	P	24	15	3028
Astronaut Rest Period		6		3034
Replenish Pitch Gas Supply	P	25	8	3067
Replenish Spin Gas Supply	P	15	8	3090
Astronaut Rest Period		5		3095
Stow Equip.-Return to CM	MSO	47	47	3189
Sub Total		240	125	
IX Release Operations				
	MSO		36	3225
Mission 3 Totals		1096	689	

NOTES:

*With Astronaut Rest Periods as Applicable

MSO - Mission Support Operation, P - Primary Objective, S - Secondary Objective

Relatively long work sessions can be accommodated by: (1) utilizing two EVA astronauts working in series; (2) supplementing work sessions, if more than three Command Module pressurization cycles can be scheduled; (3) incorporating an air lock into the AAP Command Module configuration; and/or (4) reducing the number of experiment tasks to the primary selection plus the mission support tasks. Each work session includes periodic rest periods and should be followed by at least eight hours off duty for the EVA astronaut. With such a work rest cycle, the ESMRO portion of the mission could be completed in approximately two and one-half calendar days for Missions 1 and 2, and three and one-half calendar days for Mission 3.

2.3.7 Training

The training aspects of the ESMRO missions have been examined for the rendezvous operation, CWP docking and OSO capture, astronaut transfer, and EVA useful work. The following are recommended training procedures:

- (1) OSO rendezvous training: This training would be performed with a CSM flight simulator utilizing a simulated OSO satellite. Several rendezvous runs with different target OSO lighting conditions should be practiced to cover the various visual sighting possibilities that might be encountered on an actual mission.
- (2) CWP docking and OSO capture training: These operations deal with the in-flight attachment of the CWP to the CSM docking collar and the subsequent use of the CWP to accomplish capture of the OSO satellite. The CWP docking training should be performed utilizing a six degree freedom flight simulator with an Apollo Command Module, a SLA mockup, and a CWP mechanical mockup.

The OSO capture training should include the final approach of the CSM/CWP to the OSO and subsequent capture of the satellite with the CWP attachment mechanism. The actual capture operation should be performed many times so that the various target OSO dynamic parameters that could be encountered can be practiced by the flight crew. The capture phase training should be performed on a simulator which maneuvers the CSM/CWP into contact with a spinning OSO. The capture training simulation established should be capable of simulating ten degrees of freedom, six for the CSM/CWP and four for the OSO.

- (3) Astronaut transfer training: This operation deals with transfer of the astronaut from the CSM to the CWP work platform and then back to the CSM. Included in this portion are egress from the CSM via the spacecraft forward hatch, erection of the work platform of the CWP, movement of the astronaut to the useful work position on the CWP, preparation of the experiments, and return of the astronaut to the CSM. After familiarization



training with a system mockup, the actual transfer practice would be performed in a neutral buoyancy environment utilizing a CSM mockup, a CWP mechanical mockup, and an OSO mockup.

- (4) EVA useful work training: Each useful work experiment, as described in detail in Volume II of the ESMRO final report, must be practiced in both a normal environment - for gaining familiarity with equipment and hardware, and in a neutral buoyancy environment - for gaining familiarity with equipment and hardware; time line evaluation must also be made. This training is to be performed with the CWP and a detailed OSO model. It is anticipated that this training activity will encompass the major effort associated with the ESMRO training requirements.

2.4 ESMRO PROGRAM PLANS

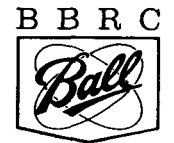
Three ESMRO missions have been defined, and detail program plans have been developed for each mission which are presented in Volume II. The object of the mission planning has been to evolutionize these three missions with respect to material retrieval, satellite refurbishment, and useful EVA performance.

2.4.1 Mission 1 Summary Program Plan

Objective. The primary objective of Mission 1 is to rendezvous, capture, perform useful work on, and release the OSO II. The useful work to be performed consists primarily of material retrieval from OSO II for analysis upon return to the earth's surface. Mission accomplishment will provide evaluation of capture techniques and development of EVA technology.

Constraints. The mission constraints are as follows:

- (1) Mission 1 is to be performed in the 1969 time frame.
- (2) The target OSO for Mission 1 is to be the OSO II launched on 3 Feb 1965.
- (3) The mission is to be initiated with the CSM in a 370 kilometer (200 nautical miles) altitude parking orbit at an inclination angle of 32.85 degrees. The CSM is to be launched from the surface in such a way that the longitude of its ascending node is within 2 degrees of that of OSO II at the time of orbit transfer initiation.
- (4) OSO II is to be in an orbit that has not significantly changed from:
 - a. Apogee: 626 km (340 nm)
 - b. Perigee: 549 km (297 nm)
 - c. Inclination: 32.85 deg
 - d. Period: 96.5 min



Experiment Tasks. The experiment tasks consist of those required for mission support operations, inspection and the following major retrieval tasks, as follows:

- NRL coronagraph occulting disk
- Pointing control sun sensor assembly
- Right hand solar array panel
- HCO ultraviolet spectrometer
- Ames emissivity sensor plate
- University of Minnesota zodiacal light telescopes
- GSFC ultraviolet spectrophotometer azimuth indexer
- University of New Mexico gamma ray telescope foil cover

Expected Results. The major expected significant results for Mission 1 are the following:

- Evaluation of orbit transfer and techniques for rendezvous with a non-cooperative satellite
- Evaluation of noncooperative satellite capture and release techniques and hardware
- Evaluation of EVA technology
- Determination of the effects of the space environment on:
 - a. Transmission optical elements
 - b. Reflection optical elements
 - c. Solar cells
 - d. Polymeric materials
 - e. Electro-mechanical devices
 - f. Electronic components
- Evaluation of unexplained failures in scientific instrumentation
- Evaluation of micrometeorite impact data unobtainable by other means
- Evaluation of additional EVA experience



2.4.2 Mission 2 Summary Program Plan

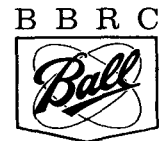
Objective. The primary objectives of Mission 2 are to rendezvous, capture, refurbish, and return the target OSO to extended orbital operation. Mission accomplishment is to provide continued evaluation of capture techniques and development of EVA technology. The useful work is to consist primarily of refurbishment of the OSO selected and to improve or extend its operation in orbit.

Constraints. The mission constraints are as follows:

- (1) Mission 2 is to be performed in the 1969 to 1970 period.
- (2) The target OSO for Mission 2 is to be partially or fully operational or have a high probability of being reactivated. Selection is to be based on the probability that extended operation yields significant new scientific or technological data from the OSO. The candidate OSO's that probably qualify for this status in this period are OSO F and OSO G. The objectives of this mission do not require that significant modifications be made to the target OSO prior to its launch; therefore, any of the above candidates or later OSOs are eligible.
- (3) The mission is to be initiated with the CSM in a 370 kilometer (200 nautical mile) altitude parking orbit, at an inclination angle equal to that of the target OSO. The CSM is to be launched in such a way that the longitude of its ascending node is within 2 degrees of that of the target OSO at the initiation of the orbit transfer.
- (4) The target OSO is to be in an orbit that has the following nominal parameters:
 - a. Circular orbit altitude: 555 ± 92 km (300 ± 50 nm)
 - b. Inclination angle: 33 ± 3 deg
 - c. Period: 96 min

Experiment Tasks. The experiment tasks consist of those required for mission support operations, inspection, and major refurbishment tasks. The refurbishment tasks cited are typical operations that could be accomplished if a failure or degradation in the OSO systems occurred. They are as follows:

- Replenish pitch gas supply
- Replenish spin gas supply
- Addition of new battery power supply



- Addition of new solar array panel
- Addition of new tape recorders
- Maintenance of nutation damper locking system
- Maintenance of arm locking system
- Addition of stabilization magnets
- Calibration of magnetometer

Expected Results. The major expected significant results for Mission 2 are:

- Additional evaluation of orbit transfer and techniques for rendezvous with a noncooperative satellite
- Additional evaluation of noncooperative satellite capture and release techniques and hardware
- Additional evaluation of EVA technology
- Refurbishment of the target OSO in the following areas:
 - a. Replenishment of the pitch and spin gas supplies
 - b. Correction for degraded power supply performance by addition of new batteries and solar array
 - c. Correction for degraded performance by addition of new tape recorders
 - d. Maintenance of possible malfunction of nutation damper and arm locking systems
 - e. Improved stabilization characteristics by the addition of permanent magnets
- In-orbit calibration of magnetometer
- In-orbit checkout of all refurbished functions

2.4.3 Mission 3 Summary Program Plan

Objective. The primary objectives of Mission 3 are to rendezvous, capture, refurbish and return the target OSO to orbital operation. Mission accomplishment should provide continued evaluation of capture techniques and continued development of EVA technology. The useful



work is to consist primarily of advanced refurbishment of the OSO selected to improve or extend its operation in orbit.

Constraints. The mission constraints are as follows:

- (1) Mission 3 is to be performed in the 1970 to 1971 period
- (2) The target OSO for Mission 3 is to be partially or fully operational or have a high probability of being reactivated. The selection is based on the probability that extended operation yields significant new scientific or technological data. The target OSO is to be specially modified to permit and facilitate the advanced refurbishment activities. The candidate OSOs that can be modified for this mission are OSO H, OSO I, and OSO J.
- (3) The mission is to be initiated with the CSM in a 370 kilometer (200 nautical mile) altitude parking orbit, at an inclination angle equal to that of OSO. The CSM is to be launched such that the longitude of its ascending node is within 2 degrees of that of the target OSO at the initiation of the orbit transfer.
- (4) The target OSO is to be in an orbit that has the following nominal parameters:
 - a. Circular orbit altitude: 555 ± 92 km (300 ± 50 nm)
 - b. Inclination angle: 33 ± 3 deg
 - c. Period: 96 min

Experiment Tasks. The experiment tasks consist of those required for mission support operations, inspection, and major refurbishment tasks. The refurbishment tasks cited are typical operations that could be accomplished if a failure or degradation in the OSO systems occurred. They are as follows:

- Replenish pitch gas supply
- Replenish spin gas supply
- Addition of new battery power supply
- Addition of new solar array panel
- Addition of new tape recorders
- Maintenance of nutation damper locking system
- Maintenance of arm locking system



- Addition of stabilization torquing coils
- Calibration of magnetometer
- Replacement of pointing control electronics
- Replacement of pointing control sensor assembly
- Replacement of experiment optics or sensors

Expected Results. The major expected significant results for Mission 3 are:

- Additional evaluation of orbit transfer and techniques for rendezvous with a noncooperative satellite
- Additional extensive evaluation of noncooperative satellite capture and release techniques and hardware
- Additional evaluation of EVA technology
- Refurbishment of the selected OSO in the following areas
 - a. Replenishment of the pitch and spin gas systems
 - b. Correction for degraded power supply performance by addition of new batteries and solar array
 - c. Correction for degraded performance by addition of new tape recorders
 - d. Correction of malfunction or improved reliability or performance by addition of new pointing control electronics
 - e. Correction of malfunction or improved reliability or performance by replacement of control sensor assembly
 - f. Improved performance by replacement of experiment optics or sensors
 - g. Maintenance of possible malfunction of nutation damper and arm locking systems
 - h. Improved stabilization characteristics by addition of torquing coils
 - i. In-orbit calibration of magnetometer
 - j. In-orbit checkout of all refurbished functions



Section 3
DEVELOPMENT SCHEDULE AND COST

Three ESMRO missions have been conceived and are described on NASA form 1138's in Volume III of this report. These missions require the development of the Capture Work Platform to perform the mission objectives. The CWP consists of major subsystems and support hardware items that are within the development state of the art, but they must be designed, fabricated and tested in this configuration.

The ESMRO development schedule is shown in Fig. 3-1 for the three mission program. The first mission can be performed in 1969 with delivery of flight hardware for integration within 22 months after a mid 1967 start date. Also, shown in Fig. 3-1 are the planned or predicted design freeze dates for the candidate OSO's for Missions 2 and 3.

Budgetary cost estimates are presented in Table 3-1 for the program phases of each mission. Also, included in Table 3-1 are the budgetary estimates for the OSO modifications and mockups required for the three missions.

Table 3-1
ESMRO BUDGETARY COST ESTIMATES

Program Phase	Mission		
	1	2	3
Phase B (preliminary design)	\$ 380,000	\$ 130,000	\$ 130,000
Phase C (detailed design engineering model and prototype fabrications and test)	3,500,000	460,000	460,000
Phase D (flight model fabrication and test. Flight spare model included in mission 1 only)	2,500,000	1,680,000	1,800,000
OSO modifications and mockups	200,000	350,000	500,000

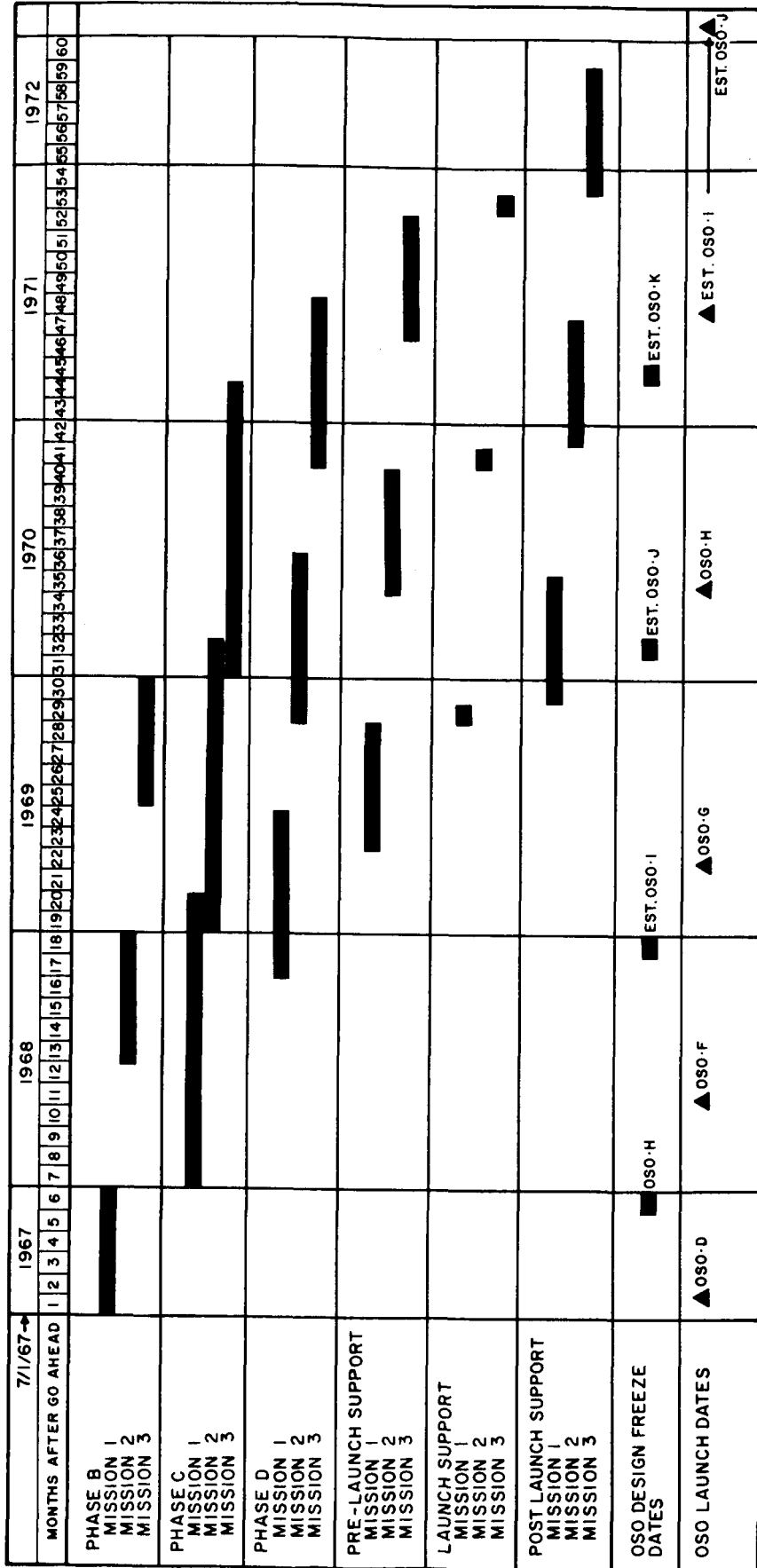


Fig. 3-1 ESMRO Development Schedule



Section 4
CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this study program are:

- (1) A mission should be conducted to rendezvous with and capture OSO II, and retrieve materials from it for analysis upon return to the surface.
- (2) Two missions should be conducted to rendezvous with, capture, refurbish, and return an OSO to extended orbital operation.
- (3) Significant scientific and technological data can be obtained from the material retrieval mission.
- (4) Significant technological development of rendezvous and capture techniques with a noncooperative satellite is to be accomplished by each of the three missions.
- (5) Significant technological development of EVA techniques is to be accomplished by each of the three missions.
- (6) The useful or productive lifetime of OSO's can be significantly extended by their in-orbit refurbishment, with only minor modification to the OSO.
- (7) The Capture Work Platform concept is readily adaptable for use with a variety of cooperative and noncooperative satellites.
- (8) The three missions can be performed with no design modification to the CSM.
- (9) The ESMRO mission hardware can be designed using present state-of-the-art engineering.

Additional effort recommended as a result of this study includes:

- Preliminary design of the Capture Work Platform and associated support hardware for an initial mission in 1969
- Design and fabrication of modifications and additions to the candidate OSO's consistent with the development schedules for each OSO
- Analysis into the effect of launching future OSO's into the AAP orbit inclination of 28.5 degrees



- Analysis of the dynamics of the combined CSM/CWP/OSO configuration and the effect on the CSM attitude control system.
- Future development of adhesive applications to the capture operation
- Further analysis and simulation of the captive concepts to determine the operational characteristics and crew limitations
- Analysis of the location of lighting aids during the EVA operations
- Analysis of the thermal effects on the OSO and the CSM for various fixed attitudes with respect to the Sun
- Development of specific material retrieval experiments to be included in future OSO's
- Obtaining high magnification photographs and emissivity measurements on OSO surfaces prior to their launch for later comparison with retrieved data
- Analysis of contamination control requirements for materials retrieved from OSO
- Analysis of advanced modifications to OSO for EVA access to the wheel equipment and scientific experiments
- Analysis leading to design of future OSO scientific experiments and EVA servicing capability
- Simulation of useful work tasks in neutral buoyancy facilities to optimize the EVA timelines
- Development of longer distance (10 to 25 feet) life support umbilical lines, to support the ESMRO missions
- Analysis of coupling an airlock between the CSM and CWP to reduce the consumption of expendables during each pressurization cycle



Section 5 LONG RANGE PLANNING

The three missions that have been developed as a result of this study are the first steps in an emerging era of space technology. These missions are part of the NASA long range plans for post Apollo applications, including development and use of spent stages and long duration space stations. These stations will become major orbital facilities from which satellite capture operations and servicing will be performed. The results of this study can be incorporated into more detailed long range planning in several areas.

The development and performance of the ESMRO missions will lead to significant long range advancement in several areas of the space program, as indicated in Fig. 5-1. Each of these areas is discussed in the following sections.

5.1 SPACE STATION SUPPORT

The spent stage and long duration space stations will require a certain amount of EVA support servicing. This effort will include external maintenance and in some cases resupply cargo transfer and attachment to the space stations. Such designs will rely on the results of the ESMRO missions.

Other space station requirements include the operation, maintenance and data retrieval from scientific experiments that are integral with the station, such as the ATM. Film retrieval currently planned for the ATM is to be accomplished by means of EVA. Future ATM configurations should be designed for refurbishment by EVA as well as other major experiment systems that are external to the space station.

5.2 UNMANNED SATELLITE SERVICING

The long range plan for utilizing the capture and EVA technology developed during this study, should be based on the expected continuation of the unmanned space research program. A large number of observatory class satellites will be in operation during the next decade, as well as long duration weather, communications and earth resources satellites. In order to improve the probability of long duration performance from these satellites, it is recommended that they be designed for EVA servicing. In addition, the future space stations should be developed to accommodate satellite servicing, and maneuvering units developed for capturing the satellites. These areas are discussed in the following sections.

5.2.1 Satellite Maintenance

Future missions to maintain or repair a satellite should expand the effort initiated by the three ESMRO missions. This initial effort involves only simple repair of

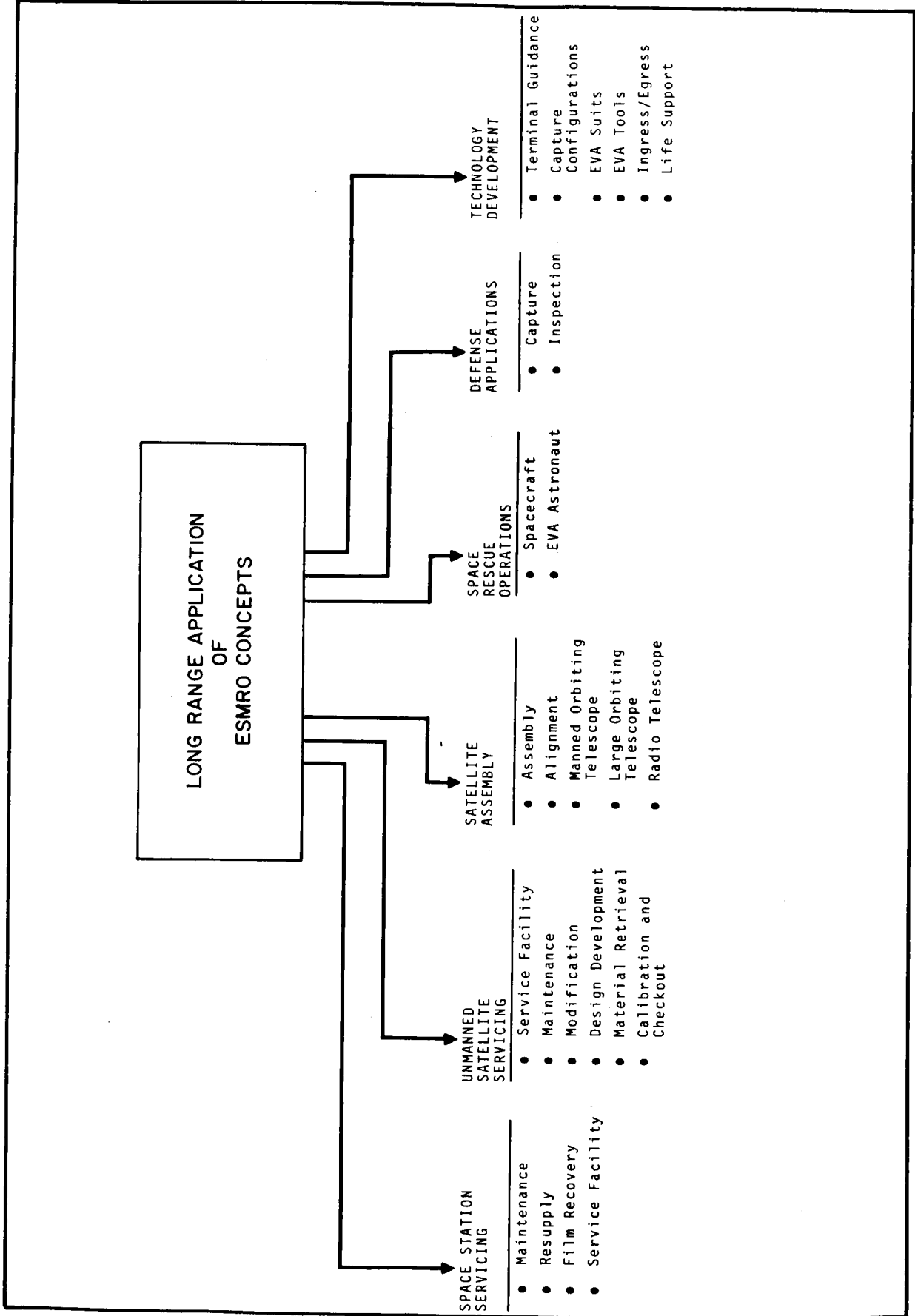


Fig. 5-1 Long Range Application of ESMRO Concepts



subsystems with easy EVA access. Future missions should include more extensive pre-planned on-site diagnosis and repair.

Erectable or inflatable structures attached to a space station with complete checkout and repair capability should be used. Unmanned satellites might be launched into parking orbits near the space station to be captured and then attached to it for an in-orbit checkout. This checkout would permit the activation of the satellite under psuedo-laboratory conditions. This would permit direct observation for diagnosis of any problem areas before they become catastrophic. Once the satellite is functioning properly, it could be moved to its operational orbit by means of an auxiliary propulsion system, such as a space taxi.

Future studies should be conducted to determine the operational and cost effectiveness of clustering the major observatories in the vicinity of a manned space station. This technique may be quite effective since the delta velocity requirements to drastically change orbits for rendezvous at the variety of orbits presently used is quite prohibitive. However, future planning should emphasize the development of more efficient propulsion systems which would permit extensive orbit maneuvering to capture satellites and bring them to the space station.

5.2.2 Satellite Modification

Relatively simple modifications to the OSO's have been proposed for the three ESMRO missions. Future missions can be planned to make more extensive modification to either the spacecraft systems or the scientific payload in-orbit. Entire subsystems or instruments might be modified to correct malfunctions or to improve their performance. Modifications could also become more extensive by placing the target satellite in the space station service facility.

The orbit parameters of a target satellite could be altered to adjust an imperfect orbit. Minor orbit changes can be performed by linking the target satellite with the CSM or a space taxi. More extensive changes could be accomplished by attaching a propulsion system to the target satellite. These changes could also facilitate de-orbiting a defunct satellite to reduce the chances of clogging the orbitways. For example, de-orbiting nuclear power systems would insure burn-up or deep-water disposal.

5.2.3 Satellite Design Development

The first three missions proposed involve relatively minor design modifications to the target OSO. However, long range planning for effectively developing and utilizing in-orbit refurbishment techniques requires that the design of future target satellites be changed to facilitate the EVA operations. In effect, probable target satellites should be designed to permit access, wherever possible, to each of the major subsystems or scientific experiments. In general, spacecraft and instrument designers should plan on in-orbit maintenance, modification, assembly, and checkout in much the same manner as they would develop laboratory equipment or plan for field maintenance.



Although many of the key subsystems of OSO are externally accessible, others are contained within the wheel section. Each wheel compartment is completely enclosed with covers that would be difficult to remove under EVA conditions. The OSO design could be modified to facilitate easy removal of the compartment covers to gain access to the internal subsystems.

The location and packaging design of these subsystems could be changed to permit access for repair or replacement. The scientific instruments located in the wheel could be designed with access ports to permit similar operations.

Further design development of the OSO for EVA improvement could involve considerably larger pointed telescopes that could be assembled to their full size during EVA or in the space station service facilities. New scientific instruments could be exchanged for obsolete ones as the satellite systems are refurbished for extended life.

In any mission not involving a CWP with its work platform, provisions should be included in the design of the satellite or space station for astronaut fixity during the EVA operations.

5.2.4 Material Retrieval

Many experiments could be planned and designed into the scheduled satellites to take advantage of the retrieval capability. Such experiments would include various materials and mechanisms that would be effected by long exposure to the space environment, and the performance of which could not be measured except by surface laboratory techniques. An example of such an experiment is the wear of a lubricated bearing in the space environment, which can only be determined by laboratory microscope examination techniques. This type experiment could be designed for easy EVA retrieval and placed on one of the future observatories. These experiments should be planned and approved in the near future in order to get them into orbit as soon as possible.

Retrieval of satellite systems that failed in an unexplained manner cannot be scheduled in advance of the failure. However, if major satellite subsystems or scientific experiments were designed for easy EVA access and removal, they could be further disassembled in the space station secure facility and returned to the surface for analysis. The first step in planning for diagnostic retrieval is to design for EVA access to the major parts in future satellites that have not passed their design freeze schedule.

5.2.5 Satellite Calibration and Checkout

Calibration and checkout of satellite subsystems or scientific experiments should be extended from the preliminary effort of the three ESMRO missions. These activities will be required on the major observatories to be developed as they are assembled and aligned in orbit. Calibration and checkout could be facilitated in the space station service facilities.

5.3 SATELLITE ASSEMBLY

Future generations of space stations and observatories are destined to grow in size; this means that they must be assembled from their ascent stowed arrangement. Such effort will require extensive EVA, much broader than the scope of the relatively simple assembly tasks of the three ESMRO missions. More extensive assembly operations should be performed in followon missions, such as assembling and attaching large telescopes to the space station, or to an unmanned observatory.

Typical configurations that will probably require EVA to assemble are the large diameter radio and optical telescopes, such as the manned orbiting telescope (stellar) (MOT) or the long solar telescopes such as the orbiting astronomical support facility (OASF).

Since the large orbiting telescopes of the future will require EVA assembly, much of their alignment will also be performed by EVA techniques. No major telescope alignment is proposed for the three ESMRO missions due to its relative complexity. However, in-orbit alignment should be performed on follow-on missions to develop the techniques required, possibly utilizing the space station service facilities.

5.4 SPACE RESCUE

One obvious value in furthering the development of the techniques of this study is in-orbit space rescue. The CWP could be used for capturing another manned spacecraft that had become inoperative. Specific attachment heads could be developed for the capture of the various manned spacecraft configurations or for EVA personnel. Future missions should include an effort to evaluate such attachment heads and to develop the capability to dispatch an emergency maneuvering unit from the space station to capture the spacecraft in trouble and return it to the space station.

5.5 DEFENSE APPLICATIONS

The results of this study have shown the feasibility of capturing and inspecting a noncooperative satellite. These techniques have obvious application for defense surveillance of unknown satellites, and future effort should be planned to develop their application.

5.6 TECHNOLOGY DEVELOPMENT

This study has shown that the three ESMRO missions can be conducted with state of the art techniques and hardware. However, if the technology is to support the capture and EVA support requirements of the future, additional development should be planned. Some of the major areas that should be developed are itemized below:

- (1) Terminal guidance: Specific tracking aids should be developed to assist the crew in the terminal guidance maneuvers.



- (2) Capture configurations: Utilization of special purpose capture attachment heads should be planned for a variety of cooperative and noncooperative satellites.
- (3) EVA suits: Further development of EVA suits should be planned to facilitate the work operations remotely at the satellite or within the space station service facility.
- (4) EVA tools: Utilization of a variety of tools should be planned for work operations in the space station service facility, for large telescope assembly, and for cargo handling.
- (5) Ingress/egress: Further development of personnel airlocks should be planned to make EVA a fully operational part of space station activities, and to minimize the use of expendables during pressurization cycles.
- (6) Life support: Further development of umbilical and personnel life support systems should be planned to facilitate the EVA operations.

5.7 LONG RANGE SCHEDULE

Many of the long range aspects of capture and EVA discussed in the previous sections are related to the development of the spent stage and long duration space stations as well as to the availability of the scientific experiments and unmanned satellites. A general schedule for the pertinent items discussed is shown in Fig. 5-2, to show that in order to achieve the long range operational objectives, continuous effort must be sustained starting with the three ESMRO mission. It should also be noted that the third ESMRO mission could be performed in conjunction with the inflatable/erectable structures or the repair facility hangar. This would facilitate more extensive repair and refurbishment, such as interchange of complete scientific experiments.

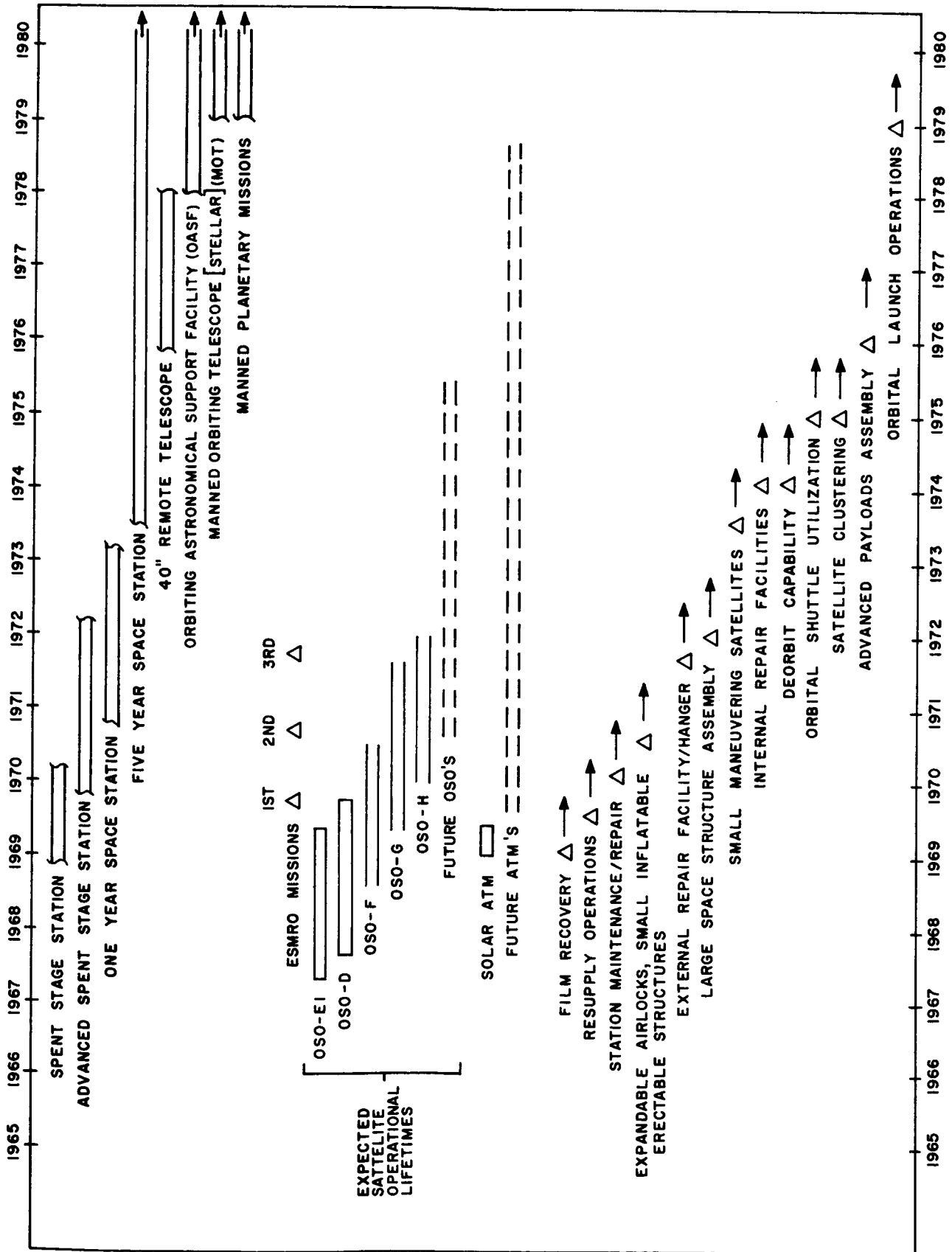


Fig. 5-2 Correlation of Long Range Activities